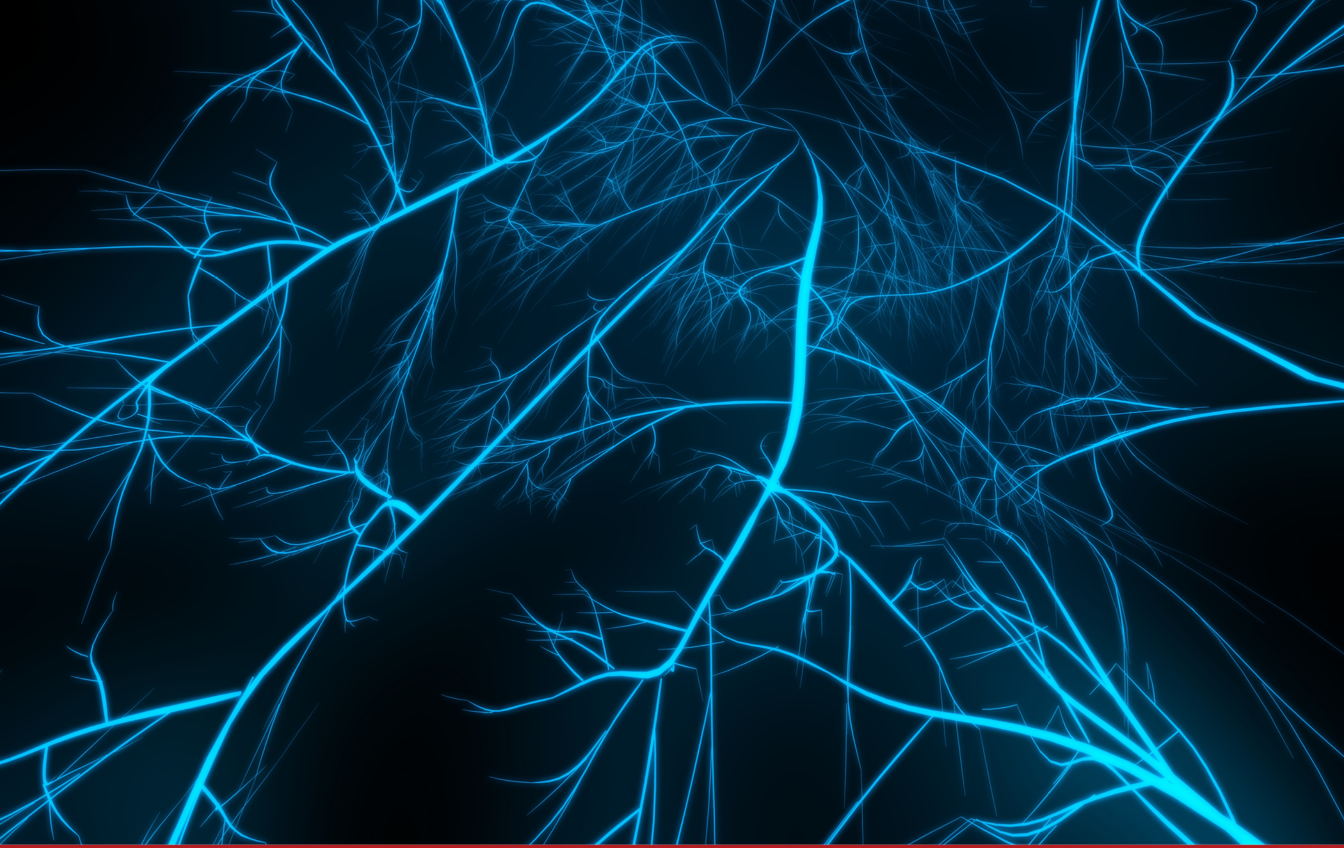

CONTEMPORARY MANAGEMENT OF ACUTE AND CHRONIC VENOUS DISEASE

Edited by

Juan Carlos Jimenez

Samuel Eric Wilson

CRC Press
Taylor & Francis Group

Contemporary Management of Acute and Chronic Venous Disease

With a focus on evidence-based, contemporary, and clinically relevant information, this practical new resource provides a concise, clinical, and techniques-focused guide to the medical, endovenous, and surgical management of patients with acute and chronic venous disease.

Internationally recognized chapter authors cover the general principles of the pathophysiology, diagnosis, indications, and decision-making around the management of acute and chronic venous disease. The text emphasizes endovenous and surgical techniques where applicable and also addresses symptomatic peripheral venous insufficiency, deep venous thrombosis, and the care of patients with symptomatic central venous disease.

Vascular surgeons will find this a valuable guide, providing insights into key techniques and approaches to the treatment of acute and chronic venous disorders. This book is an invaluable resource for vascular trainees preparing for examinations and for physicians in other specialities looking to expand their knowledge base.

Contemporary Management of Acute and Chronic Venous Disease

Edited by

Juan Carlos Jimenez, MD, MBA, FACS

Professor of Surgery
Director, Gonda (Goldschmied) Vascular Center
Division of Vascular Surgery
David Geffen School of Medicine at UCLA
Los Angeles, California

Samuel Eric Wilson, MD, FACS

Distinguished Professor of Surgery and Chair Emeritus
University of California Irvine
Irvine, California

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Juan Carlos Jimenez: "For Daniel and Christian, my inspirations!"

Samuel Eric Wilson: "This one's for Sandy."

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Preface

From the first description of varicose veins in the papyrus of Ebers in 1550 BCE to Keller's saphenous vein stripper in 1905, and on to the beginning of the 21st century, treatment of superficial venous disease remained limited to often ineffective pressure bandages, sclerosants, and a few surgical techniques. Since then, the rapid progression in evidence-based technologies to treat patients with venous disease cannot be overstated. Over the last 20 years, multiple endovenous therapies have emerged with equal to improved outcomes over open surgery, decreased patient morbidity, and increased safety.

This comprehensive overview of the contemporary management of venous disorders focuses on clinical diagnosis, imaging modalities, decision-making, medical management, and descriptions of endovenous and open surgical techniques. Results of evidence-based methods, along with analysis of current clinical practice guidelines issued by international societies are discussed. Our goal for this collection is to improve working knowledge and overall ability to provide up-to-date care for patients suffering from venous disease.

Sincerely,
Juan Carlos Jimenez
Samuel Eric Wilson

Contributors

Jose I. Almeida, MD, FACS
University of Miami
Miami, FL, USA

Samuel P. Arnot
Pitzer College
Claremont, CA, USA

Charles A. Banks, MD
University of Alabama at Birmingham
Birmingham, AL, USA

Paola Batarseh, MD
Yale School of Medicine
New Haven, CT, USA

Mary A. Binko, MS
University of Pittsburgh
Pittsburgh, PA, USA

Tyler Callese, MD
University of California Los Angeles
Los Angeles, CA, USA

Drayson Campbell, BS
Ohio State University
Columbus, OH, USA

John G. Carson, MD
Maine Medical Center
Portland, ME, USA

Ankur Chandra, MD, RPVI
Scripps Clinic
La Jolla, CA, USA

Amanda L. Chin, MD, MBA
University of California Los Angeles
Los Angeles, CA, USA

Christopher Chow, MD
University of Miami
Miami, FL, USA

Lucas Cusumano, MD
University of California Los Angeles
Los Angeles, CA, USA

Leo Daab, MD
Oregon Health & Science University
Portland, OR, USA

Fachreza Aryo Damara, MD
Cleveland Clinic
Cleveland, OH, USA

Steven M. Dean, DO, FSVM, RPVI
Ohio State University
Columbus, OH, USA

Benjamin J. DiPardo, MD
University of California Los Angeles
Los Angeles, CA, USA

William Duong, MD
University of California Los Angeles
Los Angeles, CA, USA

Young Erben, MD
Mayo Clinic
Jacksonville, FL, USA

Steven M. Farley, MD
University of California Los Angeles
Los Angeles, CA, USA

Savannah Fletcher, MD
University of California Los Angeles
Los Angeles, CA, USA

Ana Fuentes
Mayo Clinic
Jacksonville, FL, USA

Hugh A. Gelabert, MD
University of California Los Angeles
Los Angeles, CA, USA

Roberta Lozano Gonzalez, MD
Mayo Clinic
Jacksonville, FL, USA

Eric S. Hager, MD, FACS
University of Pittsburgh
Pittsburgh, PA, USA

Antalya Jano, BA
University of Pittsburgh
Pittsburgh, PA, USA

Juan Carlos Jimenez, MD, MBA, FACS
University of California, Los Angeles
Los Angeles, CA, USA

Aniket Joglekar, MD
University of California Los Angeles
Los Angeles, CA, USA

Nii-Kabu Kabutey, MD
University of California, Irvine
Irvine, CA, USA

Manju Kalra
Mayo Clinic
Rochester, MN, USA

Misaki M. Kiguchi, MD, MBA, FACS
MedStar Washington Hospital Center
Washington DC, USA

