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Original Article

Evaluation of volume status in a prehospital setting by ultrasonographic measurement of inferior vena cava and aorta diameters

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A B S T R A C T

Objectives: The aim of this study was to evaluate the utility of ultrasonographic measurement of the diameter of the inferior vena cava (IVCD) and abdominal aorta (AAD) for assessing volume status.
Material and methods: This was a prospective, observational study. A total of 23 volunteers participated in the study. Each participant was selected randomly. All participants completed the 2016 Kaunas Marathon. Participants filed out a brief survey about their fluid intake (in standardised glasses) in the 24 h before the race and during the race. Participants underwent ultrasound measurements 10–40 min before the start of the race and 3–15 min after finishing the race. To visualize respiratory variation, M-mode was used, with the beam crossing the IVCD 2 cm from the right atrium. The AAD was measured 1 cm above the celiac trunk. IVCD in expiration (IVCDexp)/AAD was calculated by dividing the value of IVCDexp by the value of AAD. The findings were compared with difference in body mass index.
Results: The mean weight lost after the marathon was 2.93 kg ($p < 0.001$). Mean IVCD in inspiration (IVCDins) after the run was lower by 0.39 cm ($p < 0.001$) then before the run. Mean IVCDexp/AAD after the run was 0.24 cm lower than before the run ($p = 0.03$). Before and after the marathon, there was a statistically significant negative correlation in weight difference, with mean IVCDexp difference ($p = 0.047$). There was no statistically significant difference in caval index before and after running.
Conclusion: Ultrasonographic assessment of IVCDexp could be useful in the evaluation of volume status.

1. Introduction

In the emergency department (ED) and prehospital setting, hypovolemia must be rapidly reversed before organ damage is sustained and becomes irreversible.[1] The evaluation of volume status is important for diagnosing hypovolemic patients and replacing their volume deficit.[2] Invasive central venous pressure (CVP) is difficult to measure in the ED or prehospital setting, and the use of a pulmonary artery catheter is not practical, as these invasive procedures have some complications that can be lethal. Bedsides ultrasound, measuring the diameter of the inferior vena cava diameter (IVCD) is another method to evaluate volume status.[3] In the ED, ultrasound is used as a rapid and non-invasive method for determination of preliminary diagnoses and guiding the initial therapy.[4] In the evaluation of IVCD, the subxiphoid view is the most reliably assessed, and the suprailiac view produces superior correlations with CVP.[5] An image of the suprailiac IVC is not obtainable in more than half of cases because of body habitus or bowel gas.[5] Akilli et al. found that IVCD, 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).[6] Unfortunately, despite obtaining successful results, data are controversial regarding the correlation of IVCD and CVP.[7] Earlier studies found that the optimal IVC cut off for detecting volume responsiveness was 40%, and there were missed multiple fluid responders.[8] IVC size alone has not been proven to be a marker of fluid responsiveness. Furthermore, there are only a few studies that

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have investigated IVCD's (minimum, maximum, caval index) correlation with quick weight loss.[9] The IVCD/abdominal aorta diameter (AAD) index could be a new, useful ultrasound parameter for evaluation of volume status to detect the early phase of hypovolemic shock with blood loss less than 15%.[3] However, there has been little subsequent investigation of the utility of the index in evaluating volume status in adults.[10]

The aim of the study was to evaluate the success of the IVCD/AAD index to determine volume deficit, using healthy runners as a model of dehydrated patients.

2. Materials and methods

2.1. Study design and setting

This was a prospective, observational study using an experimental design. This study was performed during the real race, in which both professional and nonprofessional athletes participated. Our goal was to not affect the natural habits of athletes with regard to fluid intake, so all participants learned about the study from the flyers on the same day the race was held. All participants were selected randomly by choosing every fifth in the row registration number. There were 77 runners selected from 387 participants. Inclusion criteria were age 18 years and older, no symptoms of or known cardiopulmonary disease, and the ability to complete the marathon in less than 5 h. The exclusion criterion was running a distance less than a marathon. A total of 23 volunteers participated. All participants completed the 2016 Kaunas Marathon, which was held in June 2016 on a sunny morning with an ambient temperature of 7.7–14.2 °C. There were 14 water stops on the track, at which standard-size plastic cups (100 mL) were filled with water. Each participant took water from these stops, and the number of glasses taken was measured.

