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● *Original Contribution*

ECHOCARDIOGRAPHIC CHARACTERIZATION OF THE INFERIOR VENA CAVA IN TRAINED AND UNTRAINED FEMALES

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Abstract—The aim of the study was to explore the long- and short-axis dimensions, shape and collapsibility of the inferior vena cava in 46 trained and 48 untrained females (mean age: 21 ± 2 y). Echocardiography in the subcostal view revealed a larger expiratory long-axis diameter (mean: 24 ± 3 vs. 20 ± 3 mm, $p < 0.001$) and short-axis area (mean: 5.5 ± 1.5 vs. 4.7 ± 1.4 cm^2, $p = 0.014$) in trained females. IVC shape (the ratio of short-axis major to minor diameters) and the relative decrease in IVC dimension with inspiration were similar for the two groups. The IVC long-axis diameter reflected short-axis minor diameter and was correlated to maximal oxygen uptake ($r = 0.52$, $p < 0.01$). In summary, the results indicate that trained females have a larger IVC similar in shape and respiratory decrease in dimensions to that of untrained females. The long-axis diameter corresponded closely to short-axis minor diameter and, thus, underestimates maximal IVC diameter. (E-mail: kristofer.hedman@liu.se) © 2016 The Authors Printed in the USA. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Key Words: **Inferior vena cava, Echocardiography, Athlete's heart, Exercise training, Sports cardiology, Maximal oxygen uptake.**

INTRODUCTION

The effect of chronic endurance exercise on cardiac dimensions is well acknowledged, and abundant echocardiographic studies have provided evidence of a physiologic increase in atrial and ventricular dimensions in both male and female endurance athletes compared with sedentary persons (D'Andrea et al. 2013; D'Ascenzi et al. 2014; Hedman et al. 2015b; Pelliccia et al. 1996; Pluim et al. 2000). Furthermore, recent comprehensive reviews describe evidence for larger dimensions of peripheral arteries (Green et al. 2012) and of the aortic root (Iskandar and Thompson 2013) in endurance athletes. Only a few studies provide evidence in support of a larger inferior vena cava (IVC) in trained than in untrained persons (D'Ascenzi et al. 2013; Erol and Karakelleoglu 2002; Goldhammer et al. 1999; Zeppilli et al. 1995), although these findings remain to be verified in female athletes.

The diameter of the IVC is, together with the extent of IVC collapse during inspiration, used for estimation of right atrial (RA) pressure (Lang et al. 2015). The finding of a dilated IVC in an endurance athlete is suggested to represent a physiologic adaptation to repeated, intermittent volume loading and not to reflect an increased RA pressure (D'Ascenzi et al. 2013). In theory, it is possible that the highly compliant, dilated IVC is somewhat collapsed in athletes during resting conditions when cardiac output is similar in trained and untrained persons. This could affect echocardiographic measures of IVC diameter obtained in a single plane. Previous measurements of IVC diameter and collapsibility in athlete–control comparisons are limited to measurements in the subcostal long-axis (LAX) view, and thus, possible differences in IVC shape are not accounted for. Extending the IVC examination to the cross-sectional short-axis (SAX)

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view could provide additional information on 2-D IVC dimensions, including IVC area and shape.

Our main purpose was to characterize and compare the size, shape and respiratory decrease in dimensions of the IVC in both the long- and short-axis views in trained and untrained females. Our secondary aims were to compare corresponding long- and short-axis IVC measurements and to relate IVC dimensions to maximal oxygen uptake ($VO_{2\ max}$).

METHODS

Subjects

We included 94 healthy, non-pregnant, non-smoking females younger than 26 y. All subjects were screened for cardiovascular disease, including a resting electrocardiogram, and underwent maximal bicycle ergometer testing. Forty-six females were endurance trained (ATH), currently training 13 ± 5 h/wk (mean ± standard deviation), and had been competing for 6 ± 2 y at a national or regional level in a variety of endurance sports (17 orienteers, 6 middle- and long-distance runners, 5 tri-athletes, 5 canoeists, 4 bi-athletes, 3 cyclists, 3 swimmers, 3 handball players). The remaining 48 females were high school and college students not engaged in regular endurance or resistance training for several years before the study (CON). Of these, 18 were categorized as "normally active," including, for example, females riding a bike or walking to school, whereas 33 negated any regular physical activity and were categorized as "inactive."