Ducksoo Kim, MD
Boston VA Healthcare System
Boston, MA, USA

Peter F. Lawrence, MD
University of California Los Angeles
Los Angeles, CA, USA

Reid C. Mahoney, MD
Oregon Health & Science University
Portland, OR, USA

Justin McWilliams, MD
University of California Los Angeles
Los Angeles, CA, USA

Gregory Moneta, MD
Oregon Health & Science University
Portland, OR, USA

Christopher Montoya, MD
University of Miami
Miami, FL, USA

Oscar Y. Moreno-Rocha, MD
University of Michigan
Ann Arbor, MI, USA

John Moriarty, MD
University of California Los Angeles
Los Angeles, CA, USA

Andrea T. Obi, MD
University of Michigan
Ann Arbor, MI, USA

Cassius Iyad Ochoa Chaar, MD, MPH, MS
Yale School of Medicine
New Haven, CT, USA

Marc A. Passman, MD
University of Alabama at Birmingham
Birmingham, AL, USA

Neeraj Rastogi, MD
Boston, MA, USA

David Rigberg, MD
University of California Los Angeles
Los Angeles, CA, USA

Johnathon C. Rollo, MD
University of California Los Angeles
Los Angeles, CA, USA

Indrani Sen
Mayo Clinic Health Systems
Eau Claire, WI, USA

Jacob W. Soucy, MSI
Pennsylvania State College of Medicine
Hershey, PA, USA

Jordan F. Stafford, MD
Ohio State University
Columbus, OH, USA

Emily Swafford, BS
University of Miami
Miami, FL, USA

Jesus G. Ulloa, MD, MBA, MSHPM
University of California Los Angeles
Los Angeles, CA, USA

Thomas W. Wakefield, MD
University of Michigan
Ann Arbor, MI, USA

Samuel E. Wilson, MD, FACS
University of California Irvine
Irvine, CA, USA

Section 1

General Principles

Chapter 1

Non-Invasive Imaging of the Venous System

Ankur Chandra

INTRODUCTION

Appropriate diagnosis of venous disease without proper imaging is a challenge for clinicians. Venography, through the introduction of an intravenous catheter and administration of contrast, was the initial invasive imaging modality used to diagnose venous pathology including thrombotic and insufficiency disorders. Unfortunately, this modality was painful and would result in complications such as venous thrombosis and embolism. The application of continuous wave Doppler by Strandness and Sigel[1,2] throughout the 1960s provided the first non-invasive assessment of venous flow. Prior to the development and validation of duplex scanning and pulse wave Doppler principles, there was widespread use of physiologic methods such as impedance phlebography in the 1970s–1980s. However, since that time, duplex scanning has been the predominant non-invasive imaging used to diagnose disorders of the venous system. In this chapter we will begin by discussing the principles that underlie duplex ultrasound. Then we will describe the targeted application of both continuous wave Doppler as well as pulse wave Doppler/duplex ultrasound in the diagnosis of common venous conditions including thrombotic events, venous insufficiency, anatomic assessment of superficial veins, and clinical follow-up after treatment of venous reflux.

PRINCIPLES OF DUPLEX ULTRASOUND

The application of ultrasound to the development of vascular imaging and Doppler-based measurements has enabled the clinical study of normal and pathologic venous hemodynamics. Beginning in the 1960s, a continuous wave Doppler was first applied to assess blood flow in battlefield scenarios and then transitioned to routine clinical care. The application of piezoelectric crystals to transmit ultrasonic waves into tissue was then modified by varying the pulse frequency of these waves with more sophisticated algorithms to generate visual images of the underlying tissue. Dr. Eugene Strandness and his vascular surgery colleagues at the University of Washington are credited with the further development of the application of Doppler principles to existing B-mode ultrasound to create duplex imaging. This discovery enabled modern day non-invasive vascular imaging. This section will cover the concepts of ultrasound physics and instrumentation, Doppler shift, and duplex imaging.

Ultrasound Instrumentation and Physics

A clinical ultrasound machine involves three components: the probe (or transducer), a signal translation algorithm, and a display. The probe serves as the interface with the patient to send and receive sound waves, the signal translation algorithm converts the received sound wave from the probe to functional clinical data, and the display is used to present this data. An ultrasound probe is composed of a small array of piezoelectric crystals. A piezoelectric crystal

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$$\Delta f = \frac{2\,fV\ \cos\theta}{C}$$

Figure 1.1 Doppler equation showing the Doppler frequency shift (Δf) is equal to the product of frequency of the insonent sound wave (f), the velocity of the object in motion (V), and the cosine of the angle of insonation (Θ) divided by the speed of sound in tissue (C = 1540m/sec).

changes its shape when an electric current is applied across it. The new shape of the crystal holds the stored mechanical energy and, when a variable current is applied, the transducer produces sound waves at precise frequencies transmitted in the direction of probe. This concept also holds in reverse, in that, if a force such as a sound wave is applied to the piezoelectric crystal, the crystal will create voltage that can be measured. This is the mechanism in which piezoelectric crystals on an ultrasound transducer both transmit sound waves and measure the reflected sound wave that returns from tissue.

A continuous wave Doppler is an ultrasound probe that continuously transmits and receives soundwaves. A pulse wave Doppler is a probe that transmits sound waves in packets of varying lengths and frequencies and varies the window during which it receives them. The continuous wave Doppler sacrifices the ability to distinguish location or depth in tissue in exchange for requiring far less computational effort in its signal translation algorithm. These probes traditionally use a speaker as its display to produce an audible Doppler signal. An example of a continuous wave Doppler is the bedside Doppler "pencil" or probe. A pulse wave Doppler generates a visual result on a video display of both tissue structure (grayscale or brightness ["B"] mode imaging) and blood velocity (Doppler effect) through the decoding of the ultrasound pulses. The combination of B-mode imaging and doppler effect is called duplex ultrasound. The standard clinical ultrasound machine used in vascular labs is a pulse wave machine which produces duplex imaging.