The study was approved by the Ethical Committee of Lithuania University of Health Science.

2.2. Study protocol

2.2.1. Measurement methods

Investigators were emergency medicine residents (second and third year) who completed a basic ultrasound course (1 month in the radiology department), trained by radiologist, and a special practical ultrasound course on IVCD and AAD evaluation (25 scans of IVCD and AAD with a radiologist and the same count of scans done alone and saved for review). Each participant was scanned before and after running by two investigators. In the case of different measurements, a third investigator was ready for evaluation. The measurement tolerance between the two investigators for IVCD and AAD was 1 mm. Each investigator's measurement results were recorded separately; they were blinded from each other's result.

The minimum IVCD in the inspiration phase (IVCDins) and the maximum diameter of the IVCD in the expiration phase (IVCDexp) and AAD were taken with an ultrasound in the subxiphoid view in the supine position. In this study, we used three ultrasound machines: SonoSite EDGE II, SonoSite MICROMAXX, and Philips EpiQ7. Curvilinear probes 3.5–5 MHz were used with B and M mode scans.

The probe was placed on the patient's abdomen just below the sternum with the marker facing the head of the patient. At this point, the IVCD was visualized in the longitudinal plane as it enters the right atrium. The IVCD was measured 2 cm from its entering to the right atrium. To visualize respiratory variation, M-mode was used, with the beam crossing the IVCD 2 cm from the right atrium (Fig. 2). AAD was measured 1 cm above the celiac trunk.

IVCDexp/AAD was calculated by dividing the value of IVCDexp by the value of AAD. Both M-mode and B-mode measurements were averaged over 3 respiratory cycles to account for variations in respiratory efforts, and the arithmetical mean of 3 measurements was taken for analysis. The IVCD collapsibility index was calculated as the formula caval index = (IVCDexp − IVCDins)/IVCDexp) × 100.

All measurements were completed within less than 5 min. All results were written down on a special form by the investigator's assistant. One assistant worked with one investigator.

2.2.2. Data collection

All participants signed a written informed consent. Participants were invited to undergo ultrasound measurements 10–40 min before the start of the race and 3–15 min after finishing the race. Participants were met at the finish line by research assistants and escorted to the data collection station located approximately 30 m from the finish line.

After signing the informed consent and answering the survey questions, the height and weight of participants were measured (we used the Non-Automatic Weighing Instrument type PB version 02 manufactured by CAS Corporation in 2010, EC-TAC number UK 2882). Participants stood barefoot on the scales, wearing only their running shirts and tights or shorts (same before and after the run) and were informed to come with an empty bladder. The data collection is shown in Fig. 1.

2.3. Statistical analysis

Data were analysed using SPSS version 20.0, registered to the university. The demographic characteristics included age, height, weight, blood pressure, heart rate, and body mass index (BMI). The Shapiro-Wilk test for testing the normality of data was used. IVCDins and IVCDexp before marathon, IVCDins difference, IVCDexp difference, IVCDexp/AAD index after marathon, IVCDexp/AAD index difference were not normally distributed.

Ultrasound measurements included the IVCDins, IVCDexp, caval index, AAD, and IVCDexp/AAD index before and after the marathon were analysed by using Wilcoxon method. The correlation between weight loss and BMI, IVCD, AAD, and IVCDexp/AAD index was analysed using Spearman correlations for nonparametric data. All statistical analyzes were performed at 95% confidence interval, a p value of less than 0.05 was considered statistically significant.

