ARTICLES

Characterizing Triphasic, Biphasic, and Monophasic Doppler Waveforms

Should a Simple Task Be So Difficult?

ROBERT SCISSONS, RVT

Doppler waveform analysis is a fundamental part of evaluating peripheral arterial disease. Waveform characteristics are traditionally defined as multiphasic (triphasic, biphasic) and monophasic. The purpose of this investigation is to evaluate whether sonography professionals correctly classify waveforms into these three categories. Thirty Doppler waveforms (15 continuous-wave [CW] and 15 pulsed-wave [PW] Doppler) were obtained from patients with previous noninvasive peripheral arterial evaluations. Participating readers were asked to interpret waveforms as triphasic, biphasic, or monophasic using standard definitions. "Other" was used to classify waveforms whose morphology could not be determined or accurately classified as triphasic, biphasic, or monophasic. Because multiphasic waveforms with pandiastolic flow have been associated with biphasic and monophasic waveform terminology, answer key responses were based on waveform descriptors used by interpreters of the originating noninvasive evaluation. There were a total of 97 participants, and of all Doppler waveforms, 73% were correctly identified (75% CW and 71% PW). Participants training or specializing in medical sonography misidentified an average of 27% triphasic, biphasic, or monophasic CW and PW Doppler waveforms and correctly interpreted more CW than PW waveforms. Because there is considerable variability among sonography professionals and educators in defining and classifying peripheral arterial waveforms, this issue deserves higher priority.

Key words: waveform, characterization, analysis

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Doppler waveform analysis is fundamental to the evaluation and correct interpretation of peripheral arterial disease. Many factors, however,

directly affect waveform appearance. Arterial resistance, vasodilatatory changes, vessel wall compliance, and atherosclerotic disease significantly alter waveform morphology.

Doppler waveforms are traditionally defined as either normal or abnormal.[1–6] Normal resting peripheral arterial waveforms are multiphasic. The primary components of a normal waveform are (1) high forward flow during systole due to left ventricular contraction, (2) transient period of flow reversal in early diastole resulting from reflection from a high-resistance outflow bed, and (3) a forward flow component resulting from reflection from a closed aortic valve during late diastole. Normal waveform appearance can be altered if there is low impedance in the distal vascular bed (e.g., during reactive hyperemia or after exercise). In these instances, there will be pandiastolic flow in diastole, and the reverse flow component of the triphasic waveform will be lost.[1–8] Abnormal waveforms can have an attenuated systolic component and absence of flow reversal. This characteristic waveform is most commonly attributed to arterial flow found distal to a high-grade stenosis or occlusion.

Vascular sonography publications and educators generally show the characteristics of normal (triphasic) waveforms in a high-resistance vascular bed and abnormal (monophasic) waveforms for the same vascular bed.[1–6] Transition characteristics of normal waveforms with different peripheral resistance, and even the definition of what phasicity means, have not been clearly addressed. The purpose of this investigation is to evaluate whether sonography professionals correctly classify waveforms into triphasic, biphasic, and monophasic categories.

Methods

Thirty Doppler waveforms, 15 pulsed wave (PW) and 15 continuous wave (CW), were compiled from previous vascular sonography examinations. Each CW and PW waveform group had 10 normal (triphasic or biphasic) and 4 abnormal (monophasic) waveforms with varying levels of peripheral (outflow) resistance. There were 2 "other" waveforms: a CW femoral artery waveform with significant venous interference (Figure 1)

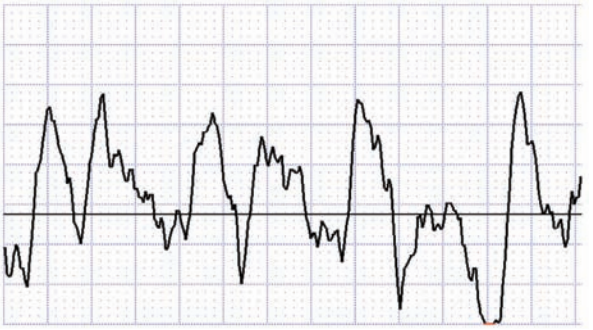

FIGURE 1. Continuous-wave (CW) femoral artery waveform with significant venous interference. Responses: triphasic, 9%; biphasic, 8%; monophasic, 4%; other, 78%.