The use of pulse wave imaging to generate a velocity versus time waveform occurs through the application of a fast Fourier transform (FFT). This process allows the binning of discrete frequency data over time to generate a spectral waveform. The frequencies in the spectral waveform are converted to velocities through the Doppler equation (Figure 1.1). This is how the clinical velocity over time waveform used in duplex interpretation is generated. There are unique waveforms for each venous segment based on the location and presence of thrombotic or reflux disease.

Doppler Shift and Duplex Imaging

Through the measurement of the frequency shift of a reflected sound wave, the velocity of blood can be noninvasively measured within a vein. The velocity of blood is derived using the Doppler equation (Figure 1.1). The Doppler effect represents a phenomenon when an insonant sound wave reflects off an object in motion and its frequency predictably changes based on the velocity of the reflecting object. The Doppler equation shows that the velocity of the reflector is directly proportional to the speed of sound in a given medium (c) and the difference in the transmitted frequency (F_T) and retuned frequency (F_R). This velocity is inversely proportional to the transmitted frequency (F_T) and the cosine of the angle theta. Theta is the "angle of insonation" or the angle at which the sound contacts the blood vessel.

For very superficial veins, it is frequently impossible to interrogate velocities perpendicular to the flow direction, as this would result in theta equal to 90 degrees for which the cosine of 90 degrees is zero. To measure the accurate velocity of blood, the ideal angle of insonation is

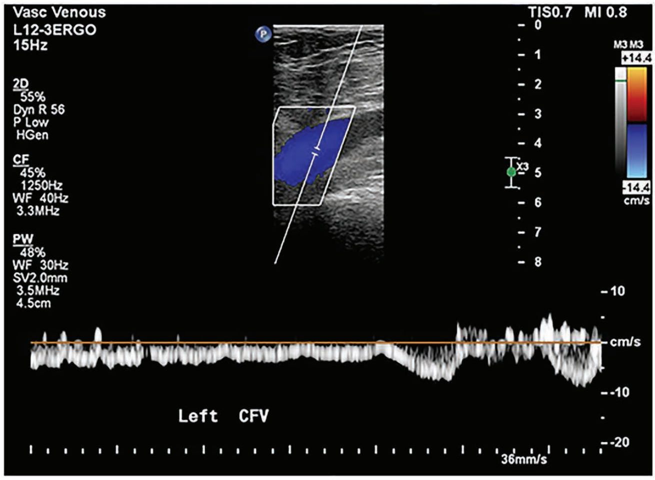

Figure 1.2 Duplex exam of the common femoral vein with flow heading away from the probe in a cephalad direction shown in blue and represented on the color bar as negative (away from probe). This also corresponds to flow waveform below the baseline which is normal for most venous scanning.

as close to 60 degrees as possible. This produces a cosine value of 0.5. As theta approaches zero degrees and the vessel is interrogated nearly parallel to flow, the cosine would approach 1 resulting in artificially elevated results. In venous duplex imaging, velocity direction is displayed as color flow with a legend corresponding the velocity and the direction of flow relative to the ultrasound probe (Figure 1.2).

CLINICAL APPLICATIONS

Acute Deep Venous Thrombosis

A physical exam is often inadequate in the diagnosis of acute DVT of the leg. As a result, the sensitivity and specificity of the non-invasive diagnosis of acute thrombotic occlusion has significantly improved with the application of duplex ultrasound. The continuous wave device was previously a crucial tool for assessing acute DVT in the leg. However, it has been replaced by more advanced imaging techniques using pulsed wave Doppler/duplex. Duplex scanning is now the primary method for diagnosing acute DVT, with alternative imaging studies reserved for cases with inconclusive results or when a scan is unattainable. This practice has been justified by the high accuracy achieved by different investigators.[3–6] Scanning offers significant benefits, including pinpointing the exact location of disease, particularly when multiple thrombi are present. It also detects partially obstructing thrombi, overcoming a major drawback of earlier physiological methods. Scanning not only helps confirm the initial diagnosis but also tracks changes and improvement during treatment.

Continuous Wave Doppler Exam

Occluded segments can be identified by the absence of flow on Doppler examination. The patient lies supine with their head slightly raised, and deep veins are located near the corresponding arteries. Healthy veins exhibit spontaneous flow with respiratory-related fluctuations. Breath-holding or a Valsalva maneuver reduces or halts flow, while its release leads to a brief increase in the signal. Briefly compressing the extremity below the probe results in flow enhancement, often followed by a short decrease upon release. Applying pressure on the upper abdomen or leg diminishes or stops the flow signal, which then increases upon release. Doppler examination detects changes in venous flow patterns, and various types of external compression can cause similar alterations. Abnormal results may stem from venous issues or external compression due to large hematomas, severe edema, or ruptured popliteal cysts. False-positive tests can also occur in cases of advanced pregnancy, ascites, extreme obesity, or abdominal masses that compress the inferior vena cava.

