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Comparison Between Duplex Ultrasound and Multigate Quality Doppler Profile Software in the Assessment of Lower Limb Perforating Vein Direction

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WHAT THIS PAPER ADDS

By means of innovative sonographic software, the present investigation demonstrates the discrepancy between the traditional definition of perforating vein incompetence (i.e., diastolic outward flow lasting more than 500 ms) and the real net outward flow of these vessels. These data pave the way for further investigations on the real haemodynamic features of the perforating veins and on their pathophysiological role of pressure equalisers inside conjoined vessels.

Objectives: The aim was to assess more accurately the net flow of the lower limb perforating veins (PVs).
Material and methods: This was an observational prospective study. Two hundred and twenty one limbs with chronic venous disease (C1–6EpAs,pPr) of 193 patients underwent a duplex ultrasound (DUS). All identified PVs were scanned also by means of quality Doppler profile (QDP) multigate analysis in order to determine their net inward and outward flow direction. A comparison between the traditional pulsed wave Doppler analysis and QDP was performed to detect potential discrepancy between the traditional definition of PV incompetence and a net outward flow.
Results: The DUS investigation identified 774 PVs. Only 7.7% of the PVs showed an outward flow lasting more than 500 ms. Among the PVs showing a longer than 500 ms outward flow, QDP assessment revealed net outward flow in only 84% of the PVs along the thigh and in 28.6% along the lower leg. Among the PVs showing a shorter than 500 ms outward flow, QDP assessment reported a net outward flow in 2.4% of the PVs along the thigh and in 47.3% of those along the lower leg. The sensitivity of an outward flow lasting more than 500 ms in detecting an actual net outward flow was 13.9% (9–20.1%). The specificity of an outward flow lasting less than 500 ms in detecting a net inward flow was 96.4% (93.2–98.3%).
Conclusions: A lack of overlap exists between the finding of a PV outward flow lasting more than 500 ms and the net outward flow of the same vessel. The traditional definition of PV incompetence is challenged by the reported data and further investigations are required to identify a gold standard assessment.

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INTRODUCTION

In lower limb venous pathophysiology, perforating vein (PV) haemodynamics remain consistently controversial, nourished by limited and contradictory literature.[1–3] The distinction between muscular systo-diastolic outward and inward flow represents the focal point of the incompetence definition and related matter of debate. Previous investigations pointed out the presence of bidirectional flow in PVs, with an inward and outward orientation.[4,5] The correlation between the increased number of incompetent PVs and chronic venous disease (CVD) severity testifies the haemodynamic role of these vessels, for which a dedicated, yet controversial, treatment has been proposed during recent decades.[6,7] According to both the ESVS and SVS/AVF guidelines, elective treatment of incompetent PVs is not recommended in patients with uncomplicated varicose veins (CEAP C2) (Grade 1B). A PV can be treated whenever presenting an outward flow lasting ≥500 ms, a diameter of at least 3.5 mm and a localisation beneath a healed or open venous ulcer (Grade 2B).[8,9] Despite growing evidence of the need for deeper PV haemodynamic analysis,[1] the characterisation of an

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incompetent PV and its subsequent potential treatment is still linked to the detection of outward flow. Nevertheless, up to now, no diagnostic tools have been developed to precisely report the PV net flow, rather than just the time of inward and outward flow.[8,10,11] Indeed, traditional ultrasound scanning cannot simultaneously report the spectral analysis of all the PV tract. It only measures the segment assessed by the sample volume, which is limited by the vessel tortuosity (Fig. 1).

An alternative evaluation of PV flow has recently become available using innovative sonographic software to analyse multigate quality Doppler profiles (QDPs). This QDP technology allows assessment of both the inward and the outward flow velocity component and indicates the net flow velocities in real time, during both the systolic and diastolic phases. As velocities can be measured simultaneously at different depths, this is particularly important for evaluating PVs, which are often quite tortuous. The same technology has been used in previous investigations studying neck and intracranial vessels,[12–14] the aorta,[15,16] the inferior vena cava, and the uterine arteries.[17]

The primary endpoint of the present investigation was to assess the PV flow direction both by the traditional protocol and by QDP, thereby identifying the number of normally considered incompetent PVs presenting not just a long lasting outward flow, but also a real outward net flow.

The secondary endpoint was the localisation of the incompetent PV, highlighting a potential prevalence in the thigh or in the lower leg region.

METHODS

In the present study 193 patients suffering from CVD in 221 limbs (C1–6EpAs,pPr) were included.

The study excluded patients reporting previous surgical procedures on the lower limb, venous treatments, major trauma, lymphoedema, venous thrombosis, severe postural defects, and hypomobility. All patients were investigated with duplex ultrasound (DUS) in the standing position. All the assessments were performed using the same DUS device (MyLAB Vinco, Esaote Genoa Italy) with a variable frequency (7.5–11 MHz) linear array transducer. Scanning was performed by the same experienced sonographer in a room at a controlled temperature after the patient had been standing still for 1 min.

Duplex ultrasound assessment of perforating veins

Perforating veins where divided into two anatomical groups: thigh and lower leg. Scanning covered both the lower leg and the thigh, and all around the limb circumference; the pulse repetition frequency value was set between 0.7 and 1 kHz, while the sample volume was opened up to the vessel wall limits.[18] Reflux was elicited by the active dorsiflexion manoeuvre.[19] The evaluation focused on both physiological and refluxing PVs exhibiting a bidirectional flow. The flow from the superficial toward the deep venous compartments was considered inward, while the drainage from the deep system toward the superficial was considered outward. Flow velocities in one or other direction were analysed with the usual pulsed wave Doppler spectral analysis. PV were considered refluxing whenever showing outward flow velocities lasting more than 500 ms.[8,9]

Multigate quality Doppler profile assessment of perforating veins

Multigate QDP is a fast Fourier transform based Doppler technology.

A spectral profile is obtained from multiple depths analysis. The spectrum is created by gathering together the echoes of up to 256 sample volumes, covering a total length of 9 cm. Looking at the spectral profile, spatial distribution is on the vertical axis and velocity on the horizontal axis. The brightness of any pixel reports the power of the corresponding spectral density. Thanks to these features QDP

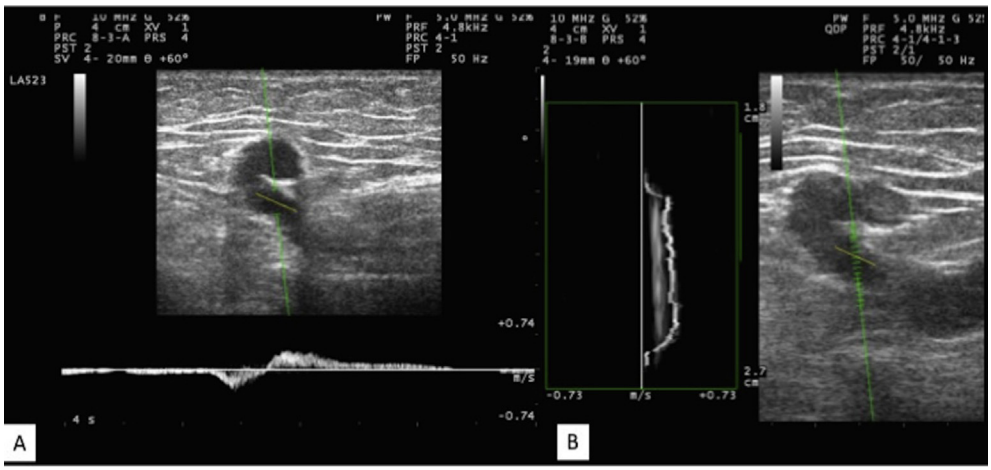

Figure 1. Comparison between pulsed wave (PW) (A) and quality Doppler profile (QDP) (B) analysis in a tortuous perforating vein. The single gated analysis with the PW produces a bidirectional spectrum (A) that is translated by QDP multigate analysis into a monodirectional curve reporting the net inward/outward direction. While in the PW (A) analysis the direction of the vessel and the consequent steering influence the assessment outcome, in a QDP analysis the flow detection is independent of the vessel tortuosity because the Doppler signals of multiple sample volumes are analysed simultaneously.

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enables the simultaneous analysis of different segments of the same tortuous vessel, providing data about the direction of its net flow, so avoiding the limitations of a traditional single gate analysis.[20,21] The mean frequency of each gate is calculated, amplified, and added to all the other gates analyses, so resulting in a line which gives immediate evidence of the net flow direction (so called DIR algorithm)[22] (Fig. 2).

QDP analysis was performed in all the identified bidirectional PVs of the patients included in the present study for a qualitative multiple directional net flow velocity assessment.

