Normal Lower Limb Venous Doppler Flow Phasicity:
Is It Cardiac or Respiratory?

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OBJECTIVE. The purposes of this study were to determine the origin and nature of normal lower limb venous Doppler flow phasicity and to assess normal and respiratory variations.

SUBJECTS AND METHODS. The common femoral veins of 12 healthy volunteers (three men and nine women; age range, 21–50 years; mean, 29 years) were evaluated by detailed spectral Doppler examinations with simultaneous ECG and respirometric tracings. The examinations were performed using a 5- or 7-MHz linear-array transducer with breath held in mid respiration, at the end of deep expiration, at the end of deep inspiration, during Valsalva's maneuver, and during quiet and deep breathing. The tracing obtained during breath-hold in mid respiration was considered the baseline. Tracings obtained during the other respiratory phases were analyzed for changes from the baseline. Doppler tracings were analyzed for phasicity, waveform frequency, components, velocities, velocity ratios, and presence of retrograde flow, all in correlation with simultaneous ECG and respirometric tracings. Tracings were analyzed independently by two observers to assess interobserver variability.

RESULTS. With breath-hold in mid respiration, the common femoral vein Doppler tracings consisted of multiphasic waveforms that had a frequency similar to that of the heart rate. Each waveform consisted of systolic, *v*, diastolic, and *a* waves. The systolic wave occurred 0.4 sec later than the QRS complex of the ECG and was always antegrade. The *v* wave was always retrograde without flow reversal. The diastolic wave was always antegrade. The *a* wave was always retrograde but showed flow reversal in nine of 12 subjects. The systolic:diastolic velocity ratio ranged from 0.9 to 1.5 (mean, 1.1). The minimum:maximum velocity ratio ranged from –0.4 to 0.2 (mean, –0.15). With breath-hold at the end of expiration, the waveforms became slightly damped, becoming biphasic in five subjects and remaining multiphasic in seven. With breath-hold at the end of inspiration, the waveforms became nonphasic or biphasic in nine and decreased in velocity in 12. With Valsalva's maneuver, flow stopped. With normal respiration, cardiac waveforms were modulated by higher amplitude and less frequent biphasic respiratory waves. The plasticity was equal in two, dominantly cardiac in six, and dominantly respiratory in four. Flow velocity increased with expiration and decreased with inspiration. With deep breathing, the respiratory waves further increased, while the cardiac ones decreased in amplitude. The latter continued to modulate the respiratory phasicity in 10 subjects.

CONCLUSION. During quiet respiration, lower limb venous Doppler tracings consisted of both cardiac and respiratory waveforms. Although respiratory waveforms disappeared when patients held their breath, Doppler tracings continued to be multiphasic and cardiac. Therefore, cardiac phasicity in lower limb venous Doppler tracings does not necessarily indicate cardiac disease. Other respiratory phases can modulate this basic cardiac pattern. Decrease in or loss of phasicity in these waveforms does not always mean proximal obstruction, because it can be caused by respiratory factors. Finally, the presence of minimal cyclic retrograde flow that is 5 cm/sec or less does not necessarily indicate cardiac disease.

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Since duplex Doppler sonography has emerged as the preferred technique for evaluating lower limb veins for thrombosis, authors have agreed that the normal lower limb venous Doppler flow is spontaneous, antegrade, and phasic. However, confusion exists about the nature and origin of this phasicity. Although most Doppler experts believe that it is caused by the changes in the intrathoracic pressure in re-