Pulse Wave Doppler/Duplex Exam

Duplex scanners' high resolution enables visualization of venous thrombosis, with a focus on imaging. Thrombus appears within the vein lumen with varying echogenicity levels (Figure 1.3). Sometimes fresh thrombus may resemble flowing blood, necessitating further evaluation by compressing the vein using the probe. Normally, gentle pressure completely flattens the vein (Figure 1.3). However, a partially or fully occluding thrombus inhibits collapse under external pressure. Compression is carried out in the transverse mode to ensure accurate assessment. During longitudinal examination, it is possible to misalign the ultrasound beam, causing the vein to appear collapsed when it is not. Doppler velocity signal abnormalities at rest or during augmentation maneuvers suggest lesions that may not be visible through imaging. Color-coded Doppler is particularly useful for detecting partially occluding thrombi. The color scanner also enhances the examination of calf veins, which are more challenging to visualize without color flow due to their location alongside arteries. Most centers conduct a thorough examination from the inguinal ligament to the calf veins, including imaging of superficial veins. The primary challenge in many exams is tracing the vein through the adductor canal. The common femoral and femoral veins are assessed in the supine position with moderate leg dependency (the deep femoral vein is typically not examined beyond its origin). The popliteal vein is best imaged with the patient in a lateral or prone position. Infrapopliteal

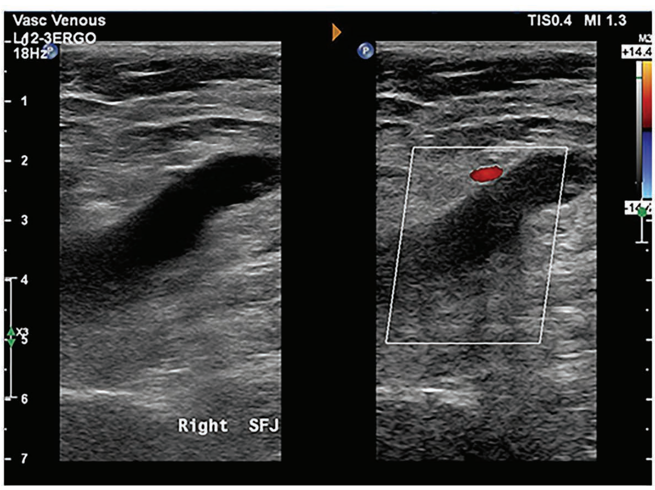

Figure 1.3 Acute DVT of the saphenofemoral junction, which appears echolucent on the noncompressed window (left) but is noncompressible when compression is applied (right), which is diagnostic for occlusive thrombus. Age is estimated as acute by presence of echolucency, whereas thrombus would appear more echogenic for subacute or chronic thrombus.

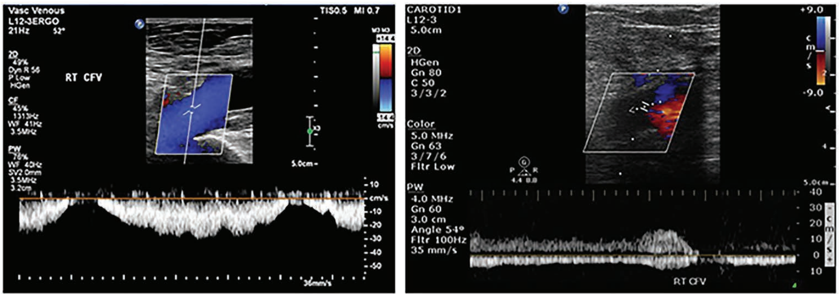

Figure 1.4 Unobstructed venous flow through the proximal iliac veins and IVC has respiratory variation as seen in normal scan on left. When proximal venous obstruction in iliocaval system is present, the flow waveform becomes continuous (right) and is diagnostic for proximal venous obstruction from thrombus or compression even if direct visualization of DVT is not possible.

branches can be challenging to fully evaluate, but extra attention should be given to these if the patient has focal calf symptoms.

Another problematic area is detecting thrombus in the common or external iliac veins. Imaging these veins is difficult, so indirect evidence from the common femoral vein flow signal is often relied upon. Proximal occlusion results in a loss of respiratory phasic variation and limited or no change with the Valsalva maneuver (Figure 1.4). Vogel and colleagues suggested using the change in common femoral vein diameter during the Valsalva maneuver, with an increase of less than 10% indicating suspicion of iliofemoral thrombosis.[3]

Recurrent/Chronic Deep Venous Thrombosis

Diagnosing recurrent DVT in patients with post-thrombotic syndrome poses a significant challenge for clinicians. Worsening symptoms can resemble the original thrombosis, often leading to anticoagulant administration without objective evidence of recurrence. Non-invasive testing can provide objective diagnosis, and comparing a new study with a previous one can help determine if a new thrombus has formed. Duplex scanning can also identify residual chronic thrombus due to its high echogenicity. Other features include thickened vein walls, fibrosed segments of occluded veins, and valvular insufficiency with reverse flow on Doppler examination. These characteristics enable examiners to differentiate recent from chronic clots using a duplex scan, unlike venograms, which display all lesions as filling defects.