A comparison between the DUS detected diastolic outward flow and QDP detected systo-diastolic net flow direction was performed in order to detect potential discrepancy between the traditional PV incompetence definition (outward flow lasting more than 500 ms) and an outward net flow.

All patients signed an informed consent. Institutional Review Board approval was obtained.

Statistical analysis

Statistics were performed using InStat GraphPad (GraphPad Software, Inc, La Jolla, CA, USA). The patient population demographics are presented as mean $\pm$ SD, while other data are the absolute values. Sensitivity and specificity of the assessment of the outward flow in net flow determination was calculated. Statistical analysis included a comparison between the localisation of incompetent PVs in the thigh and in the lower leg. The differences between the number of PVs exhibiting a outward flow lasting more than 500 ms and the PVs presenting a net outward flow was tested using the two tailed Fisher exact test. The same test was used to assess the frequency of PVs with net outward flow along the thigh or lower leg. The level of significance was defined as $p < .05$.

RESULTS

The mean age of the cohort was 53 $\pm$ 13 years; there were 67 males and 126 females; 14 cases were bilateral

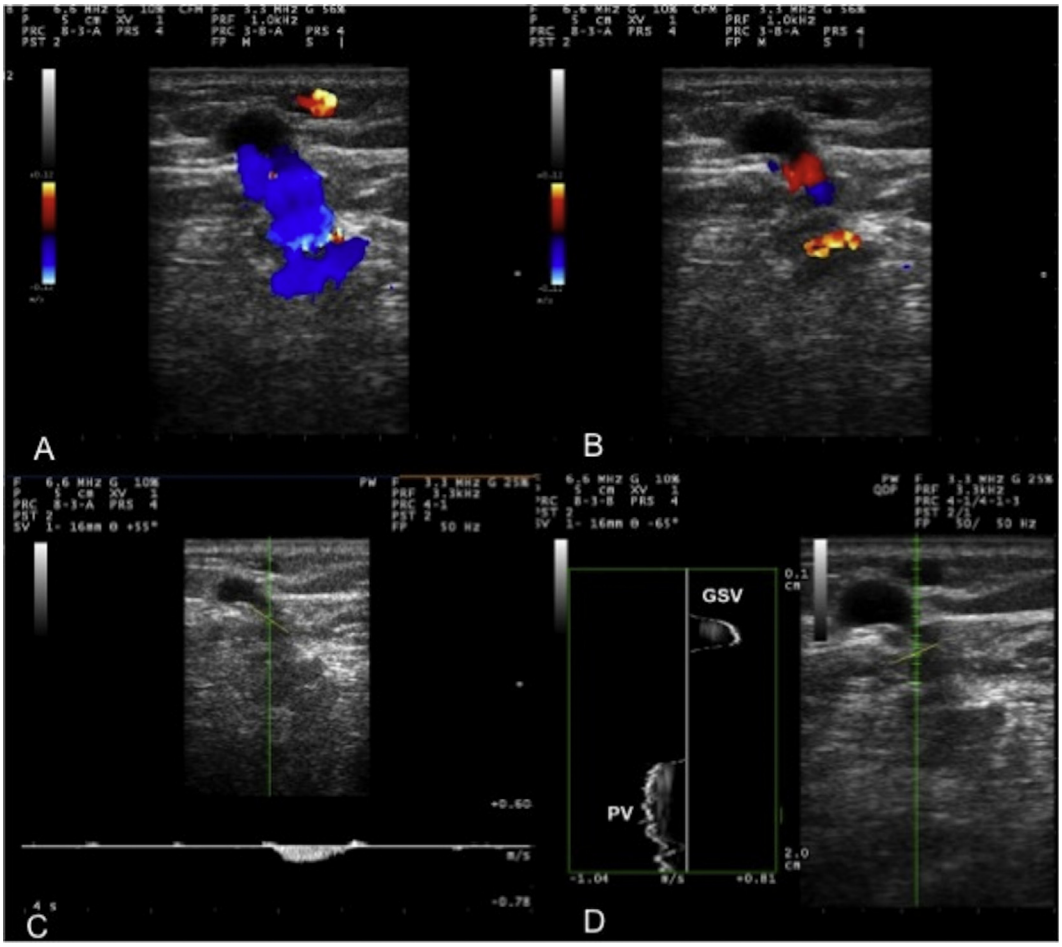

Figure 2. Perforating vein duplex ultrasound and quality Doppler profile (QDP) assessment: (A) Color Doppler analysis showing in blue the entire perforating vein (PV) flow moving away from the transducer and (B) in red the flow toward the transducer. (C) Pulsed wave spectral analysis reporting the flow velocities in the PV at the site of sample volume (D) Great saphenous vein (GSV) and PV net flow direction assessment by quality Doppler profile, showing the prevalent drainage direction of the entire PV. Based on the localisation of the curve on the baseline it is possible to detect a net outward (right side of the baseline) or inward (left side of the baseline) flow. The green line represents the analysis segment of 256 sample volumes involved in QDP analysis. The yellow angle is included since the software also allows extrapolation of pulsed wave (PW) analysis.