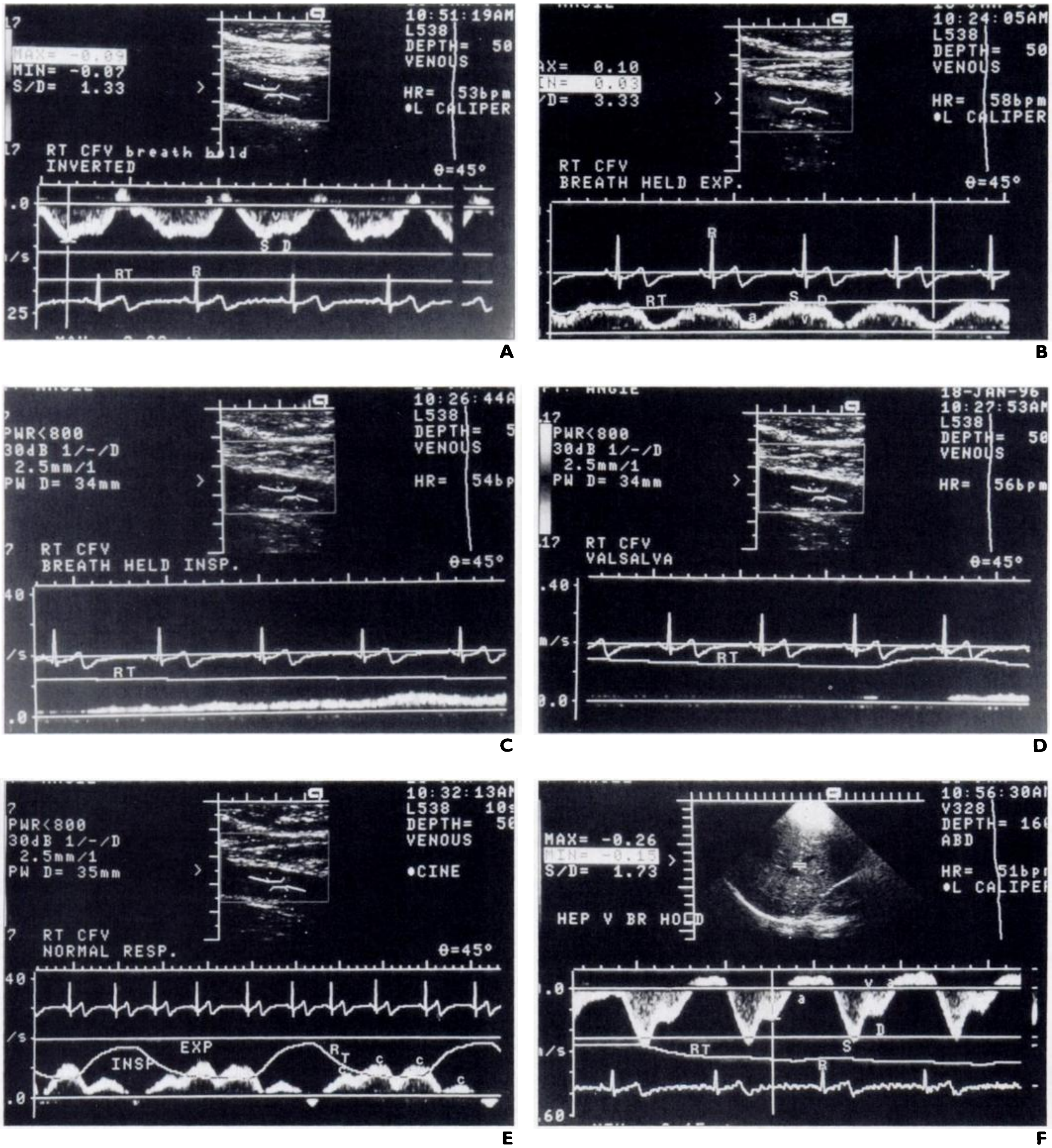

Fig. 1.—Detailed Doppler tracings with simultaneous ECG and respirometric tracings (RTs) in healthy 23-year-old woman.

A, Doppler tracing with breath-hold in mid respiration shows multiphasic waveforms made up of four waves that span 1.2 sec (one cardiac cycle on ECG tracing). Antegrade systolic wave (S), which begins at crossing of Doppler tracing with baseline, is delayed by 0.4 sec after QRS complex (R) on ECG tracing. Note small (≤5 cm/sec) retrograde *a* wave (a) preceding systolic wave and directly after antegrade diastolic D wave (D). Note also small antegrade *v* wave (v) between systolic and diastolic waves. RT CFV = right common femoral vein, θ = angle of Doppler interrogation. (Reprinted with permission from [7])

B, Doppler tracing with breath held at end of expiration (EXP.). Waveforms are predominantly biphasic and cardiac. Note that antegrade shift of *a* (a) and subtle *v* (v) waves causes decrease in waveform phasicity. RT CFV = right common femoral vein, θ = angle of Doppler interrogation, S = systolic wave, D = diastolic wave.

C, Doppler tracing with breath held at end of inspiration (INSP.) shows complete loss of phasicity. RT CFV = right common femoral vein, θ = angle of Doppler interrogation.