3. Results

Twenty-three participants (mean age 40.30 years ± 14.69, 95% CI 34.43 to 46.52) were included in the study. There were 21 men and 2 women. The mean height of the participants was 180.09 ± 7.93 cm (95% CI 176.52 to 183.17), and the mean amount of fluids taken during the marathon was 1100.00 ± 565.69 mL (95% CI 878.37 to 1330.43). All demographic characteristics are shown in Table 1. Mean weight lost after the marathon was 2.93 ± 1.13 kg (95% CI -3.37 to −2.43) ($p < 0.001$). Mean systolic blood pressure after running was lower by 16.52 ± 19.41 mmHg (95% CI -20.9 to −0.81) ($p < 0.001$) than before the run. Mean diastolic blood pressure after marathon decreased from 83.26 mmHg to 76.48 mmHg (mean of differences 6.78 ± 14.15 mmHg, 95% CI -10.71 to 2.36) ($p = 0.02$). Heart rate after the marathon increased from 70.30 to 88.96 beats/min (SD 15.68, 95% CI 11.87 to 25.43) ($p < 0.001$). The permissible difference between the measurements received by both investigators was determined to be 2 mm, and the third investigator was required in 3 cases. Compared with after running, the IVCDexp/AAD before running was higher, and this difference was statistically significant (Mean of differences 0.24 ± 0.58, 95% CI -0.48 to 0.03) ($p = 0.03$). IVCDins decreased by 0.39 ± 0.63 cm (95% CI -0.69 to −0.12) ($p = 0.004$; Table 2).

