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Tips and tricks for facilitating teaching of Doppler waveforms and ankle-brachial index in undergraduate level: A practical guide

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Although the measurement of ankle-brachial index (ABI) is considered a fundamental skill in assessment and diagnosis of peripheral arterial disease and a predictive tool for cardiovascular events, real-world practice shows that the experience of many health professionals is far from ideal. Not only teaching and practice of ABI measurement in undergraduate medical curricula are limited but various mistakes in the process of calculation, estimation, and interpretation of ABI results in the postgraduate practice have also been documented. Because vascular surgery is a core subject in our medical school, we deal with the difficulties and challenges that undergraduate medical students and nurses face to measure and comprehend ABI. We came up with useful tips and maneuvers to overcome these difficulties. Accordingly, this article provides twelve easy-to-follow useful tips to enhance and facilitate the teaching and comprehension of ABI. Moreover, it favors the simultaneous teaching of Doppler arterial waveform examination as a means to facilitate accurate interpretation and validation of ABI results. (J Vasc Nurs 2018;37:64-68)

Although the measurement of ankle-brachial index (ABI) is considered a fundamental skill in the diagnosis and assessment of peripheral arterial disease and a predictive tool for cardiovascular events, real-world practice shows that current teaching and practice of vascular assessment is far from ideal.[1] Indeed, previous studies documented a poor level of baseline knowledge regarding calculation and interpretation of ABI among internal medicine residents, irrespective of the year of residency.[2,3] Likewise, Chaudru et al reported poor scores of 22%, 13%, and 41% among 68 residents from six different medical schools in France regarding correct ABI measurement, calculation, and interpretation, respectively.[4]

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It is acknowledged that teaching vascular surgery and angiology is underappreciated in the undergraduate medical curricula. For example, a recent survey among Greek medical schools showed that vascular surgery is taught as a core subject in only one department, whereas teaching heterogeneity among others does not guarantee sufficient clinical skills acquisition.[5] There is considerable uncertainty about the skills expected of medical students with respect to vascular examination.[6] Yet, a recent survey of ABI use by general practitioners in the United Kingdom revealed that in routine practice, 79.5% of ABI measurement is performed by nurses.[7] Similarly, Davies et al recorded a high percentage of nursing involvement (67.4%) in ABI measurement.[8] Therefore, better training of both doctors and nurses in ABI measurement is necessary.[9]

Our Medical School is the only one in Greece considering vascular surgery as a core subject in the undergraduate curriculum. Our experience in teaching the principles of ABI measurement and Doppler waveform analysis helped us form certain helpful tips to facilitate the understanding and proper utilization of the aforementioned tasks. These tips are presented and analyzed in the following sections.

TIPS AND TRICKS TO FACILITATE DETECTION OF THE TIBIAL ARTERIAL SIGNALS

Hold your hand steady over the patient's dorsal foot to estimate dorsalis pedis artery

In our experience, the commonest mistake of students is to falsely grip the hand-held Doppler transducer from its top end, that is, at its greatest distance from the patients' limb. Figure 1A shows such improper placement of the device's probe

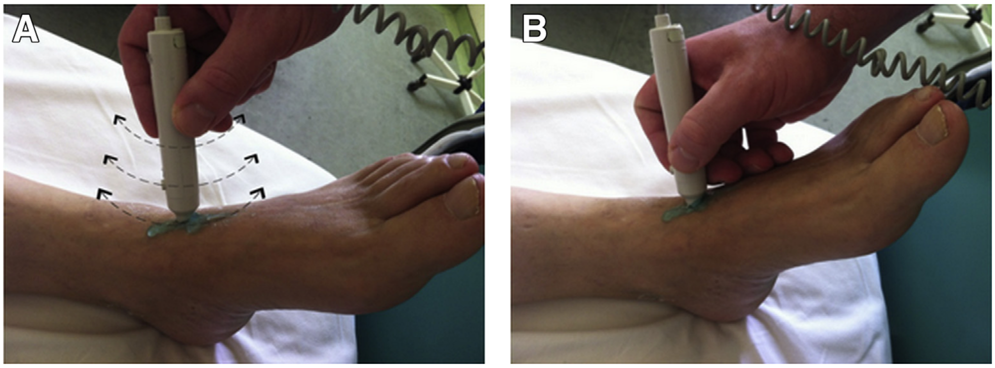

Figure 1. (A) Holding the Doppler probe away from the dorsal foot surface results in inadequate support during arterial flow detection and ankle pressure measurement due to subtle tremor movements that are augmented over the examined area leading to loss of arterial signal, especially when the manometer cuff is inflated. (B) Therefore, the examiner's hand should be supported over the foot's surface.