D, Doppler tracing with Valsalva's maneuver shows absent flow. RT CFV = right common femoral vein, θ = angle of Doppler interrogation.

E, Doppler tracing with normal respiration (RESP.) shows small cardiac waveforms (c) riding on higher amplitude and less frequent respiratory waveforms that encompass four cardiac cycles on ECG and Doppler tracings. Doppler flow decreases with inspiration (INSP) and increases with expiration (EXP) when Doppler tracing is correlated with respirometric tracing. RT CFV = right common femoral vein, θ = angle of Doppler interrogation.

F, Doppler examination of hepatic vein (HEP V) shows that each waveform is made up of four waves that span 1.2 sec (one cardiac cycle on ECG tracing). Note that systolic wave (S) on Doppler tracing occurs 0.08 sec after QRS complex (R) on ECG tracing. Note also that systolic wave is larger than diastolic (D) wave, but both are antegrade; *a* wave (a) is retrograde, and *v* wave (v) is reduced velocity antegrade wave. BR = breath. (Reprinted with permission from [7]) sponse to respiratory movements [1–3], others refer to it sometimes as respiratory and other times as cardiac [4]. Still others believe that lower limb venous Doppler flow is a steady flow that becomes phasic or pulsatile only with right-sided heart failure [5]. Recently, investigators found that the time each waveform spans on the *x*-axis of the Doppler spectrum is 1 sec or less, and they concluded that the phasicity is cardiac, reflecting changes in right atrium pressure [6, 7]. We wished to determine the nature and origin of the phasicity seen in normal lower limb venous Doppler waveforms and to assess normal and respiratory variations.

Subjects and Methods

In a prospective study, we performed detailed, high-resolution, spectral Doppler sonography of the common femoral vein of one lower limb, with simultaneous ECG and respirometric tracings, in 12 volunteers with no known cardiac, respiratory, or venous disease (three men and nine women, 21–50 years; mean, 29 years). No special tests were performed to evaluate the health status of each subject for the purpose of this study. The simultaneous ECG and respirometric functions are options that we added to one of our sonographic machines for physiologic imaging. The examinations were performed using state-of-the-art equipment with a 5- or 7-MHz transducer (128; Acuson, Mountain View, CA) and were recorded on radiographs. The subjects were connected to three ECG monitor leads: one on each shoulder and a third on the right lower chest. A thermosensitive respirometric probe was clipped to the nasal septum just inside the nares. The Doppler parameters were set at the lowest velocity scale to maximize the tracing size, and the time-gain compensation was set to a point just below background noise, with the sweep set at variable levels. Filtration was set at minimum and gate at 2–3 mm.

The tracings were obtained in the supine position during breath-hold in mid respiration, at the end of deep expiration, at the end of deep inspiration, during Valsalva's maneuver, and during quiet and deep breathing. The Doppler flow tracing obtained during breath-hold in mid respiration was considered the baseline examination. Doppler tracings obtained during the other respiratory phases were analyzed for changes from the baseline. They were analyzed by two sonologists for their phasicity, frequency, waveform components, velocities, and velocity ratios and for the presence of retrograde flow, all in correlation with the ECG and respirometric tracings. Flow toward the heart was considered positive or antegrade and away from the heart negative or retrograde. Interobserver agreement was calculated.

Results

With breath-hold in mid respiration, the Doppler tracings in all 12 common femoral veins consisted of multiphasic waveforms that had the same frequency as that of the cardiac rhythm (100% interobserver agreement) (Fig. 1A). Each waveform consisted of an antegrade systolic wave, flow-slowing retrograde *v* wave, antegrade diastolic wave, and retrograde *a* wave.

The systolic wave started its downward slope about 0.4 sec after the QRS complex on the ECG tracing, which was always antegrade with a peak velocity range of 5–22 cm/sec (mean, 12 cm/sec); followed by the *v* wave, which was always retrograde, representing a decrease in flow, with a peak velocity from 3 to 18 cm/sec (mean, 8 cm/sec); followed by the diastolic wave, which was always antegrade with a peak velocity from 5 to 21 cm/sec (mean, 11 cm/sec); followed by the *a* wave, which was always retrograde with flow reversal in nine of 12 subjects and a peak velocity from –5 to 2 cm/sec (mean, –1.8 cm/sec). The systolic:diastolic velocity ratio ranged from 0.9 to 1.5 (mean, 1.1). This ratio was greater than or equal to 1.0 in all but one subject. The minimum:maximum velocity ratio for the *a* wave ranged from –0.4 to 0.2 (mean, –0.15).