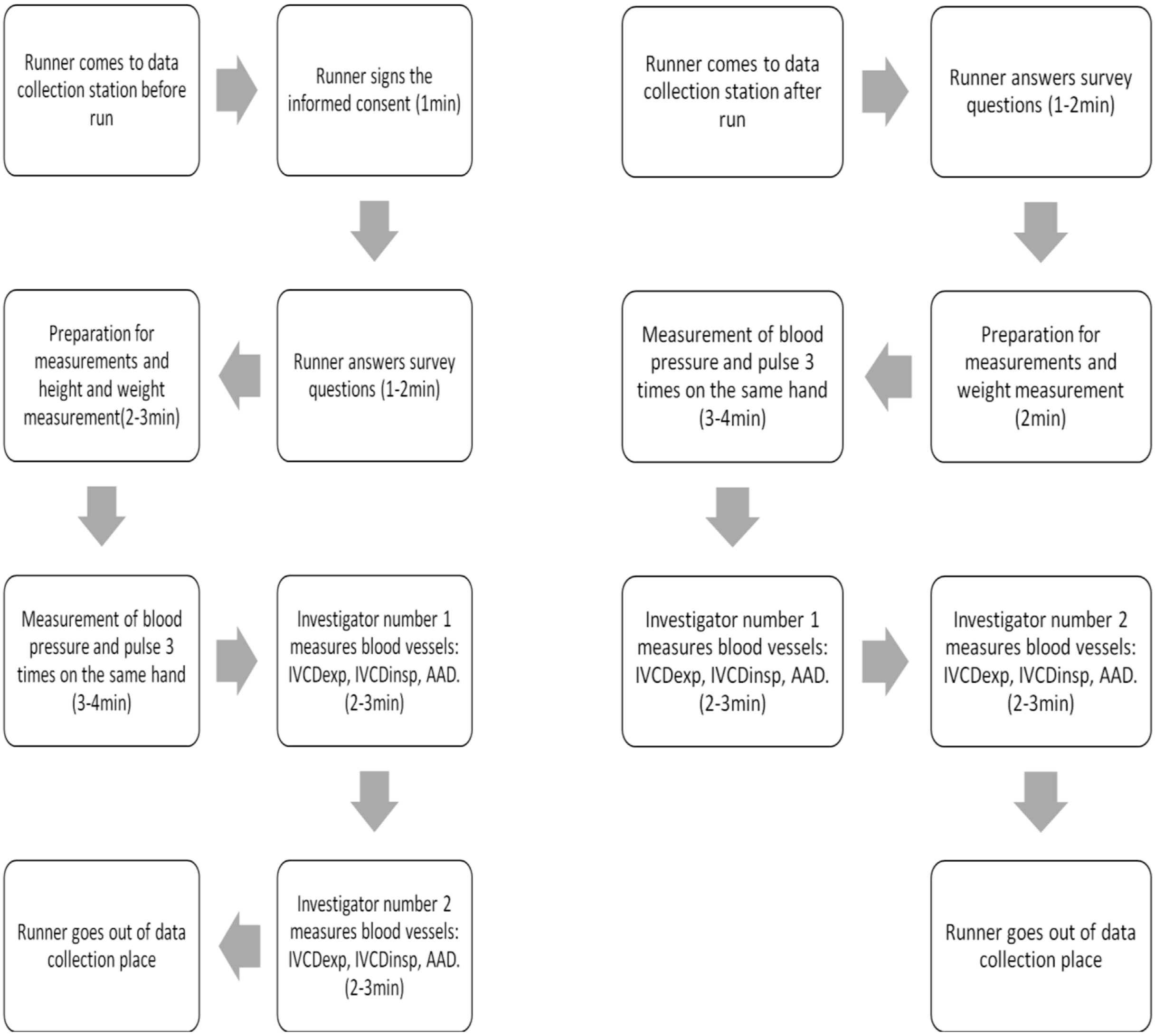

Fig. 1. The workflow chart.

The correlation between body weight changes and ultrasound parameters is shown in Table 3. There was a statistically significant negative correlation between weight loss with IVCDexp (r coefficient −0.36, 95% CI -0.68 to 0.09) ($p = 0.047$) before and after the run. Weight loss was statistically significantly correlated with BMI (r coefficient 0.98, 95% CI 0.91 to 0.99) ($p < 0.001$). Table 4 shows the correlation between BMI and clinical and ultrasound parameters. The correlation between BMI and all variables was not statistically significant.

It was analysed correlation between clinical data and ultrasound parameters. Differences in systolic and diastolic blood pressure had negative correlation with AAD difference (accordingly r coefficient −0.40, 95% CI -0.64 to −0.03, p=0.03, and r coefficient −0.47, 95% CI -0.73 to −0.08, p=0.01). There were no other statistically significant correlations.

4. Discussion

Vital organ hypoperfusion leads to shock, which, if not rapidly managed, is directly related to mortality.[11] Clinical signs, symptoms, and hemodynamic data of shock help to initially assess, monitor, and provide adequate resuscitation for the patient. Physical examination findings of shock and tissue hypoperfusion, vital signs, tissue perfusion measurement, biochemical markers of metabolism, CVP measurement, and ultrasound parameters help to assess volume status.[12] However, before organ failure is obvious, most internal organs (liver, lung, kidneys) can lose up to 75% of functional mass without life-threatening organ failure, and blood pressure can be maintained at a normal level with up to 30% of total body water loss.[13,14] However, a loss of 30% or 40% of blood volume can be fatal.[13] In the early stage of hypovolemic shock, there are compensatory neural, hormonal, and chemical mechanisms, which keep cardiac output and perfusion at normal levels.[15] Thus, there are few early clinical signs or changes in hemodynamic parameters showing life-threatening circulatory failure. Studies in the past have demonstrated that IVCD is closely based on the arterial system, such as blood pressure, pulse rate, and the diameter of the aorta.[14]

Ultrasound is one of the non-invasive methods of diagnosing hypovolemia. IVCDexp and IVCDexp/AAD measurement by ultrasound can improve the assessment of volume status in the ED.[16] In patients with hypovolemia, the elasticity of the IVC according to respiration can be more pronounced and lead to a high caval index.[17] The AAD correlates with body surface area, weight, age, and