In all subjects, the use of oral or implantable contraceptives was recorded, as was the number of days since the first day of latest menstruation. The phase of the menstruation cycle was then categorized as either of the following: (i) no regular menstruation; (ii) early follicular phase (days 1–7); (iii) late follicular phase (days 8–14); (iv) early luteal phase (days 15–21); (v) late luteal phase (day ≥22). The menstruation cycle phases were further dichotomized into follicular phase (categories i + ii) and luteal phase (iii + iv).

Informed consent was obtained from all subjects. The study was approved by the regional ethical review board in Linköping, Sweden.

Echocardiography

Standard echocardiographic investigation was performed with subjects resting in the lateral decubitus position using commercially available standard equipment with offline storage (Vivid 7/Vivid E9 and EchoPAC Version BT 11, GE Healthcare, Horten, Norway). Athletes were instructed to refrain from strenuous exercise at least 24 h before the examination. Standard 2-D and M-mode echocardiography were performed in accordance with current recommendations (Lang et al. 2015). Our protocol for cardiac measurements has been described in detail previously (Hedman et al. 2015a, 2015b). In brief, we determined ventricular dimensions in diastole and atrial areas in systole using 2-D echocardiography. The modified Simpson biplane technique was used for calculating left ventricular end-diastolic volume (LVEDV) (Lang et al. 2015).

Inferior vena cava. Subjects were examined in the supine position, lying on a horizontally leveled examination table with a small pillow as head support, and images were obtained in the standard subcostal view. Images from three consecutive respiratory cycles were recorded during quiet respiration, without a sniff maneuver. Measurements of IVC dimensions were performed offline by the same investigator, and all measurements were determined as maximal dimension during expiration (EXP) and minimal dimension during inspiration (INSP) within the one respiratory cycle with the most optimal image quality (Fig. 1).

In the long-axis view, IVC diameters were determined perpendicular to the IVC long axis (LAX_{EXP} and LAX_{INSP}), proximal to the junction with the hepatic vein approximately 3 cm from the right atrium (Fig. 2). Short-axis dimensions were determined in images obtained after a 90° rotation of the transducer, with the aim of recording LAX and SAX measurements at the same position. Special care was taken to obtain a SAX plane perpendicular to the long-axis, that is, where the area was smallest and not falsely too large because of angulation. Maximal IVC area during expiration ($SAX_{EXP\text{-}AREA}$) was determined first, followed by major-axis IVC diameter, defined as the largest IVC diameter at maximal area ($SAX_{EXP\text{-}MAJOR}$). Minor-axis diameter was defined as the largest IVC diameter perpendicular to the major-axis diameter ($SAX_{EXP\text{-}MINOR}$). Finally, the same measurements were applied at minimal area during inspiration ($SAX_{INSP\text{-}AREA}$, $SAX_{INSP\text{-}MAJOR}$ and $SAX_{INSP\text{-}MINOR}$, respectively).

The IVC shape during expiration and inspiration was calculated as the ratio of SAX major diameter to minor diameter ($SAX_{EXP\text{-}MAJOR}/SAX_{EXP\text{-}MINOR}$ and $SAX_{INSP\text{-}MAJOR}/SAX_{INSP\text{-}MINOR}$, respectively). The inspiratory decrease in IVC dimension (%) for each measure was calculated as 100 × (expiratory dimension−inspiratory dimension)/expiratory dimension, and for long-axis diameter, this has previously been termed the *IVC collapsibility index* (Lang et al. 2015).

To reduce the influence of differences in body size between the groups, IVC area was indexed by body surface area (BSA) and IVC diameter by square-rooted BSA, adopting the suggested approach of indexing in the same dimension as measured (Batterham and George 1998).

Statistical analysis

Normally distributed continuous data were expressed as means ± standard deviations (5th–95th percentiles),