US of the Penis: Beyond Erectile Dysfunction

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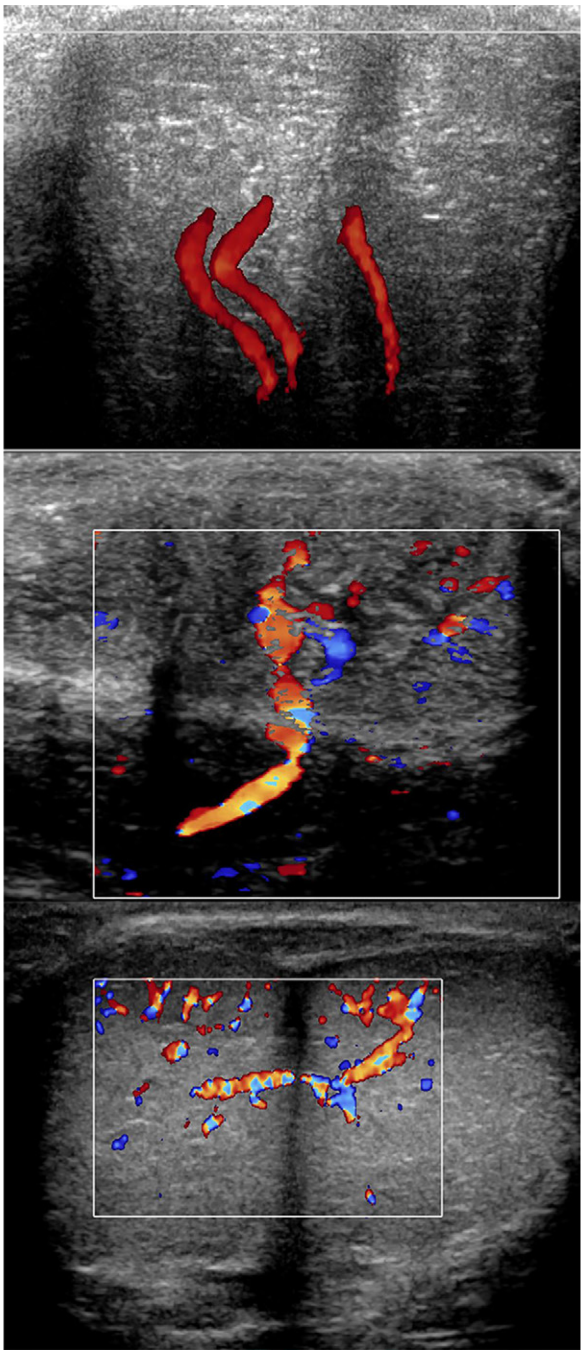

High-frequency US, with a linear transducer and gray-scale, color, and spectral Doppler US techniques, is the primary imaging modality for evaluation of the penis. It can allow delineation of anatomy and assessment of dynamic blood flow; it is easily available and noninvasive or minimally invasive; it is cost effective; and it is well tolerated by patients. US assessment after pharmacologic induction of erection is an additional tool in assessing patients with suspected vasculogenic impotence, and also in selected patients with penile trauma and suspected Peyronie disease. Penile injuries, life-threatening infections, and vascular conditions such as priapism warrant rapid diagnosis to prevent long-term morbidities due to clinical misdiagnosis or delayed treatment. US can facilitate a timely diagnosis in these emergency conditions, even at the point of care such as the emergency department, which can facilitate timely treatment. In addition, color and spectral Doppler US are valuable applications in the follow-up of patients treated with endovascular revascularization procedures for vasculogenic erectile dysfunction. Image optimization and attention to meticulous techniques including Doppler US is vital to improve diagnostic accuracy. Radiologists should be familiar with the detailed US anatomy, pathophysiologic characteristics, scanning techniques, potential pitfalls, and US manifestations of a wide spectrum of vascular and nonvascular penile conditions to suggest an accurate diagnosis and direct further management. The authors review a range of common and uncommon abnormalities of the penis, highlight their key US features, discuss differential diagnosis considerations, and briefly review management.

Introduction

US is the imaging modality of choice for evaluation of the penis due to its superficial location and soft-tissue nature. In addition, US is readily available in most institutions and has widespread patient acceptance, reproducibility, and cost effectiveness compared with other modalities such as MRI. MRI of the penis is primarily used for problem solving and can add value to the US findings in patients with certain abnormalities.