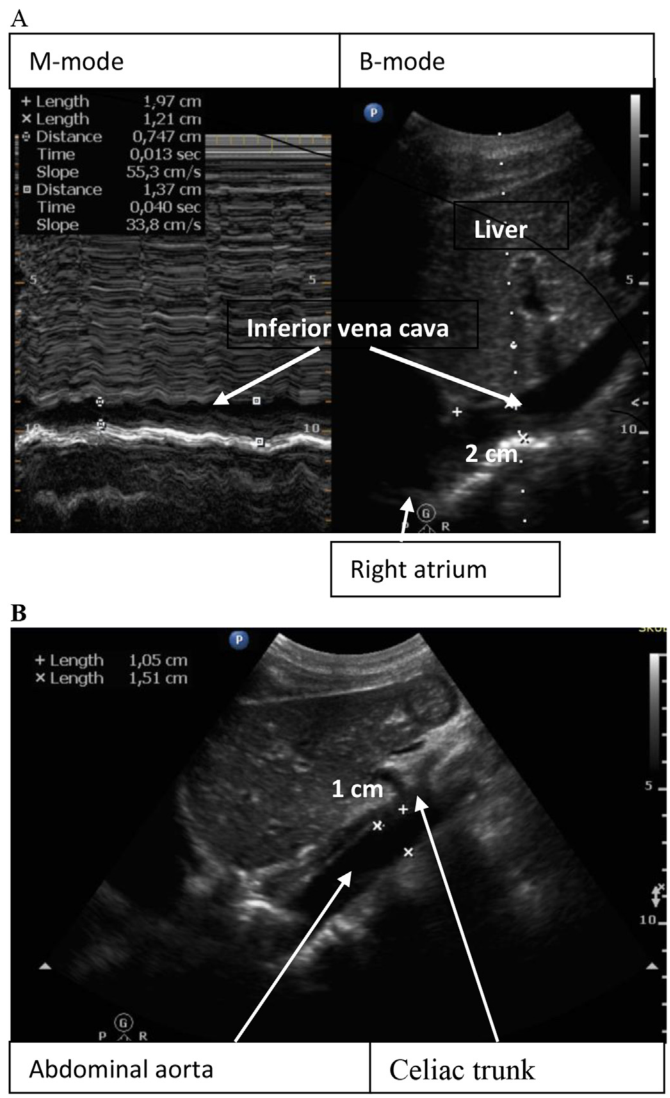

Fig. 2. Visualization of IVCD by ultrasound
A - Measurement of the diameter of inferior vena cava
B - Measurement of the diameter of abdominal aorta.

sex and is a non-collapsible structure irrespective of volume status.[17] Ultrasonographic assessment of the IVCDexp/AAD obtained in the transverse or longitudinal view is an easy examination from the technical point of view, and after a 4-h training, persons without experience in sonography are capable of measuring the IVCD and AAD with an accuracy comparable to the precision of experienced examiners.[18]

In our study, we decided to evaluate volume status in marathon runners, because such activity can lead to severe dehydration and display the early stage of hypovolemia. The runners experienced a significant weight loss, and these changes suggest a change in hydration status likely resulting from exercise-induced fluid loss.[19] The hydration status in the athletes is assessed by monitoring weight and urine concentration. We assessed weight loss and found that after running, there was a significant decrease in body weight. IVCDins measured by ultrasound decreased after the race. The collapsibility of the IVCD, indicating exercise-induced fluid loss over the course of the race, did not significantly change, but the difference in weight loss was statistically significantly correlated with IVCDexp difference. An earlier study found that the IVCD index was not influenced by any of the individual characteristics investigated. The IVCDexp/AAD index was more strongly influenced by individual characteristics than was IVCmax in adults, because the aorta is more susceptible to individual characteristics than are any of the IVC parameters. Gui et al. found that weight has a statistically significant correlation with AAD but not with IVCDexp/AAD index.[10] The caval index is lower in athletes than in controls; this is likely due to a training effect of a chronically increased venous load and cardiac output. In measuring the collapsibility of the IVC, it is important to consider the amount of intrathoracic pressure generated during each inspiration.[9] However, IVCDexp is less affected by respiratory variation and is a better hydration status measurement, especially when intravascular volume changes are small. In our study, IVCDexp correlated with weight loss after running and suggests that this measurement may be important for detecting early dehydration.

