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Effect of position and weight force on inferior vena cava diameter – Implications for arrest-related death

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ABSTRACT

Introduction: The physiology of many sudden, unexpected arrest-related deaths (ARDs) proximate to restraint has not been elucidated. A sudden decrease in central venous return during restraint procedures could be physiologically detrimental. The impact of body position and applied weight force on central venous return has not been previously studied. In this study, we use ultrasound to measure the size of the inferior vena cava (IVC) as a surrogate of central venous return in the standing position, prone position, and with weight force applied to the thorax in the prone position.
Methods: This was a prospective, observational study of volunteer human subjects. The IVC was visualized from the abdomen in both the longitudinal and transverse section in the standing and prone positions without weight force applied, and with 100 lbs (45 kg) and 147 lbs (67 kg) of weight force on the upper back in the prone position. Maximum and minimum measurements were determined in each section to account for possible respiratory variation of the IVC.
Results: The IVC significantly decreased in size with each successive change: from standing to prone, from prone to prone with 100 lbs (45 kg) weight compression, from prone with 100 lbs (45 kg) weight compression to prone with 147 lbs (67 kg) weight compression ($p < 0.0001$). The vital sign measurements had no statistical change.
Conclusions: The physiology involved in many sudden, unexpected ARDs has not been elucidated. However, in our study, we found a significant decrease in IVC diameter with weight force compression to the upper thorax when the subject was in the prone position. This may have implications for the tactics of restraint to aid in the prevention of sudden, unexpected ARD cases.

1. Introduction

The physiology of many sudden, unexpected arrest-related deaths (ARDs) proximate to restraint has not been elucidated. Previous work by Chan et al. did not suggest a relationship between position, restraint, and weight force (up to 102 kg) with a clinically important impact on respiration [1–3]. The impact of these variables on central venous return has not been studied. It is possible that a sudden decrease in central venous return with either body position or applied weight force in custodial arrest settings could be physiologically detrimental, especially in a compromised individual. In this study, we use ultrasound to measure the size of the inferior vena cava (IVC) as a surrogate of central venous return in the standing position, prone position, and with weight force applied to the thorax in the prone position.

2. Methods

This was a prospective, observational study of volunteer human subjects. The institutional review board at the Hennepin County Medical Center/Minneapolis Medical Research Foundation (Minneapolis, MN) approved the study. The subjects were a convenience sample of law enforcement officers and civilians. After providing informed consent, the study physician screened for exclusion criteria. The exclusion criteria included: known pregnancy, a musculo-skeletal condition that would preclude weight applied to the thorax, or a body mass index (BMI) calculation over 30 kg/m^2. The BMI exclusion criterion was chosen to ensure adequate visualization of the IVC with ultrasonography. Subjects also provided health histories for demographic data collection.

A commercial skin resistance analyzer (Omron Fat Loss Monitor HBF-306, Omron Healthcare, Inc., Bannockburn, IL) was used to determine body fat percentage. All subjects were in a rested condition at the time of the experiment. Subjects had an initial IVC ultrasound performed by a professional ultrasonographer with certification as a Registered Diagnostic Medical Sonographer (RDMS) using a Sonosite M-Turbo ultrasound machine (Sonosite Inc., Bothell, WA). Ultrasonographic images of the IVC

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Fig. 1. Experimental setup.

were obtained in B-mode with a phased array (5–2 MHz) transducer in the standing position. The IVC was visualized from the abdomen in a substernal location in both the longitudinal and transverse section. Maximum and minimum measurements were determined in each section to account for possible respiratory variation of the IVC. The ultrasonographer determined the recorded values, and rechecked them at her discretion. Vital signs (blood pressure and heart rate) were taken with an automated monitor (Nonin 2120, Plymouth, MN). Subjects were then laid prone on a flat, level table that had a 10 cm opening at the upper abdomen/lower chest to facilitate ultrasonography on the prone subject. The IVC measurements and vital signs were repeated in this position after approximately 1 min. Subjects then had 100 lbs (45 kg) of weight lowered onto their upper back and the IVC measurements and vital signs were repeated, approximately 1 min after placement of the weight. This delay was intentional to assess subject tolerance before measurements. Finally, the subjects had the weight increased to 147 lbs (67 kg) and the IVC measurements and vital signs were repeated, again, approximately 1 min after the placement of the weight. The 147 lbs of final weight was unintentional. The study authors intended to have the weight be 150 lbs (68 kg), but when the final constructed weight apparatus was weighed, it was 147 lbs (Fig. 1).