High-resolution gray-scale US, with color and spectral Doppler US, allows the radiologist to evaluate anatomy, demonstrate dynamic variations to blood flow in real time, and assess for vasculogenic impotence (1). Although erectile dysfunction (ED) has been the main indication for penile US and Doppler US studies, the modality has also been shown to be valuable in patients with other abnormalities such as priapism, Peyronie disease (PD), penile trauma, and penile masses. Furthermore, imaging after

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Abbreviations: ED = erectile dysfunction, PD = Peyronie disease

TEACHING POINTS

- The US transducer should be applied gently with minimal compression on the penis, because firm pressure leading to vessel compression can impede blood flow and affect the accuracy of velocity measurements, especially during diastole. In addition, using a copious amount of coupling gel as a standoff gel pad reduces the pressure placed on the skin, which in turn minimizes the compression of the superficially located dorsal vein.
- Doppler US in patients with PD is performed to assess for any associated vascular abnormalities due to fibrous plaques. Doppler US can help to differentiate between veno-occlusive disease (considered to be the primary vascular cause of impotence in PD) and arterial insufficiency, which can direct correct treatment.
- Rapid diagnosis and treatment are important to prevent long-term sequelae such as segmental fibrosis, which can result in permanent ED, mainly due to failure of the veno-occlusive mechanism. In addition, traumatic injuries can also result in arterial insufficiency due to posttraumatic stenosis leading to vasculogenic impotence. In these patients, Doppler US may show a dampened waveform on the affected side, a peak systolic velocity of less than 25 cm/sec, or asymmetric velocities greater than 10 cm/sec between the two sides.
- Penile Mondor disease is usually diagnosed clinically, but when there is diagnostic uncertainty, US can help to exclude mimics such as PD and malignancy or can be used in patients who do not respond to initial conservative management. Findings on US images include a noncompressible vein and echoes within the vein and absent color flow, but increased color flow within the perithrombosed vein from active inflammation may be found.
- Penile Doppler US may suggest the presence of silent coronary artery disease in men presenting with ED, because ED has been reported to be a marker of endothelial dysfunction and an early manifestation of cardiovascular disease.

pharmacologic induction of erection improves the diagnostic accuracy in certain challenging situations such as identification of subtle tears of the tunica albuginea in patients with acute penile trauma (in the absence of priapism) and of small plaques of PD that can be occult in the flaccid state. In this article, the authors provide a comprehensive review of a broad spectrum of penile abnormalities beyond ED seen at US and their anatomic and pathophysiologic characteristics, US and Doppler US techniques, clinical presentations, and treatment.

Penile Anatomy

The penis is composed of three longitudinal cylindrical erectile bodies that include two corpora cavernosa and a corpus spongiosum (Fig 1A). The corpora cavernosa are the main erectile bodies located in the dorsal two-thirds of the shaft, while the corpus spongiosum is located in the ventral one-third of the shaft. The corpus spongiosum contains the urethra and expands anteriorly to form the glans penis distally. The tunica albuginea is a strong nondistendable fascial sheath that encloses the corpora, and typically, it is less than 2 mm thick. The tunica albuginea forms the septum in the median plane that separates the two corpora cavernosa and contains multiple fenestrations in its proximal segment that allow free communication between the sinusoidal spaces on both sides. The deep fascial layer, also known as the *Buck fascia*, is superficial to the tunica albuginea (Fig 1B). The dorsal arteries, veins, and nerves are situated centrally along the penile dorsum, superficial to the tunica albuginea and deep to the Buck fascia. At US, the corpora cavernosa are uniformly hypoechoic in echotexture and the tunica can be seen as a thin echogenic envelope around the corpora. The corpus spongiosum is of relatively higher echogenicity compared with that of the cavernosal bodies. The intercavernosal septum may demonstrate posterior acoustic shadowing and should not be misinterpreted as a calcified plaque from PD.

The penis is supplied by three main paired sources of arterial inflow, namely the dorsal penile artery, the cavernosal artery, and the bulbourethral artery (Fig 2A). These are branches of the internal pudendal artery, which is a branch of the anterior division of the internal iliac artery. The cavernosal artery supplies the corpora cavernosa and is the primary blood source for erection, and the echogenic arterial wall is seen coursing centrally within the cavernosa. The cavernosal artery divides into helicine branches (Fig 2B). The bulbourethral artery supplies the urethra and proximal corpus spongiosum. The dorsal penile artery supplies the glans penis, distal corpus spongiosum, and penile skin. It is important to note the separate blood supply between the corpora cavernosa and the glans penis, because abnormalities of the dorsal penile artery may result in a flaccid glans penis but be accompanied by a normal shaft erection (2).

Anatomic variants are not uncommon at Doppler US evaluation (Fig 3A, 3C). These can be in the form of the intrapenile bifid cavernosal arterial system; the intracavernosal single truncus, with right and left cavernosal arteries originating from the truncus; communication among the cavernosal, dorsal penile, and spongiosal arteries; and in rare cases, communication with the urethral arteries along the shaft of the penis. