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Measuring the Size and Expansion of the Common Femoral Vein as A New Method of Detection and Stratification of Heart Failure

Thach Nguyen [1,2,*], Duc H Nguyen [1], Bao Nguyen [1], Nga Nguyen [1], Duy Chung [1], Bao Nguyen [1], Luan Ngo [1], Hadrian Tran [1], Imran Mihas [3], Sarthak Agarwal [4], Cardy Nguyen [5], Vivian Nguyen [6], Dung Thuong Ho [7], Aravinda Nanjundappa [8], Loc T Vu [2,9], Saanya Agarwal [10], Ernest Talarico1 [1,2], Marco Zuin [11], Gianluca Rigatelli [12] , and Michael Gibson [13]

[1] *Cardiovascular Research Laboratories, Methodist Hospital, Merrillville, IN, USA*
[2] *Tan Tao University, School of Medicine, Long An, Vietnam*
[3] *Indiana University, Bloomington, IN, USA*
[4] *The University of Chicago, Pritzker School of Medicine, Chicago, IL, USA*
[5] *University of California at Berkeley, Berkeley, CA, USA*
[6] *University of Texas, Southwestern Medical School, Dallas, TX, USA*
[7] *Thong Nhat Hospital, Ho Chi Minh City, Vietnam*
[8] *Peripheral Interventions, Cleveland Clinics, Cleveland, OH, USA*
[9] *University of Medicine and Pharmacy Medical Center, Ho Chi Minh city, Vietnam*
[10] *Chesterton High School, Chesterton, IN, USA*
[11] *Department of Translational Medicine University of Ferrara, Ferrara Italy*
[12] *Cardiovascular Diagnosis and Endoluminal Interventions, Rovigo Hospital, Rovigo, Italy*
[13] *Baim Institute of Clinical Research, Harvard Medical School, Boston MA, USA*

***Corresponding author**: Thach Nguyen, M.D., F.A.C.C., F.S.C.A.I.
Cardiovascular Research Department Methodist Hospital, Merrillville, IN, USA
Email: thachnguyen2000@yahoo.com

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ABSTRACT

Heart Failure (HF) is on the end stage of the disease spectrum with many confounders and thus no specific symptoms and signs. There is a need for a test that can effectively confirm the diagnosis of volume overload in HF at its earliest to guide the initial approach and subsequent management. This study aimed to evaluate the effectiveness of a new test noted as the Size and Expansion of Femoral Vein (SEFV) in the diagnosis and management of patients with HF. This test was used specifically on asymptomatic patients or those who presented with severe comorbidities. The patients who arrived at the emergency room with a diagnosis of HF or suspected HF were enrolled. Ten patients without HF formed the control group. All patients received a standard physical examination (PE). The patients with the obvious diagnosis of HF by PE formed the HF control group. All patients with tentative diagnoses formed the HF study group. All patients underwent the ultrasound test to measure the size of the common femoral vein (CFV) and artery (CFA). The study enlisted 167 patients with HF or suspected HF. The results showed that the SEFV test was more accurate (98%) than the PE (54%). The SEFV test accurately differentiated between severely sick patients with intravascular overload and moderately sick patients with extravascular overflow. The test was accurate in patients with severe comorbidities (93%) or hypotension (100%). The SEFV test was more accurate in confirming the presence of fluid overload in patients with severe comorbidities or hypotension.

KEYWORDS Heart failure; Common Femoral Vein; Diagnosis; Volume overload; HFrEF; Ultrasonography

INTRODUCTION

The current method of history interview and physical examination (PE) for patients suspected of heart failure (HF) presented at the emergency room (ER) yields only subjective complaints and non-specific objective findings. The symptoms of shortness of breath (SOB), the sound of rales in the lungs, appearance of the jugular venous distention, hepato-jugular reflux, or the sign of pitting edema in the extremities could be seen in other medical conditions such as severe chronic pulmonary embolism, pulmonary hypertension (HTN), chronic obstructive pulmonary disease (COPD) or liver cirrhosis, etc. In real-life practice, the main goals

of PE when investigating HF are to assess the fluid level in every area of the body and to detect any fluid overload at its earliest stage, specifically in asymptomatic patients. In many cases, the search for fluid overload was negative due to the nonobvious edema in patients with chronic mildly decompensated HF, morbidly obese, or in thin Asian patients. In the US, it was more challenging to assess the presence of edema in patients admitted to the general medical units because many of them came from long-term care facilities. They often presented with an inability to communicate, contracted arms and legs, in a fetal position, or simply with generalized dependent edema after months or years confined in bed.

From a strategic disease management perspective, the current investigative protocols for HF are too narrowly designed and limited only to the clinical assessment of fluid levels in the cardiovascular system or storage areas (such as the abdominal wall, peritoneal cavity, scrotum, or presacral area). This search for fluid overload is judged to be only a late reactive tactic which hardly represents a proactive strategy expected in today's society. The current tactics are lackluster and unreliable because edema is a sign of an overwhelmed intrinsic compensatory mechanism. In contrast, recurrent and refractory edema is a sign of advanced or end-stage HF.

On top of the current limitations in diagnosis or management, patients with previously confirmed and stable HF did not come only due to decompensated HF. In a standard case, many patients arrive at the emergency room or intensive care unit with hypotension from non-cardiac or cardiac causes (e.g., sepsis, dehydration from bleeding, acute myocardial infarction, etc.). The dilemma propounded by these cases was how to assess the current intravascular fluid level (euvolemic, hypovolemic, or hypervolemic) to give or not to provide intravenous fluid (fluid resuscitation) without precipitating frank HF.

Until now, there was no bedside method or test that could accurately estimate the blood volume in the whole body. Therefore, there is a strong need for a non-invasive test that can detect the level of an overflow of the venous compartment as early as possible. This would allow for a proactive approach in which asymptomatic patients or patients with severe comorbidities along with moderate fluid overload could be preemptively treated compared to waiting until the clinical findings of HF become visible. The current method is obsolete because once recurrent HF appears, it may be too late for meaningful reversal.

In this study, we evaluated the efficacy of a non-invasive test to confirm the level of the venous fluid volume and to detect fluid overload at its earliest. Furthermore, the study aimed to assess the efficiency of this new test in the diagnosis and management of a large, diverse group of HF patients. This included patients with symptoms, no symptoms, complex comorbidities, or concomitant hypotension from cardiac and non-cardiac causes.

TABLE 1. Classification Criteria of the Three Study Groups

Group 1	**Normal Control** Patients with normal left ventricular function, without valvular abnormalities or clinical heart failure
Group 2	**Standard heart failure (HF control)** Patients with an obvious diagnosis for HF based on the Framingham criteria
Group 3	**Complex Heart failure (HF study group)** Patients with difficulties or confusion in diagnosis because of lack of symptoms, non-specific physical findings, concurrent severe comorbidities, or presentation with complex cardiac or non-cardiac problems (e.g., hypotension from sepsis, dehydration, bleeding, etc.)

METHODS

Inclusion and Exclusion Criteria

The patients were enrolled upon presentation to the emergency room with the diagnosis of HF or HF needed to be ruled out. The patients were excluded if they had significant end-stage disease with a survival time of < 6 months. A group of 10 patients with normal left ventricular function on echocardiography, without valvular abnormalities and clinical HF, served as normal control.

Study protocol

At first, all patients received standard history and PE for HF, searching for the presence of rales in the lungs, enlarged or tender liver, fluid accumulation (edema) in the abdominal wall, legs, presacral area, etc. All patients underwent an ultrasound test to check the size and expansion of the common femoral vein (CFV) at baseline and during cough. The CFV was selected based on an ultrasound study of all the superficial veins of the body. The reasons for disqualifying the jugular vein at the neck and the cephalic vein in the arm are explained in the technique section.

The patients were divided into three groups: normal control, HF control, and HF study group. Their characteristics and differences are classified and listed in detail in Table 1. The patients in the 3rd group are the main focuses of this study and are listed in Table 2.

The questions in the diagnosis and management of these 3rd group patients were whether they had excessive fluid in a complex presentation due to severe comorbidities or whether the underlying non-cardiac or cardiac disease progressed to a higher severity level and thus muddled the clinical picture of HF. It was important to differentiate these two problems because diuresis would be the answer if it was due to fluid overload. If the underlying disease's progression caused HF's decompensation, then correction of the disease etiology was needed.

Diagnostic criteria

The diagnosis of HF was based on the Framingham criteria, which consisted of the concurrent presence of either 2 major criteria or 1 major and 2 minor criteria [1] (Table 3).

TABLE 2. List of Patients with Severe Comorbidities or Complicated Presentation

Major comorbidities	Patients without prior history of heart failure or with well-compensated heart failure now presented with questionable fluid overload **Right ventricular fluid overload with normal or decreased left ventricular function** 1. Chronic obstructive pulmonary disease 2. Chronic pulmonary hypertension 3. Chronic pulmonary embolism **Increased total body fluid volume with normal or decreased left ventricular function** 4. Chronic kidneys disease 5. Cirrhosis of liver 6. End-stage renal disease on dialysis **Mechanical interference with normal or decreased left ventricular function** 7. Respiratory failure on a ventilator (interference of right ventricular fluid return) 8. Long-term bedridden status (quadriplegia, old stroke, etc.) (due to fluid accumulation in the interstitial or "third" space (nonfunctional area between cells))
Complicated Presentations	Patients with dilated cardiomyopathy and previously well-compensated heart failure now presented with 1. Hypotension and sepsis 2. Hypotension and bleeding 3. Hypotension and previously well compensated moderate mitral, aortic, tricuspid stenosis or regurgitation

TABLE 3. Framingham Criteria for Heart Failure

Major criteria	1. Paroxysmal nocturnal dyspnea 2. Weight loss of 4.5 kg in 5 days in response to treatment 3. Neck vein distention 4. Rales 5. Acute pulmonary edema 6. Hepatojugular reflux 7. S3 gallop 8. Central venous pressure greater than 16 cm water 9. Circulation time of 25 seconds 10. Radiographic cardiomegaly 11. Pulmonary edema, visceral congestion, or cardiomegaly at autopsy
Minor criteria	1. Nocturnal cough 1. Hypotension and sepsis 2. Dyspnea on ordinary exertion 3. A decrease in vital capacity by one-third of the maximal value recorded 4. Pleural effusion 5. Tachycardia (rate of 120 bpm) 6. Bilateral ankle edema