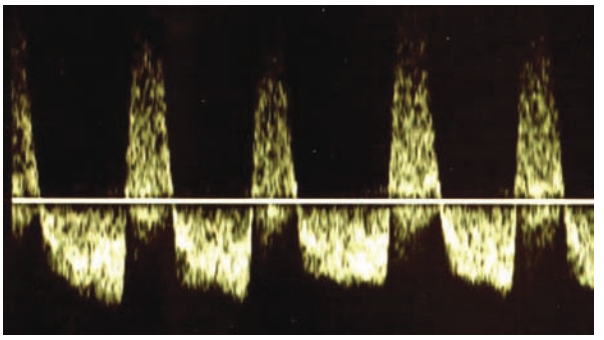

FIGURE 2. Pulsed-wave (PW) waveform within the neck of a common femoral artery (CFA) pseudoaneurysm. Responses: triphasic, 8%; biphasic, 51%; monophasic, 2%; other, 39%.

and a PW waveform within the neck of a femoral artery pseudoaneurysm (Figure 2).

All waveforms were cropped for maximum visualization and randomized with alternating formats (CW odd numbers; PW even numbers) for display in a Microsoft PowerPoint presentation. An answer sheet, numbered 1 through 30, was developed for interpreting the displayed waveforms. The introduction segment of the answer sheet requested the following participant data:

- Highest educational degree
- Medical or sonography-related certification(s)
- Number of years of sonography experience.

CW and PW waveforms were alternated during the presentation. Participants were told that each waveform would be displayed for 15 seconds, during which time they must view and score one of the following predefined waveform descriptors:

- Triphasic: three phases—forward flow, flow reversal, and a second forward component
- Biphasic: two phases—one forward flow and one reverse component
- Monophasic: single phase—forward flow with no reverse flow component
- Other: waveform considered neither triphasic, biphasic, nor monophasic or a waveform that could not be categorized.

The waveform presentation was exhibited to

- Midwestern vascular sonography students
- Midwestern vascular sonography symposium attendees
- East Coast sonography symposium attendees.

Responses were entered into a database and compared with a correct response answer key. Because multiphasic waveforms with pandiastolic flow have been associated with both biphasic and monophasic waveform terminology,[7,8] answer key responses were based on waveform descriptors used by interpreters of the originating noninvasive evaluation. "Other" was considered an incorrect response for all waveforms, excluding Figure 1 (CW waveform 29, Table 1) and Figure 2 (PW waveform 6, Table 1).

Recognizing there may be some difficulty visualizing discrete waveform details in selective projections within the designated time period, two answers were accepted as correct in three CW waveforms (5, 13, 27, Table 1) and four PW waveforms (6, 18, 20, 24, Table 1). Results were calculated as a percentage of correct responses.

Results

Details of the 97 individuals participating in the study are as follows:

- 22 sonography students
- 8 American Registry for Diagnostic Sonography (ARDMS®), Registered Vascular Technologists® (RVT)
- 18 ARDMS® Registered Diagnostic Medical Sonographers® (RDMS)
- 24 multispecialty ARDMS® RVT, RDMS, or Registered Diagnostic Cardiac Sonographers (RDCS®): 6 RVTs with RDCS and 18 RVTs with RDMS
- 25 physicians: doctor of medicine or doctor of osteopathic medicine (11 with RVT).

Sixteen participants were excluded: 5 who did not fall into any of the previously mentioned medical certification groups and 11 who failed to complete all waveform interpretations.

TABLE 1. Continuous-Wave (CW) and Pulsed-Wave (PW) Waveform Responses: Triphasic, Biphasic, Monophasic, and Other

	Triphasic	Biphasic	Monophasic	Other
CW waveform				
1	7	19	*73*	1
3	*86*	12	2	0
5	*64*	*29*	3	4
7	1	25	*72*	2
9	14	*76*	2	7
11	10	*75*	8	6
13	*67*	*13*	0	20
15	12	*78*	5	4
17	4	2	*81*	12
19	16	*70*	1	12
21	32	*40*	20	8
23	1	5	*92*	2
25	23	*39*	33	5
27	*88*	*8*	0	4
29	9	8	4	*78*
PW waveform				
2	3	20	*73*	4
4	*94*	1	0	5
6	8	*51*	2	*39*
8	*82*	12	1	4
10	2	25	*65*	8
12	42	*37*	15	5
14	28	*29*	6	37
16	16	*76*	1	6
18	*44*	*37*	0	19
20	*78*	*15*	2	4
22	3	*69*	19	9
24	3	*75*	*13*	8
26	5	21	*67*	7
28	13	*48*	34	4
30	1	9	*67*	23

Percent correct responses are italicized and shaded.