We found that weight loss but not BMI is important in the evaluation of volume status. A BMI in athletes is increased because of muscularity rather than increased body fatness. Observations from different populations showed that at the same BMI, women tend to have more body fat than men; blacks have less body fat than do Whites, and Asians have more body fat than do Whites; older people tend to have more body fat than younger adults; and athletes have less body fat than do nonathletes.[20] The relationship between height and BMI is larger in women and increases with age. BMI represents a heterogeneous mix of weight-for-height relationships and may vary across the life course and by sex.[21]

Rahman et al. measured the IVCDexp/AAD index for hypovolemia and found that the mean index difference was statistically significant in blood donors.[3] They decided that index measurement below 1.14 should be considered as fluid deprived and shows the early phase of hypovolemic shock. In our study we didn't find he correlation between IVCDexp/AAD measurement and weight loss. Waterbrook et al. analysed the correlation of IVCD and weight loss and found that IVCDexp was significantly related to weight loss, whereas the caval index was not found to correlate with weight loss in football players.[9]

Lara et al. found that marathon runners experienced dehydration, osmoconcentration, and hypovolemia.[22] They analysed the runners' electrolyte concentrations and found a very light osmoconcentration in salty runners. Body mass changes were similar, and all participants finished the race in low-to-moderate levels of

Table 1
Distribution of participants' demographic characteristics.

Characteristics	Before marathon Mean ± SD (95% CI)	After marathon Mean ± SD (95% CI)	Mean of differences ± SD (95% CI)	p value
Weight (kg)	76.93 ± 8.43 (73.29–80.58)	73.99 ± 8.48 (70.33–77.66)	−2.93 ± 1.13 (−3.37 to −2.44)	**<0.001**
Body mass index	23.09 ± 2.49 (22.68–24.84)	22.83 ± 2.51 (21.76–23.94)	−0.91 ± 0.35 (−1.06 to −0.76)	**<0.001**
Systolic BP (mmHg)	145.39 ± 12.87 (139.83–150.95)	128.87 ± 12.87 (123.30–134.44)	−16.52 ± 19.41 (−20.9 to −0.81)	**<0.001**
Diastolic BP (mmHg)	83.26 ± 11.38 (78.34–88.18)	76.48 ± 9.91 (72.19–80.76)	−6.78 ± 14.15 (−10.71 to 2.36)	**0.02**
Heart rate (beat/min)	70.30 ± 11.67 (65.26–75.35)	88.96 ± 10.03 (84.62–93.29)	18.65 ± 15.68 (11.87–25.43)	**<0.001**

BP – blood pressure, SD - Standard deviation.

Table 2
Ultrasound measurements in participants.

Ultrasound measurements	Before marathon Mean ± SD (95% CI)	After marathon Mean ± SD (95% CI)	Mean of differences ± SD (95% CI)	p value
IVCD in inspiration (cm)	1.74 ± 0.64 (1.46–2.02)	1.34 ± 0.58 (1.11–1.58)	−0.39 ± 0.63 (−0.69 to −0.12)	**0.004**
AAD (cm)	1.82 ± 0.30 (1.69–1.95)	1.88 ± 0.32 (1.74–2.02)	0.06 ± 0.38 (−0.12-0.22)	0.21
IVCD in expiration (cm)	2.45 ± 0.79 (2.10–2.79)	2.09 ± 32.61 (1.77–2.40)	−0.36 ± 0.97 (−0.76 to 0.10)	0.054
IVCD index	35.43 ± 26.48 (23.98–46.89)	34.16 ± 19.56 (25.05–41.98)	−1.27 ± 32.61 (−15.27 to 13.85)	0.48
IVCD in expiration/AAD	1.36 ± 0.44 (1.17–1.55)	1.11 ± 0.39 (0.95–1.28)	−0.24 ± 0.58 (−0.48 to 0.03)	**0.03**