Measuring the size and expansion of the common femoral vein

All patients underwent an ultrasound study measuring the size and expansion of the common femoral vein (SEFV). The test is based upon two main principles: 1. The volume of blood going through the CFA and returning through the CFV should be equivalent. If so, in normal conditions, the size of the CFA and the CFV should be somewhat equal. If the amount of venous return is delayed or lower, there would be edema in the lower leg. The arterial blood volume should not be higher than the amount of venous return because the heart cannot pump more than what it receives. 2. Most of the circulating blood in the vascular system is in the veins (65%) [2]. The amount of blood in the arteries is comparatively smaller (35%), and the size of the arteries does not change much due to persistent vascular tone in order to keep a minimal blood pressure compatible with life. On the contrary, the veins are capacitance vessels and may conformingly modify their size in order to accommodate the extra positive or negative amount of blood. As a result, the veins' size reflects better the blood volume status in the intravascular compartment or, specifically, the venous compartment.

The technique of the SEFV test

The SEFV was an ultrasound study examining the size of the CFV at baseline and its expansion with cough. It was done with the SonoSite, (FUJIFILM SonoSite, Inc. Bothell, Washington, US) but could be performed by any echocardiography machine equipped with a vascular probe. The patients were placed in a supine position with both legs straight. The initial location in which the probe was positioned was the strongest point of the right femoral pulse. Next, the probe was manipulated to image the CFA and CFV immediately proximal to the bifurcation of the superficial and deep femoral artery (Figure 1). The CFV should be imaged in the coronal plane (somewhat round structure) and not in its longitudinal axis. The common femoral artery was recognized as a round structure on the left, and the common femoral vein on the right. Without cough, they were of the same size. (Figure 2) The vein was easily identified as it collapsed when the probe was pressed down while the artery stayed the same. Calcium deposits could be seen on the wall of the common femoral artery.

In patients with normal fluid status, the size of the common femoral vein was similar to that of the common femoral artery. In a patient without fluid overload or dehydration, the common femoral vein would have expanded maximally to twice the baseline size when the patient coughed. (Figure 3) When the patient had fluid overload, the size of the common femoral vein was more significant, even twice or three times larger than the size of the femoral artery. (Figure 4) When a patient had dehydration, the size of the CFV was smaller than the CFA's. The ratio of CFV: CFA was < 0.8. (Figure 5) [3]

As this study showed the critical role of the CFV in the diagnosis of fluid overload, could other veins reflect the current status of the venous compartment? In a pilot trial, in a sitting position, one patient with HF, pulmonary hypertension, and enlarged CFV, the jugular vein became huge when the patient talked (due to high pulmonary artery pressure preventing venous return), and the vein nearly collapsed when the patient kept silent. This phenomenon showed that the jugular vein could not be used as a sensitive hallmark for venous fluid level (Figure 6). The cephalic vein was checked on the same patient and showed no enlargement even though the CFV was enlarged (Figure 7-8-9). In the US, the size of the inferior vena cava could not accurately portray the level of

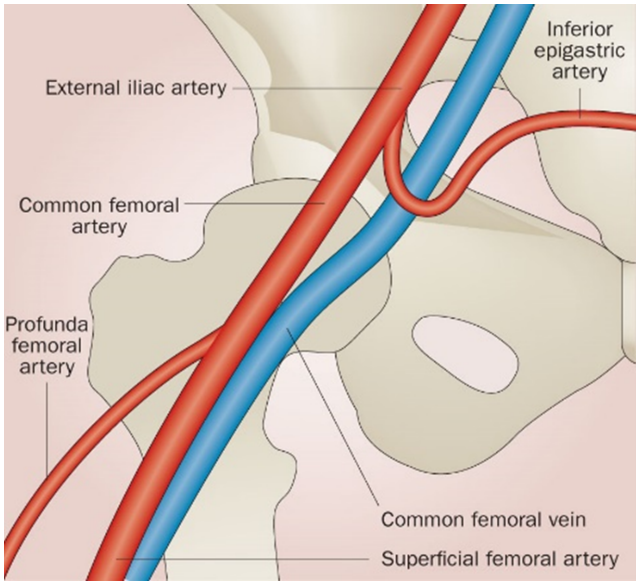

FIGURE 1. The common femoral vein was measured at the level immediately proximal to the bifurcation of the superficial and deep femoral artery. In this figure, it is important to identify with the probe the location of the common femoral artery proximal to its bifurcation with the deep and superficial femoral artery.