Data were entered into an Excel spreadsheet (Microsoft Corp., Redmond, WA) and exported into STATA 10.0 (STATA Corp., College Station, TX). Data were analyzed using descriptive statistics and k sample for equality of means test.

3. Results

A total of 25 subjects were enrolled in the study. One subject voluntarily withdrew from the study once the 100 lbs was placed due to discomfort. Of the 24 subjects that completed the study, 22 were male, and 2 were female. There was a failure to collect the demographic data on one of the subjects so their results were excluded from analysis. Therefore, a total of 23 subjects were included in the analysis. The median subject age was 35 years old (IQR, 26–43). The median subject height was 71 in. (IQR, 69–72) and the median subject weight was 185 lbs (IQR, 175–200). The median subject BMI was 26.6 kg/m^2 (IQR, 25–27.7). The subject health histories included: Achilles tendon surgery (1), cholecystectomy (1), shoulder surgery (2), nephrolithiasis (1), pilonidal cyst (1), appendectomy (2), knee surgery (1), orbital fracture (1), MRSA joint infection (1), traumatic brain injury (1), hip dislocation (1), foot surgery (1), hypertension (1), hypercholesterolemia (1).

The results are presented in Tables 1–2. The IVC decreased in size with each successive change: from standing to prone, from prone to prone with 100 lbs weight compression, from prone with 100 lbs weight compression to prone with 147 lbs weight compression ($p < 0.0001$). The vital sign measurements had no statistical change.

4. Discussion

The mechanisms involved in many sudden, unexpected ARDs are poorly understood. The infrequency, widespread geographical occurrence of the phenomenon, variable medical laboratory testing and treatment for cardiac arrest in these cases, and the varying data available at autopsy, as well as legal barriers to investigations, impairs the study of this phenomenon. Some associated risk factors for ARD have been identified through retrospective studies. Hick et al. identified a profound metabolic acidosis from forceful struggle, restraint preventing compensatory respiratory mechanisms, and stimulant drug use as risk factors [4].

Table 1
IVC measurements in centimeter.

	Standing	Prone	45 kg	67 kg
Longitudinal maximum, cm, median (IQR)	1.86 (1.57–2.16)	1.67 (1.05–2.26)	1.205 (0.83–1.58)	0.805 (0.46–1.29)
Longitudinal minimum, cm, median (IQR)	1.21 (1.01–1.51)	1.14 (0.64–1.61)	0.70 (0.45–1.02)	0.28 (0.0–0.79)
Transverse maximum, cm, median (IQR)	1.63 (1.43–1.93)	1.45 (1.17–2.02)	1.12 (0.76–1.65)	0.74 (0.46–1.13)
Transverse minimum, cm, median (IQR)	1.18 (0.93–1.39)	1.01 (0.77–1.47)	0.38 (0.0–1.15)	0.31 (0.0–0.52)

Table 2
Vital sign measurements.

	Standing	Prone	45 kg.	67 kg.
Heart rate, BPM (IQR)	74 (67–89)	72 (66–79)	70 (68–80)	80 (74–84)
Systolic pressure, mm Hg (IQR)	130 (124–142)	131 (126–147)	138 (129–151)	141 (128–151)
Diastolic pressure, mm Hg (IQR)	84 (80–88)	83 (70–89)	85 (80–90)	89 (80–95)