Continuous Wave Doppler Exam

In a chronically thrombosed vein segment, there is no flow, and nearby collateral veins exhibit a high-pitched signal. The unobstructed part of the vein beyond the blockage presents continuous flow without respiratory variation, and the Valsalva maneuver causes no alterations. Limb compression may result in limited augmentation, but it is noticeably less than in a healthy vein. The vein segment before the occlusion may display phasic flow, akin to a normal leg, but compressing the distal region induces minimal change.

Pulse Wave Doppler/Duplex Exam

Duplex scanning of deep leg veins for thrombus is technically challenging and demands significant experience for accurate diagnosis. Skilled investigators have reported sensitivities and specificities around 95% for thrombus detection.[3–6] Although most studies focus on acute thrombosis, Rollins et al. demonstrated similar accuracy in identifying chronic disease, with 89% accuracy for calf veins and 93% for proximal veins.[6] Clinicians often want to know the thrombus duration. Currently, no specific method determines its age, but acute thrombus usually appears hypoechoic and homogeneous on grayscale imaging, with a distended vein lumen and a possible "floating tail" at the thrombus' upper end. In the chronic phase, the lesion appears more echoic and heterogeneous, with a smaller-than-normal vein diameter and potential venous collaterals. If direct visualization of the iliocaval segments is not possible, examining the common femoral vein as a reference for proximal venous thrombosis (iliac/IVC) reveals continuous flow without respiratory variation (Figure 1.4).

Venous Insufficiency

Chronic venous stasis complications are often evident, but assessing the relative contributions of outflow obstruction and reflux can be challenging. While initial conservative management is similar, further surgical treatment targets the specific cause. Doppler examination can detect venous reflux and measuring reverse blood flow lasting over 500 msec provides quantitative assessment unavailable with simpler tests.[7,8] Duplex ultrasound of the superficial, perforator, and deep veins can identify the most probable site and cause of venous insufficiency, aiding in the selection of targeted interventions.

Continuous Wave Doppler Exam

Doppler venous examination can also identify venous valvular insufficiency. Under normal conditions, compression proximal to the probe or a Valsalva maneuver should not generate flow, as valves prevent flow toward the probe. However, with incompetent valves, proximal compression or a Valsalva maneuver causes augmentation due to retrograde flow.

Pulse Wave Doppler/Duplex Exam

Ultrasound is utilized to assess reflux in specific venous segments as well. Many labs perform this evaluation with patients in a recumbent position. However, Van Bemmelen et al. stressed the importance of examining patients in the standing position to maximize reflux stimulus.[7] They also highlighted the significance of sufficient compression. A reverse velocity of 30 cm/s is required for consistent valvular closure.[9] Displaying significant reverse flow lasting over 500 msec is evidence of venous insufficiency and valvular incompetence. Inadequate compression may lead to incomplete closure, allowing slow reverse flow through a normal valve and potentially misinterpreting a segment as abnormal.

Preoperative Vein Mapping

When utilizing the great saphenous vein as a surgical conduit, understanding the patient's specific anatomy is crucial. Shah et al. found through contrast venograms that only 65% of thighs and 45% of calves had a single saphenous trunk, with the remainder displaying double systems and cross-connections.[8] Due to the risks associated with contrast venography, duplex scanning has become the standard method for mapping superficial veins in both arms and legs.[10,11] The high-resolution images allow for determining size, course, double segments, and varicosities, closely correlating with the superficial venous anatomy observed during surgery.

Follow-Up of Endovenous Ablation

Endovenous closure has become the primary treatment for significant reflux in the great saphenous vein. Initial experiences with closure techniques demonstrated high vein closure rates, but concerns arose about potential thrombosis extension into the deep system and subsequent pulmonary embolization risk. Most practitioners perform a duplex scan within the first week post-procedure to check for proximal extension. Figure 1.5 displays thrombus extending from the saphenofemoral junction, adhering to the common femoral vein's anterior wall without occluding the vein. Lawrence et al. have developed a classification system for thrombosis levels following ablation procedures.[12]

CONCLUSIONS

The development of non-invasive vascular laboratory devices and techniques has expanded the amount of objective venous data that can be gathered noninvasively. However, it's crucial to remember that these tests should complement, not replace, the information obtained from a thorough history and physical examination. Unfortunately, some physicians increasingly rely on vascular laboratory test results without correlating them with symptoms and physical findings.