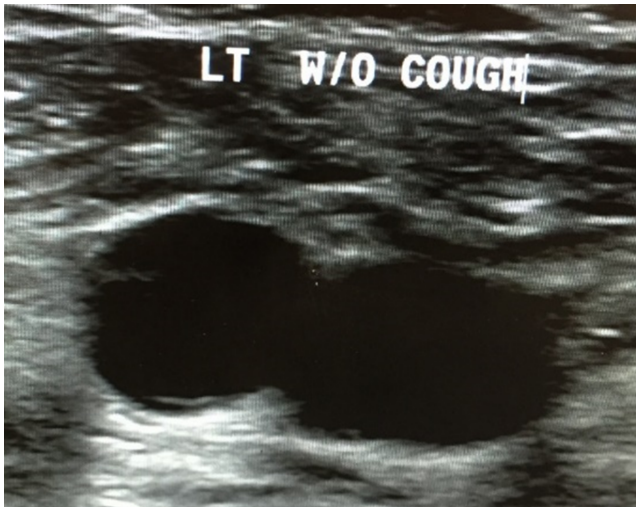

FIGURE 2. The common femoral artery was recognized as a round structure on the left, and the common femoral vein on the right. Without cough, they were of the same size. The vein was easily identified as it collapsed when the probe was pressed down while the artery stayed the same. Calcium deposits could be seen on the wall of the common femoral artery.

the venous volume because of the significant differences in weight among American patients. The large layer of air in the bowels also prevents the sharpness of the picture of the inferior vena cava.

Measurements of the size and expansion of the femoral vein

In normal individuals, the size of the CFA and CFV can vary based on body size, from 90 lbs. to 500 lbs. for American patients. The size of the CFV also changed with the

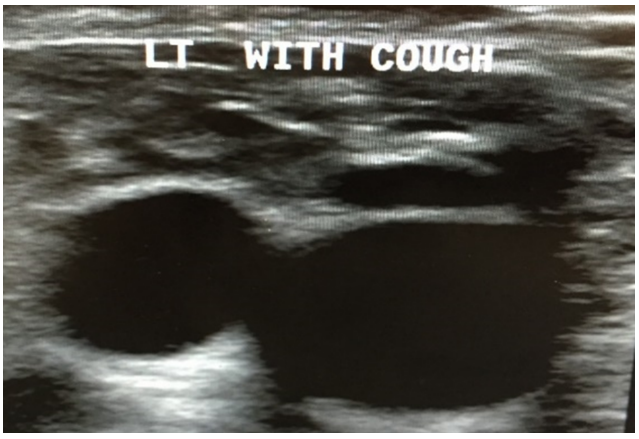

FIGURE 3. In patients with normal fluid status, the size of the common femoral vein was similar to that of the common femoral artery. In a patient without fluid overload or dehydration, the common femoral vein would have expanded maximally to twice the baseline size when the patient coughed.

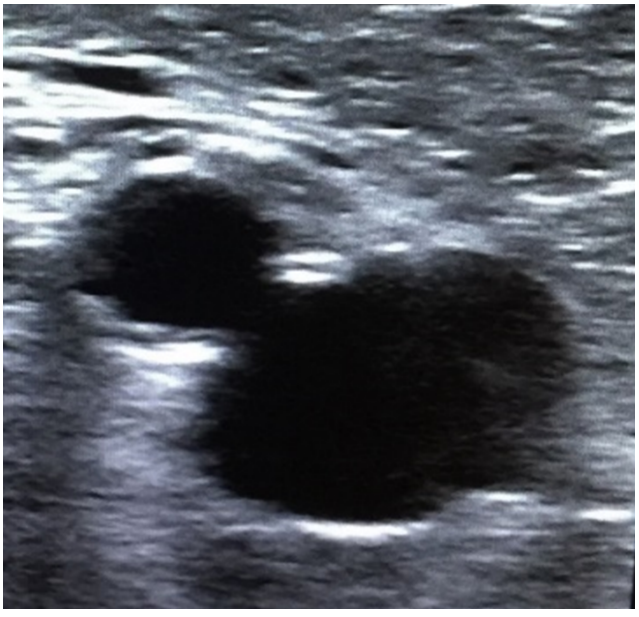

FIGURE 4. When the patient had fluid overload, the size of the common femoral vein was larger, even twice or three times larger than the size of the femoral artery.

body's fluid status. In this study, we did not use the absolute diameter of the artery or vein as the standard measurement. Instead, we compared the size of the CFV with the CFA (which was constant except during dehydration or bleeding) of the same patient and used the ratio of the CFV to CFA. The degree of expansion of the CFV was the measurement utilized to assess the fluid status in the intravascular compartment.