The designated correct CW and PW waveform response and the average percentage of triphasic, biphasic, monophasic, and "other" responses by all participants are presented in Table 1.

Participants averaged 16 years (range, 12–20 years) of education and included 22 doctors of medicine, 3 doctors of osteopathic medicine, 3 master or doctorate degrees, 20 bachelor degrees, 33 associate degrees, and 16 high school graduates.

Average number of years working in the sonography profession was 10 years (range, 0–30 years). The

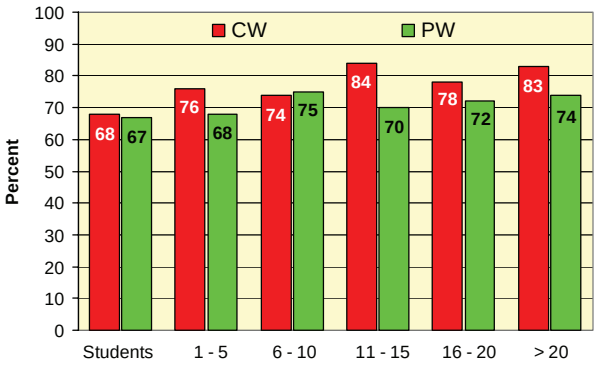

FIGURE 3. Correct continuous-wave (CW) and pulsed-wave (PW) interpretations: years of sonography experience.

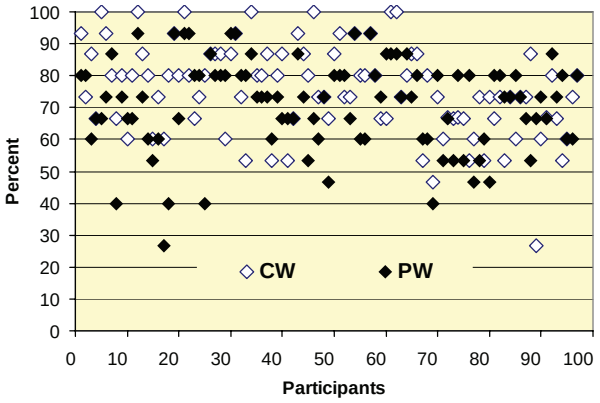

FIGURE 4. Combined (continuous wave [CW] + pulsed-wave [PW]) correct response percentages.

correct responses categorized according to years of sonography experience are displayed in Figure 3.

COMBINED (CW + PW) CORRECT RESPONSES

Of the Doppler waveforms, 73% were correctly identified (range, 27%–100%). The correct responses by participant cohort are presented in Figure 4.

CW CORRECT RESPONSES

The correct response average for all CW waveforms was 75% (range, 27%–100%). Averaged percent correct responses for each CW waveform are displayed in Figure 5.

Seven participants answered all CW waveforms correctly (15/15); the lowest individual correct response average for CW waveforms was 27%. Omitting student performance improved the correct response average from 75% to 78%.

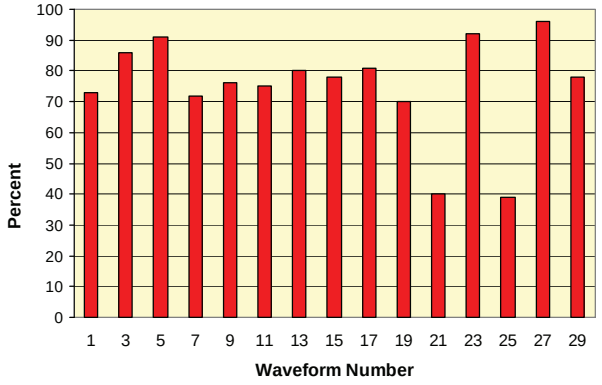

FIGURE 5. Continuous-wave (CW) waveforms: average correct responses.

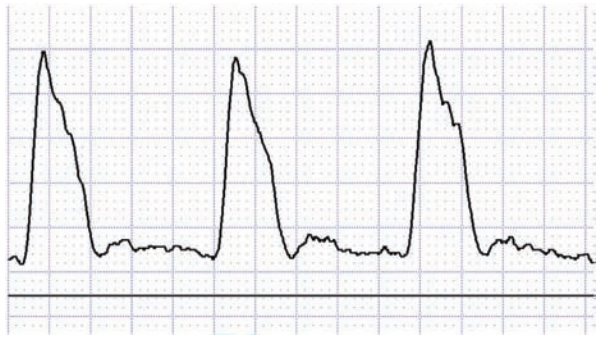

FIGURE 6. Low-resistive, multiphasic common femoral artery (CFA) continuous-wave (CW) waveform following treadmill exercise. Responses: triphasic, 23%; biphasic, 39%; monophasic, 33%; other, 5%.

A multiphasic, distal common femoral artery waveform with low peripheral resistance, induced by treadmill exercise in a patient with no significant inflow disease, generated the most incorrect responses (CW 25, Table 1; Figure 6); a normal multiphasic posterior tibial artery waveform generated the most correct responses (CW 27, Table 1; Figure 7).

PW CORRECT RESPONSES

Correct response average for all PW waveforms was 71% (range, 27%–93%). Averaged percent correct responses for each PW waveform are shown in Figure 8. Although no participant identified all waveforms correctly, eight participants

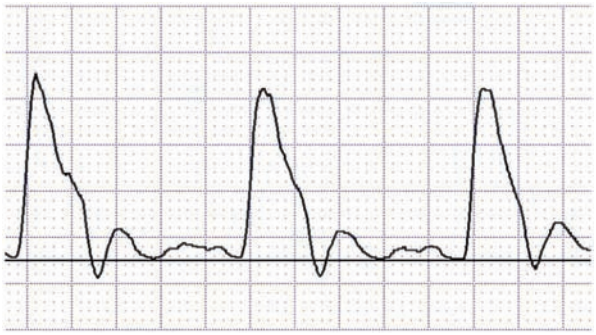

FIGURE 7. Multiphasic posterior tibial artery continuous-wave (CW) waveform (venous ulcer patient). Responses: triphasic, 88%; biphasic, 8%; monophasic, 0%; other, 4%.

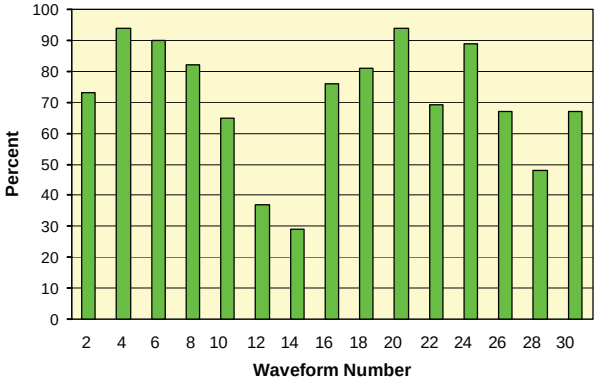

FIGURE 8. Pulsed-wave (PW) waveforms: average correct responses.

answered 14 of 15 (93%) correctly; the lowest individual correct response for PW waveforms was 27%. Excluding student responses improved the correct response average from 71% to 72%.

A multiphasic common femoral artery (CFA) waveform with high peripheral resistance, in a patient with a CFA aneurysm (PW 14, Table 1; Figure 9), had the most incorrect PW waveform responses. A multiphasic posterior tibial artery waveform with high peripheral resistance, five minutes after exercise (PW 4, Table 1; Figure 10), and a multiphasic anterior tibial artery waveform with high peripheral resistance (PW 20, Table 1; Figure 11) had the most correct PW waveform responses.

"OTHER" RESPONSES

"Other" responses averaged 24% of CW and 33% of the PW incorrect waveform responses

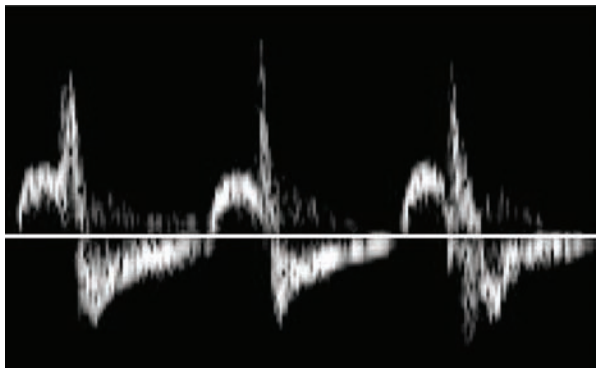

FIGURE 9. Multiphasic pulsed-wave (PW) common femoral artery (CFA) waveform in a patient with a CFA aneurysm. Responses: triphasic, 28%; biphasic, 29%; monophasic, 6%; other, 37%.