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(11 females and 3 males). The results of the study are summarised in Fig. 3. The DUS investigation identified 774 PVs, with 413 of 774 (53.4%) presenting with bidirectional flow.

Among these, only 32 of 413 PVs (7.7%) showed an outward flow lasting more than 500 ms. These PVs were more frequently located in the thigh (78.1%; 25/32).

The 381 of 413 (92.3%) PVs whose outward flow lasted less than 500 ms were located more frequently along the lower leg (298/381; 78.2%)($p < .0001$).

Among the PVs showing a longer than 500 ms outward flow, QDP technology assessment revealed a net outward flow only in 84% of the PVs along the thigh (21/25) and in 28.6% of the PVs along the lower leg (2/7). Among the PVs showing a shorter than 500 ms outward flow, QDP technology assessment reported a net outward flow in 2.4% of the PVs along the thigh (2/83) and in 47.3% of the PVs along the lower leg (141/298) (Fig. 3). The number of PVs exhibiting a outward flow lasting more than 500 ms was significantly different from the number presenting a net outward flow ($p < .0001$). The sensitivity of an outward flow lasting more than 500 ms in detecting an actual net outward flow was 13.9% (95% CI: 9%—20.1%).

The specificity of outward flow lasting less than 500 ms in detecting a net inward flow was 96.4% (95% CI 93.2%—98.3%).

DISCUSSION

Traditional PV sonographic investigation fails in reporting an accurate measurement of the entire vessel haemodynamics. The tortuosity of the vein hinders a correct positioning of the sample volume, which, in turn, provides an assessment of a single spot, rather than of the entire PV.

QDP technology offers the possibility of assessing net flow direction in the entire vessel, independently of its potential tortuosity; more specifically, in this investigation QDP has been used to assess net PV flow direction in the calf and thigh during all the muscular systo-diastolic phase evoked by an active dorsiflexion of the patient's foot. By using QDP software, the present investigation reports the lack of overlap between a traditional PV incompetence definition (outward flow lasting more than 500 ms) and a net outward flow.

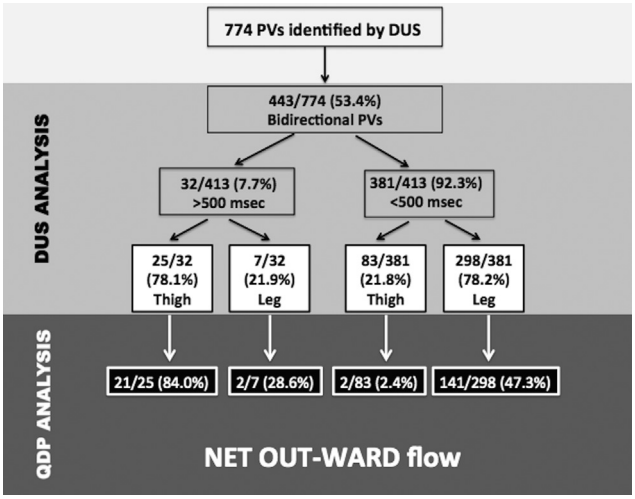

Figure 3. Perforating veins (PVs) assessed both by traditional duplex ultrasound (DUS) and quality Doppler profile (QDP) software.

In particular, among all the PVs presenting an outward flow lasting more than 500 ms, 84% in the thigh and 28.6% in the lower leg presented a real net outward drainage.

A net inward flow was identified in a significant number of the assessed PVs with QDP analysis despite their outward flow lasting more than 500 ms at DUS. This is in line with the potential role of the same PVs as communicating vessels balancing the pressure overload between the deep and superficial systems; in fact, rather than being just draining routes from the superficial toward the deep system, PVs could serve as pressure overload dissipaters draining the blood from the compartment at higher pressure toward the one with lower pressure. A typical example is the muscular systole of the calf, significantly increasing the pressure in the deep venous system, forcing the blood to move upward but also outwards toward the saphenous system through PVs.

