# *Confusion of Peripheral Arterial Doppler Waveform Terminology*

ROBERT SCISSONS, RVT
ANTHONY COMEROTA, MD, FACS, RVT

Characterization of peripheral arterial waveforms is basic to the diagnosis of vascular disease. Surveys indicate inconsistent application of traditional waveform descriptors. This study reviews literature to identify areas of confusion. Publications were reviewed to determine whether triphasic, biphasic, and monophasic terms were defined; if biphasic was linked with diastolic flow reversal; whether pandiastolic flow was associated with biphasic or monophasic terminology; and whether waveform illustrations had a zero baseline. Ninety-four publications were reviewed. Triphasic and monophasic were defined in 81%, biphasic in 48%. Biphasic was classified with flow reversal in 38%. Pandiastolic flow was not addressed in 57% but associated with monophasic in 47% and biphasic in 5%. Twenty-one percent of the publications had an illustration without a zero-flow baseline. This review suggests a lack of consensus when classifying arterial blood flow with traditional waveform descriptors. Waveform characterization inconsistencies are undermining comprehension of Doppler principles and may lead to inappropriate testing. A multisocietal consensus panel should accept responsibility for resolving this issue.

*Key words:* waveform, review, characterization, confusion

From the Jobst Vascular Center Laboratory, Toledo, Ohio.
Correspondence: Robert Scissons, RVT, Jobst Vascular Center Laboratory, 2109 Hughes Drive, Toledo, OH 43606. E-mail: bob.scissons@promedica.org.

DOI:10.1177/8756479309336216

Doppler instruments are widely used for the noninvasive evaluation of peripheral arterial disease. Auditory descriptors and graphic displays of waveforms characterize the hemodynamics of the vessel being examined. Descriptions of normal

hemodynamics and compromised perfusion have been proposed and widely accepted.[1]

Qualitative assessment of Doppler waveforms has been used extensively in diagnostic sonography laboratories for detecting and localizing arterial disease of the lower extremity. The primary physiological parameters influencing waveform shape are heart rate, blood pressure, and vasomotor changes.[2] Diastolic flow reversal has been particularly useful for differentiating normal from diseased blood vessels.[3-5]

Doppler arterial waveforms of peripheral arteries traditionally have been described as normal when they are triphasic.[5,6] When arterial disease begins to affect blood flow, the reflective forward flow element in late diastole disappears. As arterial disease progresses, flow reversal in early diastole becomes attenuated and is subsequently lost, with the biphasic waveform pattern becoming monophasic.[1]

Although triphasic, biphasic, and monophasic waveform terminology has been used by medical and sonography professionals for more than four decades, definitions for these terms are inconsistent, contradictory, or nonexistent. These issues have resulted in confusion, which has been discussed anecdotally by diagnostic medical sonographers and sonography educators, verbalized in Internet discussion forums,[7] and summarized in a survey of sonography professionals.[8] The purpose of this study is to review pertinent literature on peripheral arterial Doppler waveforms to elicit causes for this confusion.

## Methods

A literature search was performed to identify relevant publications. Diagnostic medical sonography and vascular specialty texts, periodicals, and waveform research publications were reviewed for descriptive terminology, use of terms, and application of associated arterial waveform characteristics. Texts reviewed were from institutional and personal libraries, and articles were obtained through MEDLINE searches, reviews of reference lists, and conference proceedings. Publications that focused on quantitative aspects of waveform analysis (e.g., pulsatility index, damping factor, Laplace transform), Doppler spectrum parameters (e.g., systolic and diastolic acceleration or deceleration time), lower extremity bypass graft surveillance, endograft interventions, or hemodialysis access were excluded. The publications were reviewed to

1. Assess whether triphasic, biphasic, and monophasic waveforms were specifically defined—in text, by illustration, or through referencing a previous publication that defined these terms.
   a. Waveforms were considered defined if the concept—for example, forward flow, early diastolic flow reversal, and late diastolic forward flow (triphasic)—was stated in text but did not use any of the three waveform terms.
   b. Waveforms described as *multiphasic* were not considered as an alternative definition for triphasic or biphasic.
2. Examine the association of diastolic flow reversal *below* the zero-flow baseline with a biphasic waveform.
3. Examine whether *pandiastolic* flow was associated with either biphasic and/or monophasic waveforms.
4. Identify publications that illustrate Doppler waveforms with a *clearly* delineated zero-flow baseline.

Reviewed material that was repeated by the primary author in multiple publications was calculated as a single response in the statistical analysis.

## Results

Ninety-four educational and scientific publications published between 1967 and 2006 were reviewed. Seventeen manuscripts focusing on quantitative waveform analysis were excluded, leaving 77 publications that were analyzed for waveform illustrations with a zero-flow baseline. Accepted publications included 41 books or book chapters and 36 waveform research periodicals.[1-3,5,6,9,44-80] Eight authors had multiple publications that were summarized as a single narrative, leaving 58 primary author responses for the final analysis (Table 1).

**TABLE 1.**
**Review of Vascular Surgery and Sonography Publications (Textbooks, Textbook Chapters, Journals)**

| Primary Author, Reference(s) | Tri/Bi/Mono Terms Defined | Biphasic Associated With Flow Reversal | Biphasic and/or Monophasic Associated With Pandiastolic Flow | Illustration(s) With Zero Baseline |
|---|---|---|---|---|
| Allard[65] | Tri[a]/bi[a]/mono[a] | Yes | Monophasic | Yes |
| Ascher[41] | Monophasic[b] | No | Monophasic | Yes |
| Baker[44] | Tri/mono[b] | No | No | Yes |
| **Barnes**[9,13,59] | Monophasic | No | No | Yes[9,13,59] |
| Baun[75] | Tri/bi/mono | Yes | No | Yes |
| Baur[50] | Tri/bi | No | No | No illustrations |
| Binnington[12] | Monophasic[b] | No | No | No |
| Blackburn[36] | Tri[b]/bi[b]/mono[b] | Yes | No | No |
| Cooke[25] | No | No | No | No illustrations |
| Cossman[58] | No | No | No | No |
| Daigle[30] | Tri/mono | No | Monophasic | Yes |
| de Smet[67] | Tri/mono | No | Monophasic | Yes |
| Edwards[21] | Mono[b] | No | Monophasic | Yes |
| Eiberg[72] | Tri/bi/mono | Yes | Monophasic | Yes |
| Faris[47] | No | No | No | No |
| Gerhard-Herman[79] | Tri/bi | No | Biphasic | Yes |
| Gerlock[18] | Tri/bi/mono | No | Monophasic | Yes |
| Gray[57] | Tri/bi/mono | No | No | No |
| Hamments[69] | Tri/mono | No | Monophasic | Yes |
| Jager[55] | Tri/bi/mono | Yes | Monophasic | Yes |
| **Johnston**[10,16,19] | Tri/mono | Yes | Monophasic | Yes[10,16,19] |
| Karwowski[42] | No | No | No | No |
| Katz[43,48] | Tri/bi[a]/mono[b] | Yes | Monophasic | Yes[43]/no[48] |
| Kempczinski[14] | Monophasic[b] | No | No | No |
| **Kohler**[17,20,56] | Tri/bi/mono | Yes | Monophasic | Yes[17,20,56] |
| Kupper[52] | Monophasic | No | No | No |
| Legemate[60] | Tri[a]/bi[a]/mono[a] | Yes | Monophasic | No illustrations |
| Leng[64] | Tri[a]/bi[a]/mono[a] | Yes | Monophasic | No illustrations |
| Lewis[66] | Tri/bi/mono | Yes | No | Yes |
| Needham[40] | Triphasic | No | Monophasic | Yes |
| O'Mara[15] | Tri/mono | No | No | No |
| Parks Medical Electronics[80] | Tri/bi/mono | Yes | No | No |
| Persson[49] | Tri/mono | No | No | Yes |
| **Polak**[35,37] | Tri/bi/mono | Yes | Monophasic | Yes[35,37] |
| Ridgway[33] | Tri/mono | No | Monophasic | No |
| Rooke[73] | Tri/mono | Yes | No | No |
| Rosfors[63] | No | No | No | No illustrations |
| Rose[71] | Triphasic[b] | No | No | Yes |
| Roussin[77] | Triphasic | No | No | No illustrations |
| Rumwell[31] | Tri/bi/mono | Yes | Monophasic | No |
| Rutherford[11] | Tri/mono | No | No | Yes |
| Satiani[54] | Tri/bi[b]/mono[b] | No | No | No illustrations |
| Schroedter[61] | Tri/bi/mono | Yes | No | Yes |
| Sensier[70] | Tri/mono | Yes | Monophasic | Yes |
| Shaalan[74] | Tri/bi/mono | No | Biphasic/monophasic | Yes |
| Shepherd[23] | Tri/bi/mono | Yes | No | Yes |
| Spronk[76] | Tri/bi/mono | Yes | Monophasic | Yes |
| **Strandness**[2,5,24,26,27,32,45] | Tri/bi/mono | No | Biphasic | No illustrations[24] Yes[2,5,26,27,32,45] |
| Society for Vascular Ultrasound[78] | Tri/bi/mono | Yes | No | No illustrations |
| Talbot[39] | Tri/mono | No | Monophasic | Yes |