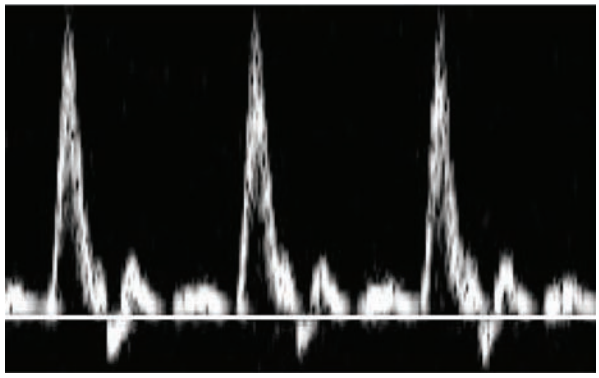

FIGURE 10. Multiphasic posterior tibial artery, pulsed-wave (PW) waveform, five minutes after exercise. Responses: triphasic, 94%; biphasic, 1%; monophasic, 0%; other, 5%.

(Figures 12 and 13). There was an average of 78% correct responses for the CW "other" CFA waveform with significant common femoral vein interference (CW 29, Table 1; Figure 1) and an average of 90% correct responses for the PW "other" waveform, at the neck of a femoral artery pseudoaneurysm (PW 6, Table 1; Figure 2). A "biphasic" response, however, was also cited as a correct answer for this pseudoaneurysm waveform.

The highest percentage of incorrect CW "other" responses 20% was for a multiphasic CFA, preprofunda stenosis with bruit and high peripheral resistance (CW 13, Table 1; Figure 14); the highest incorrect PW "other" percentage was 37% for

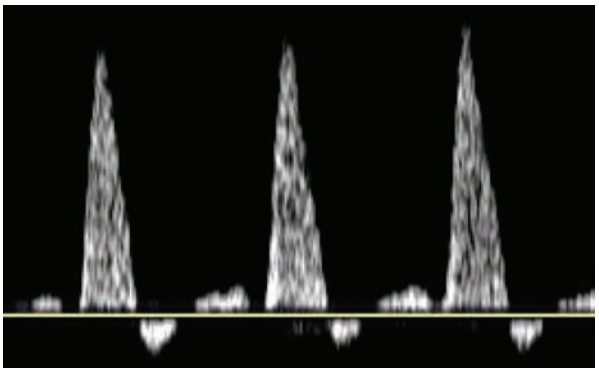

FIGURE 11. Multiphasic pulsed-wave (PW) anterior tibial artery waveform. Responses: triphasic, 78%; biphasic, 15%; monophasic, 2%; other, 4%.

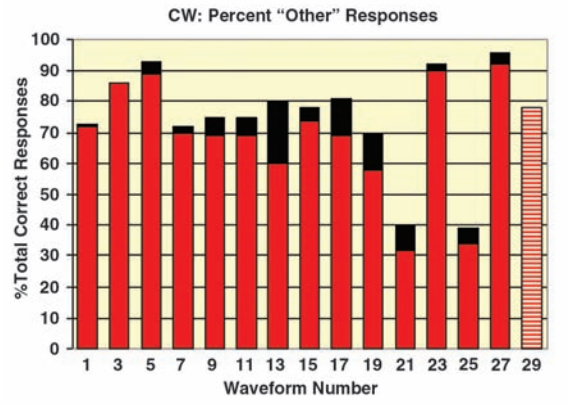

FIGURE 12. Continuous wave (CW): percent "other" responses.