With breath-hold at the end of expiration, the waveforms remained cardiac (100% interobserver agreement) and lost some of their phasicity in 11 of 12 subjects (100% interobserver agreement), remaining multiphasic in seven and becoming biphasic in five (92% interobserver agreement) (Fig. 1B). The *v* wave became less retrograde in 11 subjects and did not change in one. Five retrograde *a* waves lost their flow reversal (Fig. 1B), with a total of eight showing flow nonreversal and the remaining four showing flow reversal. The peak velocity slightly increased in five subjects, slightly decreased in five, and did not change in two.

With breath-hold at the end of inspiration, two subjects showed no flow, two showed complete loss of phasicity (Fig. 1C), two showed biphasic flow (Fig. 2A), and six showed triphasic flow (58% interobserver agreement). Phasicity decreased in all subjects, however (92% interobserver agreement). Ini-

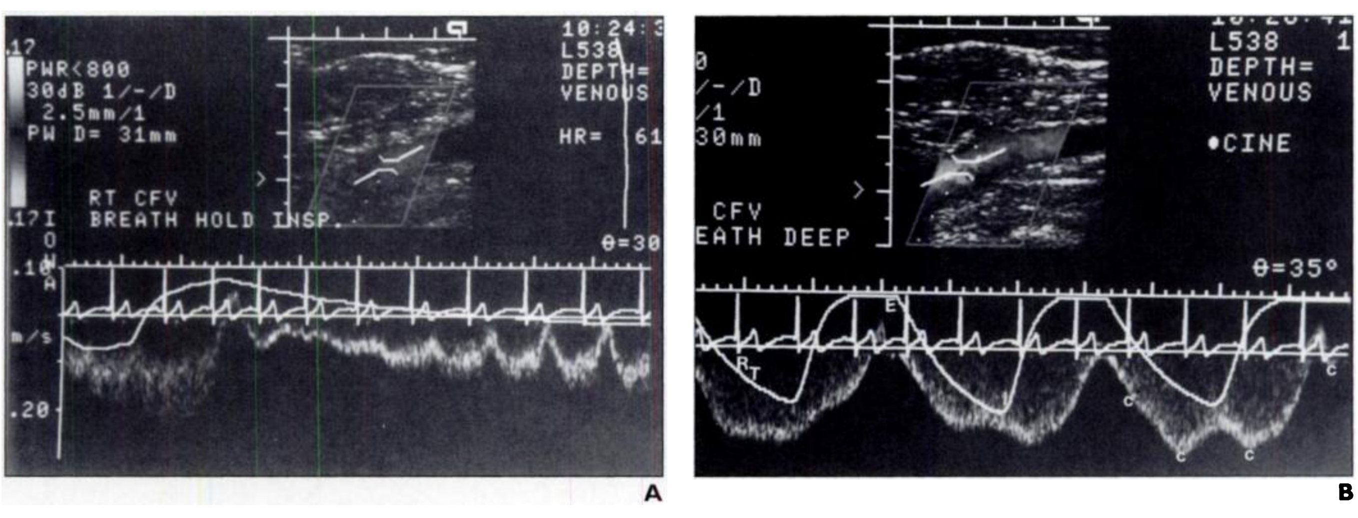

Fig. 2.—Detailed common femoral Doppler tracings with simultaneous ECG and respirometric tracings in healthy 36-year-old woman.
A, Tracing obtained during breath-hold at end of inspiration (INSP.) shows initial decrease in phasicity and velocity followed by gradual return of normal phasicity and velocity as subject continues to lose breath through expiration (indicated by respiratory tracing). θ = angle of Doppler interrogation.
B, Tracing obtained during deep breathing shows slightly indistinct small cardiac waveforms (c) riding on larger and slower respiratory ones. Inclusion of simultaneous ECG (E) and respirometric tracings (RT) facilitates analysis of this complex Doppler tracing.