Analysis protocol

At first, the sizes and expansions of the common femoral arteries and veins (SEFV) of the ten normal control patients were measured and recorded. Their results of the ratio CFV: CFA formed the normal baseline measurements. Next, the

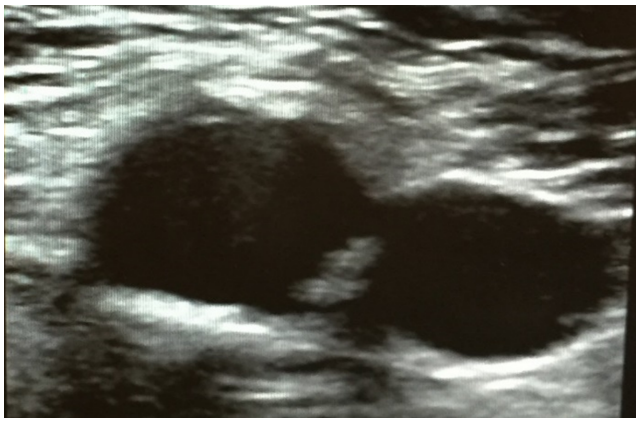

FIGURE 5. In this picture, the size of the common femoral vein was smaller than that of the common femoral artery (Ratio CFV: CFA<0.8). This patient was bleeding in the stomach due to an ulcer. The border of the vein looked sharper because it stayed immobile while the artery wall moved during systole. [10]

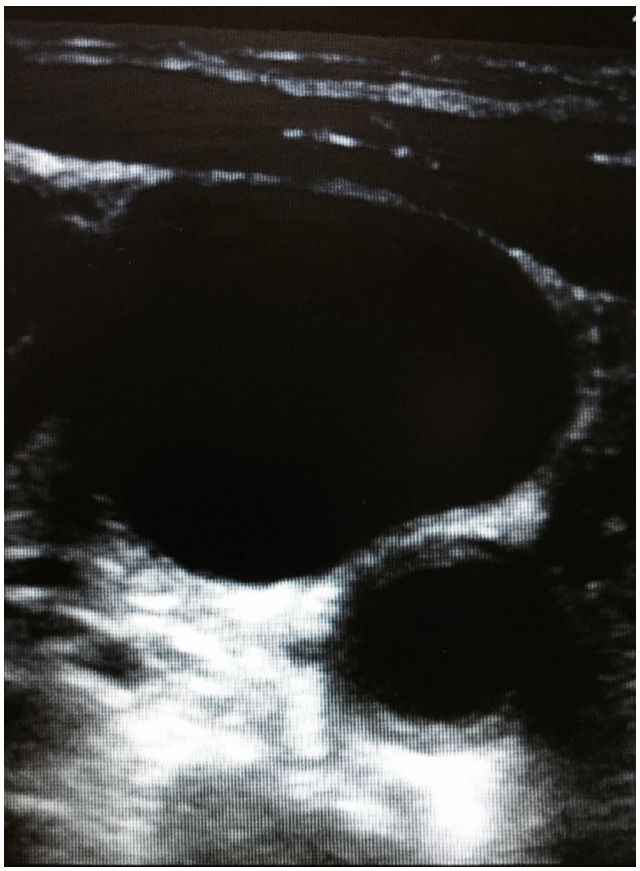

FIGURE 6. This is the carotid artery ultrasound of a patient with heart failure and pulmonary hypertension from sickle cell disease. In the sitting position, the carotid artery was seen as a round structure in the right lower corner. The jugular vein with a thin wall expanded into a huge vein when the patient talked. The huge expansion is due to increased pulmonary artery pressure preventing venous blood return. The vein returned to its baseline size when the patient stopped talking.

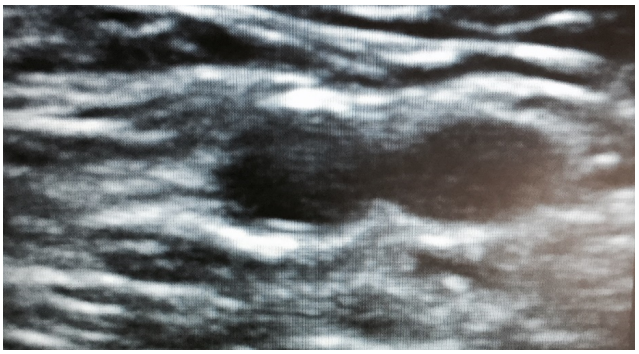

FIGURE 7. In this patient with heart failure and an enlarged common femoral vein, the brachial artery and cephalic vein size are the same at baseline.

results of the SEFV test for patients with HF confirmed by the Framingham criteria (HF control group) were recorded and calculated. Their averaged data of the ratio CFV: CFA became the standard for HF patients. Then the results of the SEFV test in patients with HF NOT confirmed by the Framingham criteria (HF study group) were recorded and calculated. In conclusion, we analyzed the correlation between the results of the SEFV test (size of CFV and its expansion with cough) and (1) the presence of fluid overload by locations (leg, liver, lungs, jugular vein, etc.) and (2) the presence of SOB and fatigue with exertion and at rest.

Statistical Analysis

Continuous variables are expressed as mean ± standard deviation (SD) for normal distributions or numbers (percentage) for categorical variables. Statistical analysis was performed using the Medcalc software program for windows, version 19.9.7. A P value of < 0.05 was considered statistically significant. This study was conducted by the School of Medicine Research Consortium and approved by the local ethical committee of the affiliated hospitals.