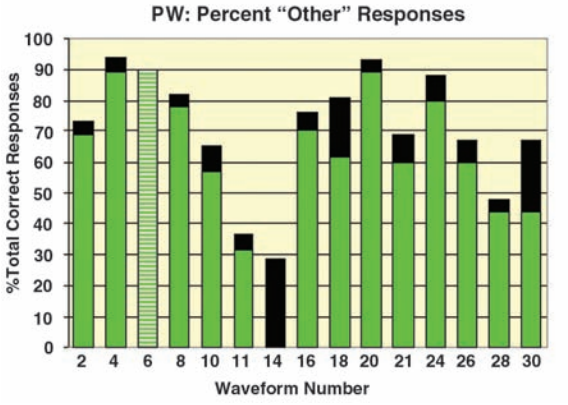

FIGURE 13. Pulsed wave (PW): percent "other" responses.

a multiphasic CFA waveform with high peripheral resistance in a patient with a CFA aneurysm (PW 14, Table 1; Figure 9).

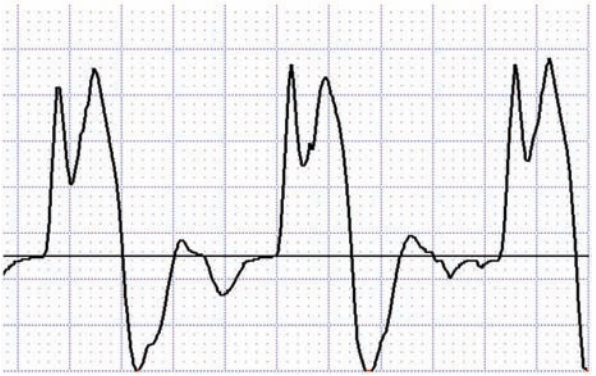

FIGURE 14. Multiphasic femoral artery, continuous-wave (CW) waveform pre–superficial femoral artery (SFA)/profunda stenosis. Responses: triphasic, 67%; biphasic, 13%; monophasic, 0%; other, 20%.

Discussion

Doppler waveform analysis is fundamental to the evaluation of peripheral arterial disease. Participants specializing in medical sonography, however, misidentified, an average of 27% CW and PW Doppler waveforms using traditional waveform descriptors.

Because there are only three conventional peripheral waveform descriptors, it would seem that characterization of a waveform as triphasic, biphasic, and monophasic should be relatively simple. Although the level of difficulty associated with waveform characterization is relatively unknown, vascular sonography experts generally agree that categorizing Doppler waveforms is not that simple because it is subjective and dependent on the experience of the interpreter.[1–6]

The findings of this study confirm the subjective nature of waveform characterization. More important, however, this study also highlights that even individuals knowledgeable about sonography and interested in vascular disease are not unified in their understanding of waveform components. Furthermore, although educators routinely emphasize triphasic (normal) and monophasic (abnormal) waveform nomenclature,[2,3,9,10] less attention is given to the transition from clearly normal to overtly abnormal. This leads to considerable variability in waveform characterization.

The greatest discordance in this study appears to originate from (1) the definition of biphasic and (2)

Doppler signal processing. Specifically, the concept of forward and reverse flow appears to be controversial. Biphasic has been defined as "having two phases or variations having a forward and reverse component."[11] In the introductory phase of this study, participants were instructed to define biphasic based on the aforementioned definition. The presented PowerPoint slide, however, defined biphasic as having "two phases—one forward flow and one reverse component." To maintain consistency in future comparisons, this definition was never amended. The author's inadvertent omission of *or* in the introductory instructions should, however, have keyed participants into answering "monophasic" or "other" (unknown) for any biphasic waveform with low peripheral resistance because there is no flow reversal present in these waveforms. There were four low-resistant, biphasic waveforms included in this study: CW 21 (Figure 15), CW 25 (Figure 6), PW 12 (Figure 16), and PW 28 (Figure 17); see also Table 1. Averaged monophasic and "other" responses for this waveform characteristic were 26% and 6% respectively, versus 28% triphasic and 41% biphasic responses. Another plausible reason for increased confusion when characterizing this particular waveform is its duality of definition. Multiphasic, low-resistive waveforms with pandiastolic flow have been characterized using both biphasic *and* monophasic terminology.[7,8]

With reverse flow inherent to triphasic waveforms and more than a quarter of the participants answering *triphasic* for the four multiphasic low-resistive waveforms, many participants may believe that *biphasic* is largely defined by the presence of a reverse flow component. The veracity of this assumption is also supported by the reality that biphasic waveforms are most often presented in the high resistive state.[12,13]