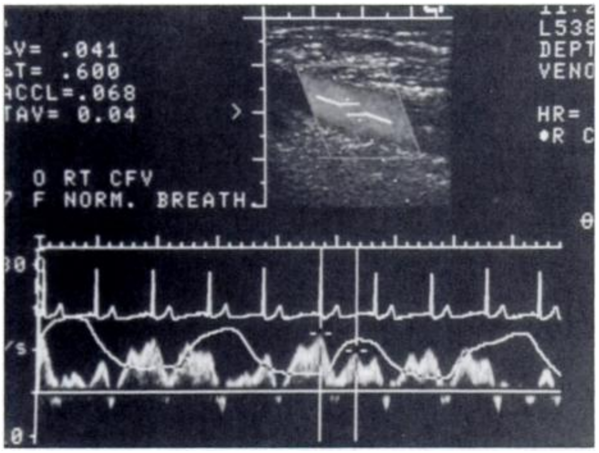

Fig. 3.—Detailed Doppler tracing with simultaneous ECG and respirometric tracings in healthy 21-year-old woman obtained during normal (NORM.) respiration shows persistence and dominance of marked triphasic cardiac waveforms over less prominent mild respiratory phasicity. RT CFV = right common femoral vein, θ = angle of Doppler interrogation.

tially all eight subjects who later showed phasic flow had a loss of flow phasicity, accompanied in most subjects by continued expiration as seen on the respirometric tracings (Fig. 2A). A significant decrease in flow velocity was seen in all subjects (100% interobserver agreement). When Valsalva's maneuver was performed, flow completely stopped in all subjects (100% interobserver agreement) (Fig. 1D).

With normal respiration, all subjects showed cardiac and respiratory phasicity (100% interobserver agreement). The cardiac waveforms rode on less frequent, higher amplitude biphasic respiratory waveforms. The cardiac phasicity was marked in six (Fig. 3), moderate in four (Fig. 1E), and minor or mild in two (75% interobserver agreement). Respiratory phasicity was marked (with inspiratory flow reversal) in one, moderate in seven, and mild in four (83% interobserver agreement). Respiratory and cardiac phasicity affected flow equally in two subjects, with the cardiac and respiratory phasicity dominant in six and four subjects, respectively. Cardiac phasicity was biphasic in seven and triphasic in five. With inspiration, a generalized decrease was seen in flow velocity, whereas with expiration a generalized increase compared with the baseline velocities was revealed (100% interobserver agreement).

With deep breathing, the respiratory waveforms had an even higher amplitude, with a further increase in velocity during expiration and a further decrease or flow reversal with inspiration. Cardiac phasicity was absent in two, mild in six, and moderate in four (100% interobserver agreement). Respiratory phasicity was mild in one, moderate in four, and marked (with inspiratory flow reversal) in seven (83% interobserver agreement). Respiratory phasicity dominated the flow pattern in nine (Fig. 2B) and affected flow equally in two, whereas cardiac phasicity was dominant in only one subject. Cardiac phasicity was biphasic in seven and triphasic in three.

Discussion

Our study shows that cardiac phasicity in lower limb venous Doppler tracings is a normal finding. With breath-hold in mid respiration, lower limb venous Doppler waveforms are similar to those described for the hepatic veins [8, 9] (Fig. 1F). We used breath-hold in mid respiration as a baseline because of the ease of performing Doppler analysis in this respiratory phase, against which waveforms in all other phases can be analyzed. The phasicity can be modulated, to varying degrees, by the respiration, depending on its phase, activity, and depth. In our study, breath held at the end of expiration causes a slight increase in the antegrade (or decrease in the retrograde) flow velocity of Doppler waveform components, especially the *a* and *v* waves, with a mild decrease in phasicity. In contrast, with breath held at the end of inspiration, flow velocity and phasicity decrease considerably. This underlying cardiac phasicity in Doppler waveforms and the changes that occur when tracings are performed in different respiratory phases also have been observed in the portal and hepatic veins [9].

The systolic wave is caused by a negative intraatrial pressure wave resulting from movement of the atrioventricular septum toward the cardiac apex; the *v* wave is produced by a positive intraatrial pressure wave resulting from atrium overfilling; the diastolic wave is caused by a negative intraatrial pressure resulting from the opening of the tricuspid valve; and the *a* wave is caused by a positive intraatrial pressure wave resulting from atrial contraction [10, 11].