over the dorsalis pedis artery. If the examiner's hand is not supported on a firm surface provided by the patient's dorsal foot (Figure 1B), it is likely that there will be subtle trembling movements of the hand and the probe, which are expected to be transmitted in an augmented way at the contact area in a pendulum fashion. This subtle trembling motion is expected to exacerbate once the sphygmomanometer-cuff is inflated until the audible sign of the arterial flow is absent. Obviously, an inadvertent movement of the hand or even a subtle slip of the surface tip of the probe will lead to loss of the arterial sign with consequent underestimation of the segmental pressure. The latter is of crucial importance in cases of critical ischemia where the pressure is already low and the arterial sigh significantly attenuated.

Hold your hand steady over the bed surface to estimate posterior tibial artery

As previously depicted, steadiness of the examiner's hand is of paramount importance for detection of arterial signal and precise assessment of pressure values. Likewise, when evaluating the ABI in the posterior tibial artery, the examiner's hand should be firm and steady against a given surface (Figure 2).

Accordingly, the 8- to 10-Mhz Doppler probe should be placed at 45°–60° to the surface of the skin, pointed toward the patient's knee (ie, toward the vessel flow). The cuff of the sphygmomanometer should be at least 40% of the limb circumference and placed just above the malleoli. The cuff should be inflated up to 20 mmHg above signal disappearance and then deducted slowly to detect the pressure level of flow signal reappearance. The ABI of a leg is defined as the ratio of higher posterior tibial or dorsalis pedis systolic pressure in the ipsilateral ankle to the higher left or right brachial systolic pressure.

Figure 2. Hand support to measure the pressure over the posterior tibial artery.

Avoid the venous interference when detecting arterial sign

The venous signal is continuous and nonpulsatile and sounds "windy." Although a central vein close to the trunk will display phasicity in response to breathing or as a response to the Valsalva maneuver (the vein will increase and decrease in caliber as the patient breathes), small peripheral veins will not display phasicity.

A frequent obstacle appears when the examiner accidentally positions the probe over the vein that crosses the dorsalis pedis artery (Figure 3). As a result of such misplacement, an audible venous signal detected by the Doppler device can interfere with the latter, obscuring the pulsatile arterial signal, tampering with the proper evaluation of the ABI or can be falsely perceived as an attenuated, barely audible arterial sign, especially in severe arteriopathy (critical ischemia), where the arterial Doppler signal is monophasic (see below). If mistaking a venous signal for arterial one, then the segmental pressure will be underestimated.

Figure 3. Avoid the venous interference when tracking for the most suitable arterial sign. In such case, the examiner will experience a continuous nonpulsatile signal as if "the wind blows through the window."

Figure 4. *The optimum triphasic Doppler signal is easily audible over the radial artery.*

Figure 5. *A typical example where measurement of ankle-brachial index is not feasible because the condition of the limb (edema, external fixation, or open wounds) does not allow application of a manometer. In such cases, careful inspection and analysis of the Doppler signal provides useful and crucial information.*

Therefore, direct placement of the Doppler probe onto the vein route should be avoided. In cases of uncertainty, gentle squeezing maneuvers distal to the examined area will enhance the venous return augmenting the venous signal and delineating the nonarterial origin of the audible finding. No matter how inexperienced the examiner is, getting used to the pulsatile nature of arterial audible signals and differentiating them from the continuous-phase venous findings is of paramount importance as the first step to build up skillful experience.

TIPS TO BETTER UNDERSTAND DOPPLER WAVEFORMS

Learn to recognize the normal from the monophasic postobstructive arterial signals

No specific teaching method has been proposed or validated for Doppler signals, even though analysis of the latter is a key element in vascular practice. A recent review presents a detailed classification of Doppler waveforms with respect to the degree of an upstream or downstream arterial stenosis.[10] The normal triphasic arterial flow waveform features the first phase consisting of a rapid ascending branch (rise time) and a rapid descending branch (fall time), the second phase of a negative diastolic component, and the third phase comprising a positive diastolic rebound until return to the baseline. The more distally the arterial waves travel, the more muscular and narrower the arterial vessels become, impending greater resistance in flow.[11] The diastolic phase is linked to the circulatory resistance prevailing downstream from the arterial Doppler waveform recording; the lower the downstream circulatory resistance, the greater the diastolic flow, with no Doppler waveforms morphology returning to baseline. The distention of elastic, large central arteries during the early systole stores a minor percentage of kinetic energy that is released at late diastole, generating the small forward wave (third element) of the triphasic waveform.

The arterial Doppler wave morphology can be characterized as triphasic, biphasic, sharp monophasic, or blunt monophasic according to ultrasound images. The alterations in morphology result from disappearance of the positive diastolic rebound (biphasic Doppler waveform), absence of the negative diastolic component (symmetrical monophasic Doppler waveform), increase in fall time (asymmetrical monophasic Doppler waveform with "blunted" systolic peak), increase in systolic rise time (still with the presence of a "blunted" systolic peak), or loss of signal phase.[10] In a simple way, the generation of biphasic or triphasic Doppler waves requires patent arterial pathway upstream, whereas a hemodynamically significant stenosis causes postobstructive arterial flow through a network of numerous collateral vessels of smaller diameter toward a vasodilated periphery of decreased resistance. In such case, Doppler waveforms are expected to be monophasic, lacking the second and third elements.

Identify the triphasic audible signal

If it is troublesome to recognize the patient's "triphasic" arterial signal, it will be effective for the examiner to access and estimate the triphasic signal over the patient's radial artery after palpation of the artery and appreciation of the pulse quality (Figure 4). Such audible signal represents "the best signal you can get."

Explain the influence of collateral arterial pathways on the waveforms and as simple as it gets

Although the recruitment of the collateral circulation is of paramount importance in case of central arterial occlusion and modifies the Doppler waveform, it is our strong belief that the vast majority of undergraduate students conceive this element in a rather confusing way. The profunda femoral artery provides a collateral network of small-caliber vessels with increased segment resistance causing flow deceleration. Furthermore, the peripheral vascular bed will be at a vasodilatation state due to ischemia (decreased resistance). We found this altered flow state to be parallel to the example of a jammed highway where the vehicle traffic is deviated through a complex network of narrower pathways where the speed is essentially slowed down and the vehicles are queued, keeping slow pace. All the aforementioned "structural and functional" changes resemble the flow alteration from a triphasic or biphasic waveform of a sharp and high systolic peak to a monophasic flow of "blunted" and decelerated systolic rise with or without continuous flow, depending on the resistance state downstream.

Underline the significance of ABI interpretation with practical examples

In certain clinical cases, the palpation of peripheral pulses or the use of a sphygmomanometer to estimate ABI to assess the

Figure 6. *Audible detection can be combined with visual inspection of the Doppler waveforms in certain commercially available devices.*

adequacy of arterial perfusion of the limb is not feasible (Figure 5); therefore, documentation of a biphasic or triphasic waveform mirrors the adequate patency of the arterial tree and makes unlikely the case of proximal occlusion, for example, due to thromboembolism, spasm, or a traumatic disruption. Moreover, the calcification of crural vessels in diabetic or dialyzed patients renders these vessels noncompressible and impedes the accurate estimation of ABI, leading to false diagnosis in these patients. Hence, in certain cases, the identification of an audible distinct diastolic component of the arterial signal precludes proximal occlusion and remotes the clinical diagnosis of critical ischemia. Furthermore, all patients with monophasic waves and some high-risk patients with biphasic waves (mostly diabetic patients) should be referred to specialized laboratories for further vascular studies and vascular surgery consult. Finally, in cases of edematic legs with a venous disease and/or venous ulcers where an appropriate compression therapy is indicated, a normal ABI screening test can rule out coexisting arterial pathology which would probably delay the initiation of the compression therapy.[12]

Combine audible signals with visual recordings

Certain Doppler ultrasound devices equipped with a screen for visual analysis of the arterial sign are commercially available. Apart from the audible signal, the visual inspection of the arterial waveform can confirm the existence of a diastolic phase (Figure 6) over the examined arteries, ensuring the patency of the arterial lumen proximally.

Use portable color duplex in the bedside teaching

Instead of lecturing the basic principles of Doppler waveform and supervising repeating measurements of ABI, we prefer to incorporate in the bedside teaching process the use of color Duplex ultrasound to comprehend the biphasic and triphasic arterial flows, discriminate the venous continuous flow, and, most importantly, understand the pitfalls in the interpretation of ABI in cases of incompressible crural vessels of diabetic or dialysis patients (leading usually to overestimation of ABI).[13] The use of ultrasound has proven to stimulate students' attention and enhance their skills when it comes to femoral vascular physical examination.[14,15]

TIPS TO FACILITATE STUDENTS' COMPREHENSION

Teach the ideal example of complete absence of peripheral resistance

In our experience, undergraduate students ask very often for practical examples to comprehend the meaning of peripheral resistance and its influence on the Doppler waveform. One interesting and easily accessible example is the arteriovenous fistula (AVF) in dialysis patients. Although this condition is not directly associated with the estimation of ABI, instead of arterial flow deviating into a system of bifurcating to smaller muscular vessels, the arterial flow in AVF deviates into a low-resistant system of compressible veins that converge to larger diameter veins downstream. These features constitute a system of negligible resistance to flow; thus, because there is no wave reflection, a palpable bruit and continuous flow (ie, nil diastolic reflection) are created in AVF instead of pulses.[16] Consequently, if a significant stenosis in the venous outflow occurs, like we can instantly impose on the vein outflow track by applying external compression with our finger, then an outflow resistance is generated with immediate generation of pulses replacing the bruit of continuous forward flow. Accordingly, the release of extrinsic pressure restores immediately the characteristic continuous flow.

Learn from others' mistakes

Because the time of teaching and practicing ABI estimation is quite limited in undergraduate medical curricula, it is advisable that tutors point out quite early in the teaching process the commonest mistakes encountered.[2,13,17] Previous articles have summarized these mistakes, namely, failure to use Doppler to assess both brachial pressures and/or assess both pedal vessels, failure to use Doppler to assess pedal pressures or accurately record Doppler signal from brachial or pedal artery, use of small arm cuff to assess pedal pressures, incorrect placement of ankle cuff over calf muscles, the use of large cuff to assess brachial pressures, and assessment of radial artery pressure instead of brachial pressure.[2] Other common mistakes include the use of lower/ipsilateral brachial pressure, exclusive use of either dorsalis pedis or posterior tibial pressure, and reversal of ABI fraction.[2] Finally, one should be aware of potential errors in the interpretation of ABI measurement (normal, mild, moderate, or severe classification).

Perform at least 20 measurements of ABI

Despite teaching and demonstration of proper ankle pressure estimation and interpretation of results, it appears that the technique of ABI measurement requires strenuous, continuous, and consistent effort. Even a 9-day ABI-focused training program may not be sufficient to ensure competency in detecting peripheral arterial disease in populations at risk, according to Monti et al, who advocated also in favor of continuous training.[18] A minimum of twenty measurements has been suggested as necessary for accurate measurement of ABI and classification of peripheral arterial disease.[19] Further suggestions to facilitate ABI training include recruitment of fellow students to teach the ABI measurement technique to younger students, working in pairs to pump up pressure cuff while detecting arterial signal using the device probe or using simulation in ABI training before performing on real patients. It is important that training be provided to residents in hospitals to improve their ABI-calculation experience.

CONCLUSIONS

Teaching of basic principles of ABI measurement and estimation can be an intriguing task, and the acquaintance of practical skills is a demanding process needing commitment, repetitive exercising, and combination of theory and practice. The understanding of Doppler arterial waveforms completes the interpretation of ABI and helps to avoid misinterpretations in vascular examination, especially in challenging cases.

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