*(continued)*

**TABLE 1.**
**(continued)**

| Primary Author, Reference(s) | Tri/Bi/Mono Terms Defined | Biphasic Associated With Flow Reversal | Biphasic and/or Monophasic Associated With Pandiastolic Flow | Illustration(s) With Zero Baseline |
|---|---|---|---|---|
| Walton[53] | Tri[b]/mono[b] | No | No | Yes |
| Whelan[62] | Tri/mono | No | No | Yes |
| Winter-Warnars[68] | Tri[a]/bi[a]/mono[a] | Yes | Monophasic | No illustrations |
| **Yao**[3,34] | Tri/mono | No | Monophasic | Yes[3,34,36] |
| **Zaccardi**[28,29] | Tri/bi/mono | No | Monophasic | Yes[29]/no[28] |
| **Zierler**[1,6,22] | Tri/bi/mono | Yes | Monophasic | Yes[1,6,22] |
| Zupan[51] | Tri/bi | No | No | No |
| Zwiebel[38] | Tri/mono | No | Monophasic | Yes |

Primary authors with multiple publications combined into a single response are depicted in bold text.
a. Neither describes concept nor uses specific waveform term but implies via direct reference to previously published material.
b. Describes concept of the waveform term but does not specifically use any of the three waveform descriptors.

All three waveform descriptors were defined in 43% (25/58) of the referenced publications; 28% (7/25) of this subgroup were defined by concept or a previously referenced publication. Nine percent (5/58) of publications failed to define any of the three traditional waveform terms. Twenty-one percent (16/77) of the publications had one or more illustrations without a clearly delineated zero-flow baseline; 13% (10/77) had no waveform illustrations.

Triphasic was defined by text, illustration, or previously referenced material in 81% (47/58); 12% (7/58) of this subgroup was defined by conceptual dialogue or a previously referenced publication. Triphasic waveforms were primarily defined as having systolic forward flow, early diastolic flow reversal, and a small secondary forward flow component in late diastole.

Biphasic was defined by text, illustration, or previously referenced material in 48% (28/58); 12% (7/58) of this subgroup was defined by conceptual dialogue or a previously referenced publication. A biphasic waveform was defined as having systolic forward flow and diastolic flow reversal in text, by illustration, or implied by a reference citation in 38% (22/58) of the publications. However, in 62% (36/58), flow reversal was not mentioned as a component of the biphasic waveform. Monophasic was defined by text, illustration, or previously referenced material in 81% (47/58); 22% (13/58) of this specific subgroup was defined by conceptual dialogue or a previously referenced publication.

Five percent (3/58) of the publications associated pandiastolic flow with the biphasic and 47% (27/58) with the monophasic waveform descriptor. Five waveform publications[56,60,64,65,68] linking pandiastolic flow to a monophasic waveform were derived from a single reference.[55] One research periodical portrayed pandiastolic flow as both a monophasic and biphasic waveform.[74] Pandiastolic flow was neither mentioned nor associated with any waveform descriptor in 50% (29/58) of publications.