For optimal use of non-invasive test results, understanding the value and limitations of specific exams is essential. Non-invasive test selection should depend on the clinical questions to answer, as some questions cannot be addressed by these techniques. Errors, including false-positives and false-negatives, can occur in all diagnostic studies, so being aware of the tests' accuracy is important. Published studies often represent the best achievable results, while newly established laboratories may not attain optimal outcomes. To appropriately apply non-invasive results, it's vital to know the accuracy of the laboratory performing the test.

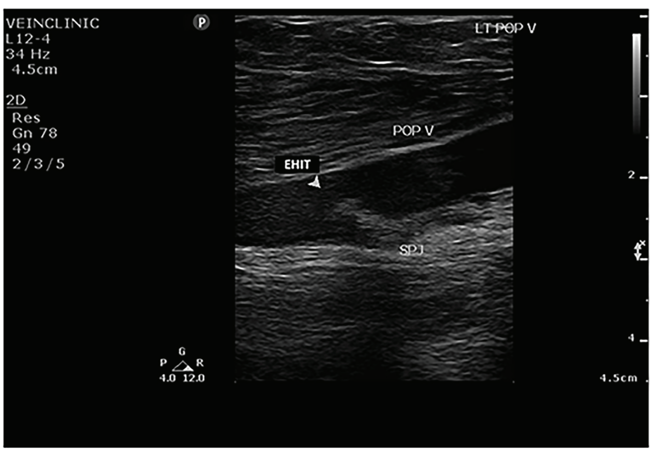

Figure 1.5 Presence of endovenous heat induced thrombus (EHIT) Lawrence level 4 at the saphenopopliteal junction, which involves the lumen of the adjacent popliteal vein as well as adherent to the adjacent wall.

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Chapter 2

Venography and Intravascular Ultrasound (IVUS) in Venous Imaging

Emily Swafford, Christopher Chow, Christopher Montoya, and Jose I. Almeida

INTRODUCTION

Historically, catheter-directed venography, also known as phlebography or simply venography, served as the primary diagnostic tool for evaluating deep venous obstruction. However, with the prevalence of non-invasive imaging modalities such as duplex ultrasound (DUS), computed tomographic venography (CTV), and magnetic resonance venography (MRV), venography became a secondary imaging modality, primarily used for assessment of post-procedural completion or for iliocaval obstruction; recently, intravascular ultrasound (IVUS) has challenged even these applications. This chapter offers an overview of venography and IVUS and aims to provide clinically focused, evidence-based information surrounding their roles in the diagnosis and management of venous disease.

VENOGRAPHY

Catheter-directed venography involves intravenous injection of contrast material through a catheter with concomitant fluoroscopic X-ray examination. Benefits include visualization of the selected venous segment and qualitative analysis of venous hemodynamics, including flow directionality and valve competency. There are two main techniques: ascending and descending venography.

Ascending Venography

Ascending venography is performed through distal injection of contrast media and relies on antegrade venous blood flow for proximal contrast delivery. The difference in density of contrast media versus blood allows for visualization of many venous segments within each vein. Traditionally, contrast material was injected into the superficial veins of the foot, but this method frequently failed to highlight the vessels of the deep venous system. Supplemental contrast was injected into the femoral vein, with superficial venous compression using an ankle-level tourniquet. For further visualization, a second knee-level tourniquet can be applied or foot movements can be utilized to increase blood flow. In competent deep veins, tourniquet application prevents contrast from entering the superficial system. Therefore, the appearance of contrast material in the superficial system aided by proper tourniquet use indirectly suggests venous incompetence.[1] Large deep venous incompetence can affect this technique by causing the pressures of the superficial and deep systems to equilibrate swiftly and potentially prevent the visualization of other venous abnormalities.

Gravitational force, in concert with the venous system's complex geometry and variations in venous segment resistance, can negatively affect contrast distribution and by extension, venographic results.[2] Therefore, patient positioning is important in regard to contrast

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distribution and venous opacification. For optimal ascending venography results, the patient should be placed in a near upright position. Despite proper positioning, imbalances in contrast dissemination will persist, with preferential distal distribution most markedly seen in large veins with slow venous flow.[3] To improve contrast distribution, manual compression of the extremity or muscle contraction maneuvers may be applied. Both constrict select venous segments and fill others more proportionately. However, muscle contraction introduces blood without contrast from intramuscular veins into the deep venous vasculature. Thus, the appearance of a partial venous obstruction secondary to dilution of contrast material may result from these maneuvers and yield a false-positive diagnosis.[4]

Similarly, another potential cause of diagnostic inaccuracy is uneven venous blood flow due to physiological variations in venous segment resistance, such as those seen with venous tone modifications, muscle contraction, and positional compression. These differences in resistance may result in uneven flow – or even halted flow – in certain segments for brief periods. If a venographic study is performed during one of these periods, only a portion of the venous system will be visualized and may lead to overdiagnosis of venous disease. The effect of varying venous segment resistance on ascending venography is exemplified by duplicated veins, which often receive little to no contrast material and frequently remain undetected. This finding is exacerbated in the setting of forced contrast injection or when implementing compression maneuvers.[5]

Additionally, the invasive nature of ascending venography imparts risks, including potential damage to the vasculature or surrounding structures, bleeding or bruising at the puncture site, and infection. Notably, catheter-direct venography is associated with greater patient discomfort, radiation exposure, and nephropathy.