RESULTS

From January 2019 to December 2020, 167 patients (mean age= 65, 56% female) met the inclusion criteria and were enrolled. An additional ten normal patients served as normal control. (Table 4)

Normal SEFV

In the normal control group (patients with normal LV function without valvular abnormalities and HF), the size of the CFV was nearly equal to the size of the CFA. The ratio between the diameters of the CFV: CFA was averaged to be between 0.9-1.1 (Figure 2). When these patients were asked to make a deep cough, the size of the CFV expanded to less than two times the baseline. The normal ratio CFV: CFA upon cough averaged 1.8-2.0 (Figure 3). These data formed the normal baseline measurements of the size and expansion of the common femoral artery and vein on the SEFV test. The meaning of a normal CFV: CFA ratio was

TABLE 4. Demographic and Clinical Features

	Mean ± SD or (%)
Age (years)	65 ± 7
Gender	
Male	44%
Female	56%
Cigarette smoking	30%
Commorbidity	
Diabetes mellitus	35%
Hypertension	43%
Coronary artery disease	42%
Previous heart failure	55%
Anemia	6%
Dyslipidemia	45%

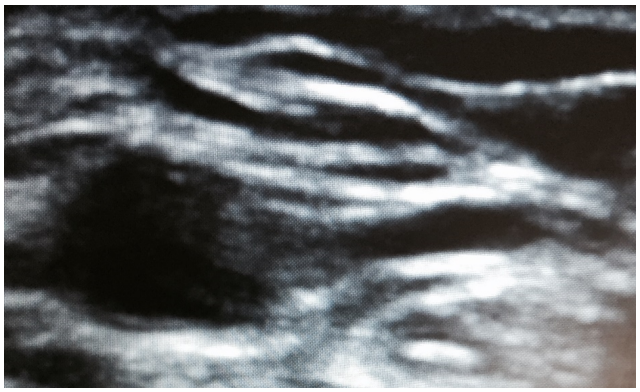

FIGURE 8. In this patient with heart failure and an enlarged common femoral vein, at baseline, the cephalic vein collapsed upon pressure on the vascular probe, while the brachial artery had no change in size.

that the blood volume in the veins was euvolemic, and the veins could accommodate an additional amount of blood if needed (Table 5).

HF Control Group

In the total of 167 patients admitted from the emergency room, PE could make a firm diagnosis of HF based on the Framingham criteria in 54% (HF control group). The

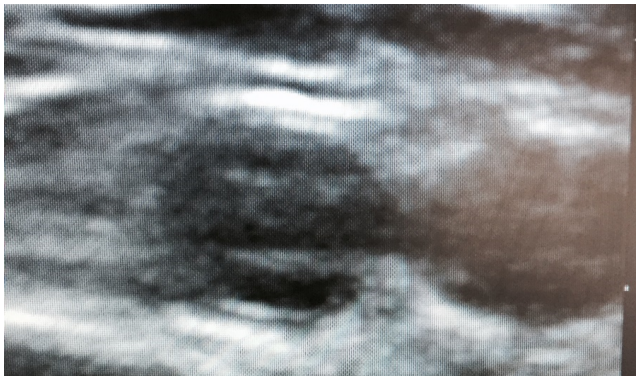

FIGURE 9. In this patient with heart failure and an enlarged common femoral vein, the size of the cephalic vein did not increase upon cough. This picture showed that the cephalic vein does not reflect well the volume status of the body fluid.

TABLE 5. Correlations between SEFV with Clinical Status and Location of Fluid overload

CFV/CFA Ratio	Expansion upon cough	Clinical Class	Vascular compartment
0.9 – 1.1	Positive	Normal	Normal intravascular volume
> 2	Positive	Moderately Abnormal	Extravascular overflow "Minimal intravascular overload
> 2	Negative	Severely Abnormal	Severe intravascular overload" Extravascular overflow

SEFV: Size and expansion of femoral vein, CFV/CFA: Common femoral vein/ common femoral artery

diagnosis of the remaining patients (46%) was questionable because of their asymptomatic status, lack of suggestive physical findings, or confusing symptoms (HF Study group). In this HF control group, the SEFV test showed the size of the CFV was more than twice larger than the size of the CFA. The ratio between the diameters of the CFV: CFA was > 2 (Figure 4). If the patient had enlarged CFV size and the CFV still expanded with cough, the fluid overload was moderate (moderately abnormal SEFV test). If the size of the CFV was large, and there was no expansion of the CFV upon cough (severely abnormal SEFV test), the venous compartment was maximally filled (Table 5). Using the SEFV technique, fluid overload could be confirmed in 100% of patients with obvious HF.

HF Study Group

For patients with questionable HF, the SEFV test could clarify and affirm the fluid status in 98% of cases. Four patients could not be diagnosed with fluid overload due to suboptimal pictures of the SEFV due to technical problems (excessive obesity, contracted hip joint without optimal access to the CFV and CFA). (Table 6)

Patients with severe comorbidities

In patients with severe morbid obesity (8 patients with weight > 400 lbs.), the conventional PE could make a diagnosis in 25% of cases, while the SEFV could confirm the presence of fluid overload in 75%. Two patients had suboptimal images of the SEFV because of their extreme body size and weight (> 500 lbs.).