The more frequently encountered net outward flow in the thigh is in accordance with the hypothesis of a diastolic pressure drop that is larger in the saphenous system than in the deep veins. This corresponds with the findings of Arnoldi[23] about systo-diastolic pressure changes and a higher frequency of incompetent femoral vein PVs (previously called Hunter PVs) rather than lower leg PVs.[21]

In the present study, PVs exhibiting an outward flow lasting less than 500 ms presented a net outward flow in 2.4% of thigh vessels and in 47.3% of leg vessels. This means that thigh PVs, which are considered competent according to the usual DUS definition, also appeared to be competent with QDP net flow analysis. This was not the case for almost half of the 'competent' lower leg PVs, which showed a net outward flow during the diastolic (relaxation) phase.

Decades ago, pioneering investigations provided extremely interesting preliminary evidence on this topic. Hojensgard et al.[24] simultaneously recorded pressure in the posterior tibial vein and the great saphenous vein in healthy controls, reporting the same pressure values during muscular systole and diastole. This finding suggests a possible PV haemodynamic role as a communicating vessel between two venous systems, so balancing potential pressure overloads. Arnoldi[23] compared the intravenous pressure of the posterior tibial vein and the great saphenous vein in CVD patients. During muscular systole, posterior tibial vein pressures were higher than in the great saphenous vein, while the opposite occurred during diastole, hence favouring an inward diastolic flow. Bjordal[25] investigated PV flow by means of electromagnetic flow recordings and equally found a prevalent inward drainage through a so called incompetent PV. This questioned the earlier blow out syndrome theory of Cockett and Jones,[26] previously described by Trendelenburg,[27] in which high pressure transmitted from the deep veins during muscular contraction progressively leads to PV dilatation, which eventually

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causes PV incompetence. Anatomical studies show that PVs, particularly with small calibres, are usually valveless or endowed with rudimentary valves: another factor suggesting a possible role for PVs as pressure equalisers.[28,29] Approximately 150 PVs have been described along the leg.[30] From a theoretical point of view, these data suggest the importance of not considering just the single perforator assessed at the DUS, rather than all the PVs, both small and large calibre, as multiple vessels connecting the deep and superficial compartments.

At this stage, Doppler and QDP PV analysis are not to be considered as independent assessment options in PV evaluation, but rather complementary investigations. The combination of both diagnostic tools could in fact provide a deeper insight to PV haemodynamics and pathophysiology. QDP analysis of PVs highlights the fact that the actual definition of PV incompetence, defined as outward flow lasting for more than 500 ms, does not correspond with the net outward flow. This means classic DUS has a very low sensitivity (13.9%) in detecting the real net outward flow.

On the contrary, assessing an outward flow lasting less than 500 ms is highly specific for net inward flow identification (96.4%).

Future upgrades of DUS technology should focus on the assessment of quantitative measures of net flow, along the entire vessel length, independently of its tortuosity. In such analysis, it will be interesting to correlate PV haemodynamics with their diameters, and with the clinical class of the CEAP classification. A second subanalysis should also compare the net flow direction detected by QDP with diastolic outward flow of more than 350 ms as a cutoff value (as recommended in the recent ESVS guidelines),[8] instead of the traditionally used 500 ms.[31]

Limitation of the study

It should be acknowledged that QDP analysis has some serious limitations, since it is a diagnostic tool providing mainly qualitative rather than quantitative measurements of the net flow.

Therefore QDP cannot represent a potential new gold standard for evaluating PV incompetence tests, but rather as useful additional software implementing the reflux time and color information provided by a traditional ultrasound assessment. Moreover, it must be stated that this investigation was performed with the patient standing, while an ideal assessment should evaluate the PVs during walking. In the late afternoon the venous system of the lower limbs is more distended and it might be expected that PVs play a more important role in balancing the pressure between the deep and the superficial venous systems.

In conclusion, the definition of PV incompetence requires further investigation of the haemodynamics of these vessels and of the underlying pathophysiological mechanisms. Multigate QDP software is not intended to be a substitute for traditional DUS analysis, but rather aims at providing a more detailed analysis of the net flow velocity during both muscular systole and diastole.

CONFLICTS OF INTEREST

None.

FUNDING

None.

APPENDIX A. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ejvs.2018.01.013.

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