IVCD - inferior vena cava diameter, AAD - abdominal aorta's diameter, SD - Standard deviation.

Table 3
Correlation between weight difference and physical data and ultrasound parameters.

	r* (95% CI)	p value
Systolic BP difference	0.11 (−0.36 to 0.50)	0.31
Diastolic BP difference	−0.23 (−0.62 to 0.24)	0.15
BMI difference	0.98 (0.91–0.99)	**<0.001**
Heart rate difference	−0.13 (−0.52 to 0.28)	0.28
IVCD in expiration/AAD difference	−0.27 (−0.65 to 0.20)	0.11
AAD difference	−0.09 (−0.54 to 0.36)	0.34
IVCD index difference	−0.13 (−0.51 to 0.36)	0.27
IVCD in inspiration difference	−0.07 (−0.44 to 0.36)	0.38
IVCD in expiration difference	−0.36 (−0.68 to 0.09)	**0.047**

*Spearman's corelation coefficent, BP - blood pressure, BMI - body mass index, IVCD - inferior vena cava diameter, AAD - abdominal aorta's diameter.

Table 4
Correlation between body mass index and clinical, ultrasound parameters.

	r* (95% CI)	p value
Systolic blood pressure difference	0.16 (−0.32 to 0.57)	0.24
Diastolic blood pressure difference	−0.17 (−0.60 to 3.52)	0.23
Heart rate difference	−0.17 (−0.56 to 0.26)	0.23
IVCD in inspiration difference	−0.07 (−0.48 to 0.37)	0.38
IVCD in expiration difference	−0.35 (−0.72 to 0.05)	0.051
AAD difference	−0.11 (−0.56 to 0.33)	0.31
IVCD index difference	−0.16 (−0.55 to 0.29)	0.23
IVCD in expiration/AAD difference	−0.27 (−0.68 to 0.19)	0.11

*Spearman's corelation coefficent, BMI - body mass index, IVCD - inferior vena cava diameter, AAD - abdominal aorta's diameter.

dehydration. However, the amounts of fluid intake or overhydration during the race were not clear. In our study, we did not measure osmoconcentration.

5. Limitations

The size of our study was relatively small. After the marathon, more than 60 runners came to the study base, but they were rejected from the study because they did not come before the run. We analysed 21 men, and only 2 women voluntary decided to take part in the study because of long distance, preventing our ability to collect data on the effect of gender on the results. The study was conducted in relatively healthy runners. It is possible that cardiac and respiratory comorbidities might have influenced the results. The IVCD in endurance athletes is often more dilated then in the average person (average value = 26 mm, upper limit = 40 mm) and could be important in data analysis.[23]

We used weight loss as a reference standard to measure dehydration. However, weight loss does not account for shifts in intracellular and extracellular fluid. The weight measurement process was not standardised, and there may have been other reasons for inaccuracy (e.g. food intake, changes in clothing). We did not analyse physical characteristics, such as total body mass, lean muscle mass, percentage of body fat, body surface area, surface area-to-mass ratio, or wearing heavy pads and helmets, which could affect thermoregulation.[9]

6. Conclusions

Ultrasonographic assessment of IVCDexp correlates with weight loss and could be useful in the evaluation of volume status.

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None Declared.

Conflicts of interest

None Declared.
TJEM_2017_195.

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