In patients from long-term care facilities with contracted lower limbs (6 patients), the conventional PE could only make a meaningful diagnosis in 17%. The SEFV could show the size of the CFV in only 67% of cases due to limited access to the femoral area and the patient's inability to follow commands to cough.

In patients with severe comorbidities (total= 46) such as severe COPD (20 patients), chronic diastolic HF (9 patients), prolonged bedridden status (6 patients), end-stage renal disease (ESRD), hemodialysis or peritoneal dialysis (7 patients), cirrhosis of the liver (4 patients), with normal left ventricular function (normal ejection fraction), an intensive history

TABLE 6. Classification of Patients

	Number and percentage
Total	167 (100%)
Control group	90 (53%)
Study group	77 (46%)
Contracted lower limbs	6
Morbid obesity	8
Comorbidities	
COPD	20
HFpEF	9
ESRD on PD or HD	7
Prolonged bedridden status	6
Cirrhosis	4
Complex presentation	
Hypotension	17

COPD: Chronic Obstructive Pulmonary Disease; HFpEF: Heart Failure with preserved Ejection Fraction; ESRD: End-stage Renall Disease; HD: Hemodialysis; PD: Peritoneal dialysis

taking and PE could not differentiate whether the shortness of breath (SOB) was due to pulmonary, hepatic or positional problem or due to fluid overload. In these patients, the SEFV tests could confirm the presence or absence of fluid overload in all 46 patients (100%). (Table 6).

In the special group of patients (17 patients) who presented with hypotension on top of dilated cardiomyopathy with low ejection fraction (EF), currently having bleeding, sepsis, end-stage renal disease, or cirrhosis of the liver, the SEFV tests were extremely useful in assessing the current fluid status in 100% of patients (Table 6, Figure 5).

Results of the SEFV – Clinical correlation analysis

There was a positive correlation between the severely abnormal SEFV test (enlarged CFV at baseline and non-expanding CFV with cough) and excess fluid in the upper part of the body (liver, lungs, jugular veins, etc.). In contrast, a moderately abnormal SEFV test (enlarged CFV at baseline and expanding CFV with cough) correlated more with the edema in the lower extremities. Both levels of abnormal SEFV test correlated with the presence of SOB. The severely abnormal SEFV result was associated with severe and persistent SOB even at rest, whereas the moderately abnormal SEFV results were coupled with only short-term SOB on exertion. There was no direct correlation between the abnormal SEFV with the presence of fatigue at rest.

DISCUSSION

Our study demonstrated that the SEFV test was more accurate (98%) in confirming fluid overload than PE (54%). This SEFV test was considerably more effective in confirming or negating the presence of fluid overload in patients with confusing symptoms or severe comorbidities (93%) and hypotension (100%). A severely abnormal SEFV test correlated with more fluid overload in the upper part of the body, while a moderately abnormal SEFV test was seen more in patients with fluid overload, mainly in the lower extremities.

The diagnosis of HF is based on PE and blood tests (Brain Natriuretic Peptide – NT-proBNP). There is no pathognomonic symptom or sign of HF. In commonly quoted studies, PE could only detect or confirm HF in only slightly more than 50% of the cases, at best [4]. There was no prior study besides the four abstracts from our laboratories utilizing the SEFV as markers of venous blood volume [5]-[8]. The size of CFV was previously reported in a single study to correlate with the left ventricular end-diastolic pressure [9].

In our study, the primary finding was that the size of the CFV accurately reflected the blood volume status (euvolemia, hypovolemia, or hypervolemia - fluid overload). At the same time, the expansion of the SEFV with cough represented the reserved volume the venous compartment could further accommodate if the extra fluid were added. The combination of an enlarged femoral vein (representing fluid overload by the SEFV) coupled with the symptoms of SOB (excluding significant pulmonary disease, e.g., COPD, pulmonary embolism, intrinsic pulmonary hypertension, etc.) constituted a new powerful formula confirming the diagnosis of HF:

Enlarged Femoral Vein + Shortness of Breath = Heart Failure

The application of this formula complemented the current armamentarium for general cardiologists because HF is a clinical diagnosis. In an example of two patients with dilated cardiomyopathy, similar low EF (e.g., 35%), and no prior history of clinical HF, one patient developed for the first time symptoms of HF, and the other had none. The symptomatic patient could be diagnosed as having HF, and the second patient could only be coded as having dilated cardiomyopathy without HF.

This application of the SEFV test brought about another essential breakthrough for cardiologists when defining the mechanism of disease and development of symptoms in patients of stage A HF by the American College of Cardiology/ American Heart Association classification [10]. These patients were at high risk for developing HF but had no structural disorder of the heart by current investigative methods. As a new addition to the investigative process, the SEFV test proved the pathological presence of fluid overload, which could precipitate HF if the class A HF patients remained unchecked and untreated.

The second important finding of this study was that the SEFV test was the most beneficiary in patients with complex or confusing diagnoses due to the presence of both confounding symptoms and symptoms from severe comorbidities. In this patient cohort, the SEFV test could confirm the presence or absence of fluid overload in 93% of patients.