## Discussion

The description of pulsatile blood flow with Doppler waveforms has been an intricate component in the assessment of normal and abnormal peripheral arteries. Although the absence of a triphasic waveform pattern has historically implied peripheral arterial disease,[3,15,31,33] this is not consistent in the literature, as some authors include biphasic as representative of normal flow.[1,66,70]

With the introduction of nondirectional audio Doppler technology in the 1960s, three waveform descriptors were used to classify arterial blood flow: triphasic, biphasic, and monophasic.[81] These rhythm-based terms were representative of one, two, or three fluctuations of the Doppler frequency per heartbeat. Early waveform publications used *multiphasic*[9,13,14,52,59] as an alternative to describe normal waveforms, and more recent publications have substituted *tardus parvus*[37,38,71,79] to characterize waveforms with a significant arterial obstruction proximal to the point of Doppler interrogation.

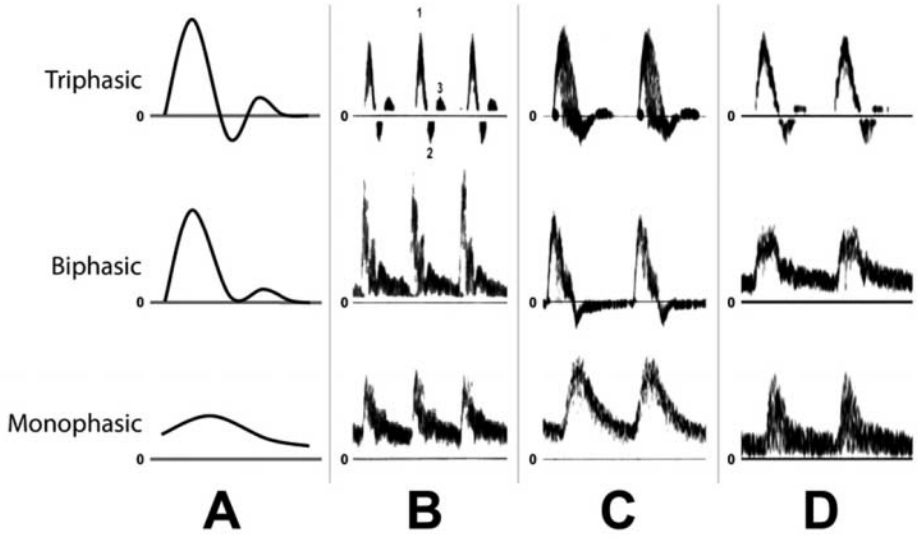


**FIGURE 1.** Waveform illustrations from four authoritative publications characterized as triphasic, biphasic, and monophasic. Reprinted with permission from *Investigation of Vascular Disorders*, Nicolaides AN, Yao JST (eds), p 543. © Elsevier, 1981.

Although Doppler waveform characterization is basic to the education of health care professionals involved in the diagnosis and treatment of peripheral arterial disease, definitions for tri-, bi-, and monophasic waveforms were absent or implied in a substantial number of the publications reviewed in this study. Furthermore, specific definitions for these waveforms were inconsistent, and references considered authoritative characterized or illustrated biphasic and monophasic differently (Figure 1).[1,74,76,79]

A triphasic waveform with three components—forward flow in systole, reverse flow (late systole/early diastole), and forward flow (late diastole)—was the most uniformly defined descriptor (Figure 2). In an investigation assessing the reliability of femoral artery hemodynamics to classify aortoiliac disease, however, waveforms with two or three phases were also defined as triphasic.[74]

Biphasic waveforms were defined in less than half of the publications. When defined, 79% (22/28) associated this term with waveforms that have two phases—systolic forward flow with diastolic flow reversal (Figure 3). Other experts, however, used *biphasic* to describe waveforms with forward flow in systole, zero diastolic flow reversal, and pandiastolic forward flow (Figure 4).[5,74,79]

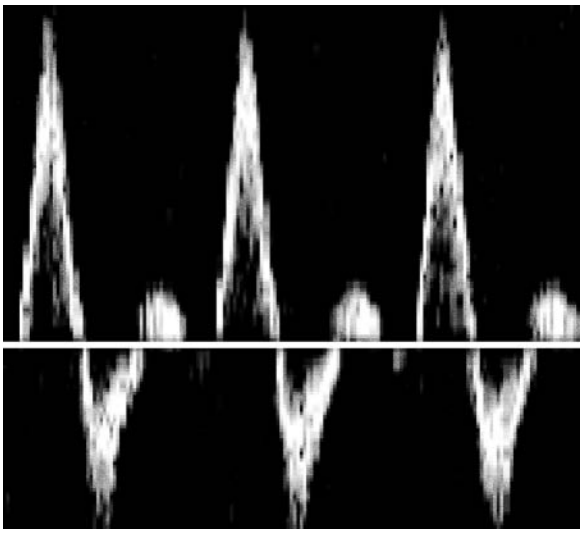

**FIGURE 2.** Triphasic (pulsed Doppler) waveform depicted with forward flow in systole, reverse flow (late systole/early diastole), and forward flow (late diastole).

To further complicate this issue, some authors characterized biphasic as "normal,"[1,66,70] whereas others labeled this waveform "abnormal."[50,54,74] These contradictory characterizations are a plausible explanation for the omission of biphasic terminology by the majority of the publications reviewed in this study.

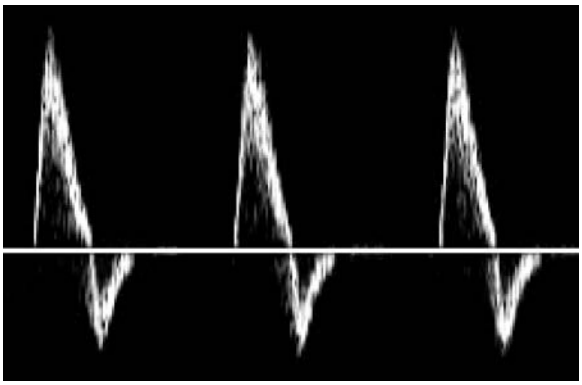

**FIGURE 3.** High-resistant, biphasic (pulsed Doppler) waveform depicted with forward flow in systole and reverse flow (late systole/early diastole), without a forward flow in late diastole.

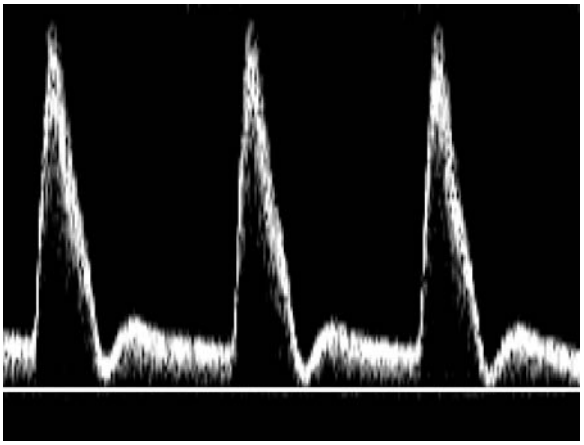

**FIGURE 4.** Low-resistant (pulsed Doppler) waveform with pandiastolic forward flow and zero diastolic flow reversal that has been described as both biphasic and monophasic.

*Monophasic* has historically been associated with waveforms that have a single phase with slow acceleration and deceleration, suggesting advanced arterial disease proximal to the point of Doppler interrogation (Figure 5). Although the majority of publications in this review reaffirmed this definition, some experts employed this term to characterize blood flow movement after vigorous exercise in patients with normally high-resistive Doppler signals.[31,37,38] This incongruity is compounded because waveforms with comparable characteristics were also labeled *biphasic*.[5,74,79]

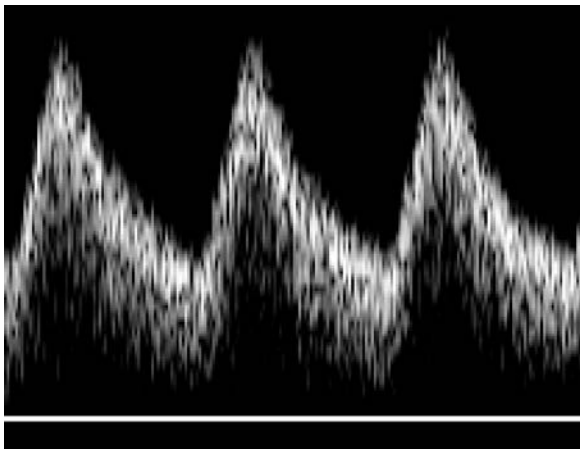

**FIGURE 5.** Low-resistant (pulsed Doppler) waveform with a single phase, slow acceleration, and deceleration historically characterized as monophasic and suggesting advanced arterial disease proximal to the point of Doppler interrogation.

Similar inconsistencies are found when describing waveform phasicity. A longstanding manufacturer of Doppler sonography equipment used *phasicity* to imply a change in flow direction[80]; others incorporated velocity and directional changes.[1] Tri-, bi-, and monophasic descriptors were also used to characterize plethysmography waveforms, thereby associating phasicity with changes in volume.[82] Although the inclusion of a zero-flow reference point is inherent to the description of waveform phasicity,[10] 21% of the publications had one or more waveform illustrations without a clearly displayed zero-flow reference point. Without this reference, one cannot determine whether a waveform has diastolic flow reversal, reaches zero flow after systole, or has pandiastolic flow. Omitting this important identifier further impedes waveform classification.

Recent evidence suggests that inconsistencies surrounding waveform classification may be undermining basic comprehension of Doppler signal analysis.

In a waveform categorization study, 28% of the participants, averaging 10 years of sonography experience, defined low-resistive waveforms with pandiastolic flow as *triphasic*.[8] If reverse flow is a fundamental component of triphasic waveforms, a disturbingly high number of experienced

sonography professionals believe that flow reversal can occur *above* the zero baseline.

Waveform analysis requires an understanding of phasicity, flow direction, and peripheral resistance. In the past, on-the-job training (OJT) was a watershed for much of this understanding. In the 1988, American Registry of Diagnostic Medical Sonographers (ARDMS) vascular technology task survey, 97% of the respondents received OJT for more than 3 years.[83] A similar survey in 2005 noted a 75% decrease in OJT, which is now defined as a short course or workshop, and 38% of surveyed participants had attended a formal sonography training program.[84] With less practice-based experience and a greater reliance on formal sonography education, definitions must be standardized. If reference material is inconsistent or contradictory, this ambiguity will be transmitted to all professionals involved with the diagnosis and management of peripheral arterial disease.

A misunderstanding of waveform characterization could also lead to unnecessary referrals to diagnostic sonography laboratories or vascular specialists. In a recent vascular sonography chapter, Baker[44] notes that an increasing number of patients are referred for noninvasive testing without a physician's assessment, resulting in "a growing number of inappropriate examinations." Changes in diagnostic sonography utilization may exacerbate this problem. According to the American College of Physicians, sonography equipment will soon become commonplace in primary care offices throughout the country.[85] An influx of nontraditional sonography users will increase the likelihood of waveform classification errors. Nearly two decades ago, one of the pioneers of Doppler waveform analysis identified challenges crucial to the advancement of noninvasive sonography diagnosis.[59] Key to accomplishing this goal is standardization. Its absence in the basic description of peripheral arterial blood flow with Doppler instruments clearly emphasizes this need.

Vascular laboratory guidelines coauthored by members of the American Society of Echocardiography and the Society of Vascular Medicine and Biology (ASE/SVMB) addressed waveform standardization, yet its recommendations are not reflective of the majority of publications reviewed in this study. Tri-, bi-, and monophasic descriptors have been historically linked to analysis of the *peripheral* circulation. In the ASE/SVMB guideline, however, waveform analysis is juxtaposed or included with analyses of the cerebrovascular and visceral circulatory systems, which normally have vastly different hemodynamics in the normal and diseased states. Furthermore, biphasic is defined with pandiastolic flow; only 5% of the publications in this review concurred with this categorization.

In a study investigating waveform analysis for diagnosing aortoiliac disease, Spronk et al.[76] suggested terminology that may foster more widespread agreement. Waveforms were classified as triphasic, biphasic, "sharp" monophasic, and "poor" monophasic. Biphasic was defined by flow reversal. Attributing flow reversal to biphasic is consistent with 79% of the publications in this study that defined this term. *"Sharp" monophasic* defined waveforms that have previously been characterized as both biphasic[5,74,79] and monophasic.[31,37,38] *"Poor" monophasic* was used to describe waveforms with "a slow diastolic fall expected in arterial segments distal to an obstruction," which is consistent with the historical application of this term and the majority of publications in this review.

In a discussion on waveform reliability for identifying inflow disease, Blebea comments in Kupper et al.[52] that there are no objective or confirmed criteria to differentiate biphasic from monophasic. Diastolic flow reversal, however, is relatively objective and has been historically linked to normal peripheral arterial blood flow.[1,66,70] Publications using *biphasic* to describe abnormal blood flow used this term to categorize waveforms that had zero diastolic flow reversal or pandiastolic forward flow.[50,54,74] Adopting monophasic subcategories may offer greater waveform consensus, as well as minimize the current confusion created by contradictions in biphasic and monophasic definitions.

In conclusion, this analysis suggests that the most crucial deficiency in waveform characterization is a lack of consensus. In particular, references considered authoritative characterize or

illustrate biphasic and monophasic differently. Waveform classification errors are largely unknown; however, recent evidence suggests that this issue may be undermining comprehension of basic Doppler principles. With a greater reliance on formal sonography education and expansion of sonography utilization into nontraditional venues, a lack of waveform standards could lead to inappropriate testing and decreased sonography laboratory or physician productivity. A multisocietal consensus panel should accept the responsibility for readdressing and standardizing peripheral arterial waveform definitions.

## Acknowledgments

The development of this manuscript was supported in part by the Caroline and Conrad Jobst Foundation, Toledo, Ohio; and, a special note of thanks to Marilyn Gravett, medical/science writer, Jobst Vascular Center.

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Article: Confusion of Peripheral Arterial Doppler Waveform Terminology
Authors: Robert Scissons, RVT
Anthony Comerota, MD, FACS, RVT
Category: Vascular Physics & Instrumentation [VPI]
Credit: 1 CME

Objectives: After studying the article titled "Confusion of Peripheral Arterial Doppler Waveform Terminology," you will be able to:

1. Characterize Doppler waveforms.
2. Differentiate between biphasic and triphasic Doppler waveforms.
3. Describe the inconsistencies between Doppler phasicity.

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1. Which of the following is not a primary physiological parameter that influences waveform shape?
   a. Stroke volume
   b. Heart rate
   c. Blood pressure
   d. Vasomotor changes

2. Peripheral arteries Doppler has traditionally been described as normal when it is which of the following?
   a. Monophasic
   b. Biphasic
   c. Triphasic
   d. Pulsatile

3. Which of the following terms has been used to imply a change in flow direction or for velocity and directional changes?
   a. Pulsatile
   b. Directional
   c. Systolic
   d. Phasicity

4. What name has been used to characterize waveforms with a significant arterial obstruction distal to the point of Doppler interrogation?
   a. Multiphasic
   b. Tardus parvus
   c. Uniphasic
   d. Multidirectional

5. Which of the following waveforms has been characterized as both normal and abnormal? Because of this, many publications have omitted the terminology.
   a. Monophasic
   b. Biphasic
   c. Triphasic
   d. Pulsatile

6. Which of the following waveforms has been traditionally characterized as having a single phase with slow acceleration and deceleration?
   a. Monophasic
   b. Biphasic
   c. Triphasic
   d. Pulsatile

7. Which of the following is useful for differentiating normal from diseased blood vessels?
   a. Systolic flow
   b. Pulsatile flow
   c. Diastolic flow
   d. Phasic flow

8. Arterial disease is characterized by flow reversal in early diastole becoming attenuated with which of the following resultant flow?
   a. Monophasic
   b. Biphasic
   c. Triphasic
   d. Pulsatile

9. Which of the following may contribute to the inconsistency associated with Doppler waveforms?
   a. Prior use of plethysmography
   b. Increased number of registered sonographers
   c. A misunderstanding of waveform characterization
   d. Fewer number of labs performing Doppler

10. Which of the following would provide the clearest answer in resolving the inconsistency associated with Doppler waveforms?
    a. Registry testing
    b. Standardization of nomenclature
    c. Position papers
    d. Increased manuscript submission