The interobserver variability in our study was not significant, especially regarding the nature of the waves and their phasicity (in mid respiration), decrease in amplitude in the various phases, and the persistence and slight dominance of the cardiac waveforms during normal breathing.

Our study also shows that the principal cardiac phasicity in lower limb venous Doppler waveforms can be modulated by the higher amplitude, less frequent biphasic respiratory waves during normal respiration, with an increase in antegrade flow velocity during expiration and a decrease during inspiration. Respiratory phasicity appears to prevail only during deep breathing, which occurs in assisted breathing using a bag and endotracheal tube. The reason for the increase in lower limb venous Doppler flow during expiration is the decrease in the intraabdominal, intrathoracic, and intraatrial pressures. The reason for the decrease in lower limb venous Doppler flow and for the loss of phasicity at the end of inspiration is probably the increase in the intraabdominal, intrathoracic, and intraatrial pressures [2]. Our findings contradict what has been reported about the strictly respiratory nature of these Doppler waveforms and the claim that cardiac phasicity is seen only in conjunction with heart failure or tricuspid regurgitation [1–3, 5].

We also found that minor degrees of cyclic retrograde flow occur in most normal lower limb venous Doppler flow tracings, which may have a bearing on the interpretation of Doppler studies for the presence or absence of pulsatile flow associated with right-sided heart failure or tricuspid regurgitation [6, 7]. This cyclic retrograde flow was seen in only 21% of routinely performed lower limb venous Doppler examinations [7]. One should be skeptical of minimal (≤5 cm/sec) retrograde flow as a sign of right-sided heart failure or tricuspid regurgitation. However, one must recognize the difference between the examinations we performed and routine examinations. In the latter, inappropriate filtration, gain, or pulse repetition frequency settings may obscure reversed *a* waves. In such cases, it may be helpful to perform a Doppler examination of the hepatic veins to rule out tricuspid regurgitation or right-sided heart failure. We also can tell from this study that the indentations or valleys seen in Doppler waveforms of veins such as lower limb and portal veins are the a waves seen in patients with predominant cardiac phasicity.

In a similar study performed to evaluate normal flow phasicity in the hepatic and portal veins using high-resolution Doppler examinations with ECG correlation, Abu-Yousef [9] found that all hepatic and most portal vein waveforms were triphasic, correlating with cardiac cycles seen on the ECG tracing and confirming their cardiac nature. In that study, no changes that could be attributed to active breathing were seen that would be similar to the changes observed in the lower limb veins in the current study. The reason for this difference is technical, because tracings of the hepatic and portal veins are obtained with breath-holding, which is not necessarily the case in lower limb venous Doppler examinations. In evaluating the portal vein, however, the temporal difference between the systolic wave and the QRS complex could not be calculated [9]. Now that we understand that the systolic wave occurs after the larger indentation on the triphasic waveforms, we can calculate the temporal difference. The significance of this discovery is uncertain, but a decrease in this temporal difference occurs after right-sided heart failure and tricuspid regurgitation [6, 7].

Simultaneous ECG tracings provided correlation that helped us understand the nature of venous Doppler waveforms in the lower limbs, as they did in the portal and hepatic veins. The use of simultaneous respirometric correlation was also essential in evaluating the effects of respiratory motion on lower limb venous Doppler waveforms. However, other factors may influence phasicity in these Doppler waveforms, such as changes in lower limb arterial flow, hydration status of the patient, position of the patient, and proximal venous obstruction [2–4].

One limitation of our study is that the mean age of the subjects was less than the mean age of patients usually examined for deep venous thrombosis, but we do not believe that age affects lower limb venous Doppler phasicity.

In conclusion, our study shows that during quiet respiration, lower limb venous Doppler tracings consist of both cardiac and respiratory waveforms, and, contrary to the prevailing understanding, the presence of cardiac phasicity in lower limb venous Doppler tracings does not necessarily indicate abnormal cardiac activity. Moreover, it shows that the only phasicity in these tracings during breath-hold in mid respiration and at the end of expiration is multiphasic and cardiac. Other respiratory phases can modulate this basic cardiac pattern, however. Decrease in or loss of phasicity in these waveforms can be caused by respiratory factors. Finally, the presence of minimal cyclic retrograde flow may not necessarily indicate cardiac disease.

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