In these patients, the PE of early or minimal liver congestion, abdominal wall infiltration, and dependent area edema could not be accurately evaluated. The sedentary lifestyle of

these patients further compounded the problems due to previous coronary bypass graft surgery, surgical or percutaneous valvular procedure, or their chronically bedridden nature. As many of these patients were older, their intravascular space could more easily become overwhelmed as its stiffer vascular wall did not expand enough to accommodate a new influx of fluid. Since their safety margin for fluid overload was lower for patients with multiple comorbidities, earlier detection of an enlarged CFV could help preempt the appearance of clinical HF.

In caring for patients with dilated cardiomyopathy and well-compensated HF, many of these patients could be seen at the emergency room presenting with hypotension due to possible sepsis, dehydration, or bleeding. As a result of low blood pressure, these patients might need aggressive fluid resuscitation, which could run the risk of developing frank HF. At this junction, the SEFV test could help determine whether the venous volume was relatively low secondary to vasodilation from sepsis or the venous volume was low due to dehydration, excessive diuresis, or bleeding. By this, the SEFV was extremely useful in guiding judicious fluid resuscitation in these delicate situations [9].

Finally, our study showed that the patients with a severely abnormal SEFV test had more fluid overload in the upper part of the body. In contrast, the less sick patients had only fluid overload in the lower extremities. In the detailed review of the locations for fluid overload in patients with severely abnormal SEFV test (enlarged CFV and non-expanding CFV upon cough), two striking details stood out and showed that the majority of these locations were intravascular and located in the upper body. The list of abnormal clinical findings included: hepatomegaly, splenomegaly, the mesenteric arterial system (positive hepato-jugular reflux), the pulmonary arteries (crackles on auscultation), and the jugular veins (jugular venous distention). The only exceptions of extravascular fluid were: the abdominal wall, the peritoneal cavity (ascites), the scrotum (for men), labia (for women), and back for patients in a supine position and lower extremities. In contrast, if the SEFV test was moderately abnormal (enlarged CFV and non-expanding CFV upon cough), the edema was found mainly in the lower extremities. The fact that the edema was pitting proved that the fluid was in the interstitial tissue or extravascular space.

The above two sets of clinical findings, separated in location, correlated well with the two types of abnormal SEFV tests based on severity. In the moderately abnormal SEFV test, the CFV was enlarged; however, it was not complete because it could still expand with cough. In these patients, the intravascular compartment was not overwhelmed, so no liver congestion, pulmonary edema, or jugular vein distention could be found. The primary location of edema was in the interstitial tissue or extravascular space. These patients had extravascular overflow. This was in contrast with the severely abnormal SEFV test, where the CFV was enlarged, and the intravascular compartment was utterly overwhelmed. This was why the CFV could not expand upon coughing. In these patients, there were liver, pulmonary congestion, jugular vein distention, or reflux on top of local edema in the dependent loose connective tissue such as the lower legs, thigh, scrotum, labia, presacral area, abdominal wall, around the arms, or in the periorbital areas, etc. In these situations, the patients had an intravascular overload and extravascular overflow. We could reconstruct the historical sequence of HF by stating that, at first, the extravascular space was flooded with extra fluid. Once the extravascular space was overfilled with a persistent fluid influx, the intravascular space became overloaded and overwhelmed.

Based on the above correlations, the SEFV test could distinguish between moderate and severe clinically decompensated HF patients by corresponding moderate extravascular overflow versus severe intravascular fluid overload (on top of extravascular overflow). This is a new concept, and its understanding could significantly aid in the management of patients with complex presentations of HF. As to the negative correlation between the results of the SEFV tests and the complaints of extreme fatigue, the explanation resulted from the mechanism of the test. The SEFV test reflected the overwhelmed fluid volume in the venous compartment. If the overload occurred in the pulmonary arteries, the patients would be presented with an SOB. The feelings of exhaustion or fatigue in severely sick HF patients emanated from a low cardiac output or ejection fraction. As the SEFV represented the volume in the right heart and did not reflect the function of the left ventricle (cardiac output), the SEFV test had no meaningful correlation with feelings of fatigue or extreme exhaustion.

Study limitations

This is a non-randomized observational study with a small number of patients. Despite all the above optimistic results, some issues remain unresolved: primarily, whether the SEFV test is more clinically efficient than the BNP test; secondly, whether the SEFV test shortens the hospitalization for HF patients; thirdly, whether the mortality of patients with HF improves with the application of the SEFV test; and finally if the SEFV test could decrease the cost of care of patients with HF. In conclusion, the SEFV test was more accurate in confirming the presence of fluid overload than conventional PE. This is a pioneering method in accurately detecting fluid overload at the early stage, even when the patient is still asymptomatic. This test was best for patients with prominent clinical confounders due to severe comorbidities or concomitant hypotension. More importantly, the SEFV test could accurately differentiate the severely sick patients with intravascular overload and extravascular overflow, while the moderately sick patients had mainly extravascular overflow. Randomized trials with more patients could confirm the preliminary benefits above.

CONFLICTS OF INTEREST

None of the authors have conflicts of interest to declare

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