Descending Venography

Descending venography shares many similarities with ascending venography but involves proximal contrast injection and is typically performed by advancing a catheter from the contralateral extremity, often the common femoral vein (CFV). Descending venography mainly functions to evaluate for venous valve incompetency but may also be useful in rare cases of deep valve reconstructive surgery. This technique requires that the patient assume a semi-erect position and engage in a reflux provoking maneuver, such as Valsalva, during contrast injection.[6,7] Of note, when specifically evaluating for saphenous valve reflux, one should inject additional contrast after the catheter is positioned distal to the saphenofemoral junction, and when evaluating for distal femoral or popliteal valve reflux, the catheter should be advanced to a location immediately proximal to the target segment.[8]

Anatomic findings of deep venous reflux from descending venography can be described using the Kistner classification, a five-point grading scale with 0 representing no reflux and 4 representing reflux from the CFV to below the popliteal vein.[6] The disadvantages of descending venography are similar to those seen in ascending venography, although descending venography requires greater radiation exposure as fluoroscopy is near continuously necessary.

Technique

In current practice, catheter-directed venography is generally performed via the femoral vein at the mid-thigh or through the popliteal vein via the popliteal fossa with intent-to-treat a lesion if identified. After positioning, prepping, and draping the patient in the typical fashion, venous access is obtained under ultrasound guidance with a micropuncture kit. The sheath can then be upsized to an 8 French (Fr) for femoral access or 5–6 Fr for popliteal access. A wire and catheter system of choice is advanced to the desired venous segment (i.e., femoral-deep femoral confluence, CFV, EIV, CIV, adjacent IVC, etc.). Contrast material is then injected to delineate the venous anatomy. A pigtail catheter with a pressure injector may be used to bolus contrast for caval lesions, and hand-injected venography may be effective for more distal lesions. Venography should be performed with at least two orthogonal views (i.e., right or left anterior oblique) in addition to the standard anteroposterior view.

Utility

Although catheter-based venography has almost been entirely replaced by more modern imaging modalities, it still important in the diagnosis and management of iliac vein obstruction.[9–11] There are four main venographic signs indicative of an iliac lesion: visual stenosis, decreased opacification, collateral vessels bypassing a segment, and "pancaking" or flattening of the vein. The presence or absence of each sign affects diagnostic sensitivity. When all present, the sensitivity ranges from 97.1% if located in the CIV, 57.7% if in the EIV, or 48.1% in the CFV. Incomplete filling is the sign associated with the highest sensitivity and has been found to be more sensitive if identified on the left side as compared to the right. If visualized in the left CIV (Figure 2.1), incomplete filling is associated with a sensitivity of 92.9%.[12]

Nevertheless, the overall sensitivity of single-plane venography for venous stenosis above 70% remains low (~45%).[13] Multi-plane venography has been shown to improve diagnostic properties when compared to single-plane venography, with the downside of significantly increased radiation exposure and contrast use. Additionally, both single-plane and multi-plane venography lack an internal scale and have demonstrated limited ability in accurately measuring vein diameter. Currently, neither are recommended as the sole imaging modality.[14,15]

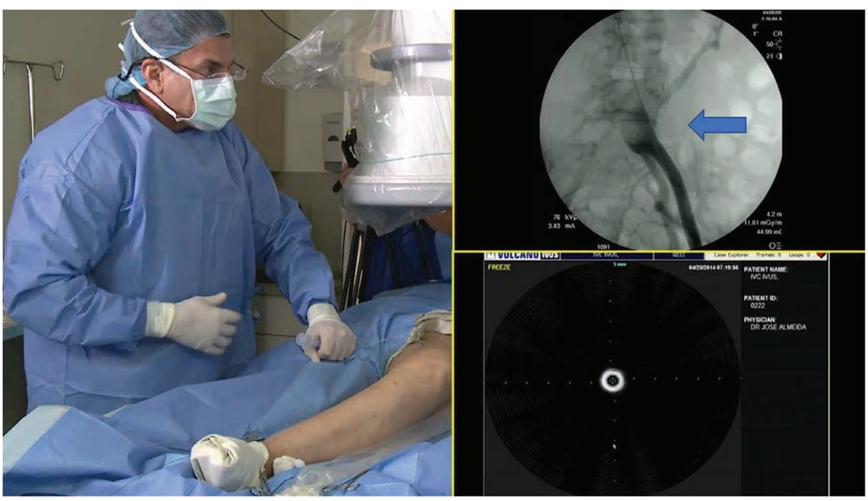

Figure 2.1 Left panel: Contrast injection via femoral vein sheath. Upper right panel: Blue arrow demonstrates left common iliac vein occlusion with visualization of ascending lumbar and hypogastric vein collaterals.