If many participants in this study believed that biphasic waveforms have a reverse flow component, another more disconcerting inference can be made. A fundamental concept in Doppler signal processing is that forward flow is represented above and reverse flow below the zero flow baseline. If reverse flow is defined by a deflection below the zero baseline, a minimum of 28% and

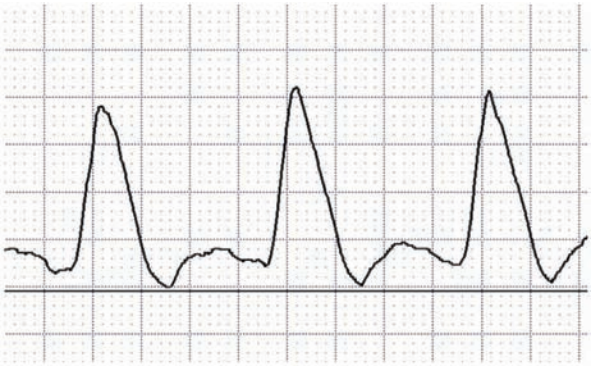

FIGURE 15. Multiphasic proximal superficial femoral artery (SFA) continuous-wave (CW) waveform with distal SFA occlusion. Responses: triphasic, 32%; biphasic, 40%; monophasic, 20%; other, 8%.

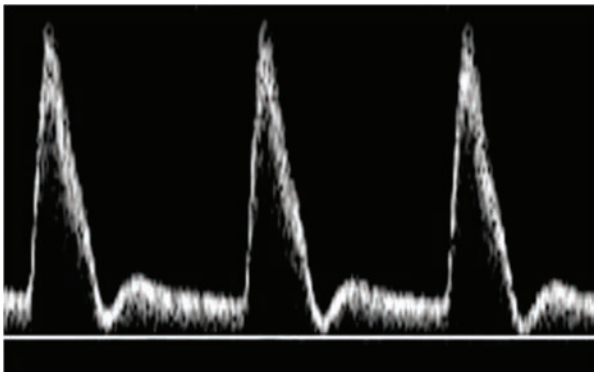

FIGURE 16. Multiphasic proximal anterior tibial artery stenosis, pulsed-wave (PW) waveform. Responses: triphasic, 42%; biphasic, 37%; monophasic, 15%; other, 5%.

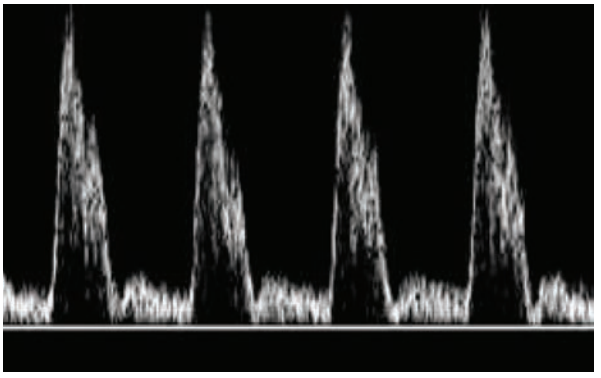

FIGURE 17. Multiphasic, common femoral artery pulsed-wave (PW) waveform with no significant inflow disease. Responses: triphasic, 24%; biphasic, 38%; monophasic, 33%; other, 5%.

maximum of 69% of participants in this study erroneously believe that low-resistive, multiphasic waveforms have flow reversal above the zero baseline.

Results of this research appear to contradict conventional wisdom as to experience being a factor in waveform characterization. Although inexperienced students averaged more incorrect waveform characterizations, if we omit student responses, overall CW accuracy increased 3% and PW accuracy increased only 1%.

Finally, in the Internet discussion forum, University of Vermont (UVM) Flownet, participants were told that the terms *monophasic* (*uniphasic*), *biphasic*, and *triphasic* "were developed for use with non-directional audio Doppler."[14] We have advanced considerably, both technologically and professionally, since this terminology was established. If waveform analysis is still considered fundamental to the evaluation of peripheral arterial disease, standardizing waveform terminology and improving the characterization of waveforms should be a major consideration.

In conclusion, there was considerable variability among sonography professionals when classifying peripheral arterial waveforms using traditional triphasic, biphasic, and monophasic descriptors. Because the gold standard for correctly defining waveforms used in this study was also interpreter dependent, the results of this investigation should be considered more speculative than formative. The critical summation of the study, however, is still undeniable; participants in this study were confused. They were confused from the student through the physician level, at the introductory and advanced levels. Furthermore, they appear most confused with biphasic waveforms in general and the concepts of forward and reverse flow in particular. Paradoxically, even in the duplex-dominated world of sonography, they were more confused with PW than CW waveform analysis.

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SDMS-JDMS CME TEST

Article: Characterizing Triphasic, Biphasic, and Monophasic Doppler Waveforms: Should a Simple Task Be So Difficult?
Author: Robert Scissons, RVT
Category: Ultrasound Physics and Instrumentation (UPI)
Credit: 1.0 CME

Objectives: After studying the article titled "Characterizing Triphasic, Biphasic, and Monophasic Doppler Waveforms: Should a Simple Task Be So Difficult?" you will be able to:

1. Discuss examples of different types of waveforms.
2. Evaluate the types of Doppler waveforms.
3. Describe the causes of different types of waveforms.

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1. Which of the following does not alter Doppler waveform morphology?
   a. Venous resistance
   b. Vasodilatatory changes
   c. Vessel wall compliance
   d. Atherosclerotic disease

2. Which is not a primary component of a normal waveform?
   a. High forward flow during systole due to left ventricular contraction
   b. Transient period of flow reversal in early diastole resulting from reflection from a high-resistance outflow bed
   c. Forward flow component resulting from reflection from a closed aortic valve during late diastole
   d. Reversal of flow in late systole

3. Which of the following may create a low impedance in the distal vascular bed?
   a. Inotropic incompetence
   b. Increase preload
   c. Reactive hyperemia
   d. Vascular resistance

4. An attenuated systolic component is most commonly attributed to which of the following?
   a. Arterial flow found distal to a high-grade stenosis or occlusion
   b. An increase in venous flow due to decreased thoracic pressure
   c. Decreased vascular resistance
   d. Hemodynamic compromise downstream to normal flow

5. Triphasic waveforms are defined by which of the following statements?
   a. One forward flow phase and one reverse component
   b. Presence of a forward flow phase with no reverse flow component
   c. Waveform having both continuous and pulsed-wave properties
   d. Phases including forward flow, flow reversal, and a second forward component

6. A biphasic waveform has been characterized by which of the following statements?
   a. One forward flow phase and one reverse component
   b. Presence of an attenuated systolic component and absence of flow reversal
   c. Waveform having both continuous and pulsed-wave properties
   d. Phases including forward flow, flow reversal, and a second forward component

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7. Monophasic waveforms are defined by which of the following statements?
   a. One forward flow phase and one reverse component
   b. Presence of an attenuated systolic component and absence of flow reversal
   c. Waveform having both continuous- and pulsed-wave properties
   d. Phases including forward flow, flow reversal, and a second forward component

8. What was the correct response average for all continuous-wave waveforms?
   a. 25%
   b. 50%
   c. 75%
   d. 100%

9. What was the correct response average for all pulsed-wave waveforms?
   a. 61%
   b. 71%
   c. 81%
   d. 91%

10. Which case had the most incorrect pulsed-wave identification?
    a. A multiphasic common femoral artery (CFA) waveform, with high peripheral resistance, in a patient with a CFA aneurysm
    b. A multiphasic posterior tibial artery waveform, with low peripheral resistance
    c. A multiphasic posterior tibial artery waveform, with high peripheral resistance, five minutes postexercise
    d. A multiphasic anterior tibial artery waveform, with high peripheral resistance

11. Participants in this study misidentified how many CW and PW waveforms?
    a. 16%
    b. 27%
    c. 39%
    d. 42%

12. Figure 1 indicates what type of waveform?
    a. Triphasic
    b. Biphasic
    c. Monophasic
    d. Other

13. Figure 6 has been characterized as what type(s) of waveform?
    a. Triphasic and monophasic
    b. Biphasic and monophasic
    c. Monophasic and other
    d. Other

14. Figure 7 indicates what type of waveform?
    a. Triphasic
    b. Biphasic
    c. Monophasic
    d. Other

15. Peripheral resistance (impedance) in the distal vascular bed of waveform Figure 15 would be?
    a. Low
    b. High
    c. Transient
    d. Absent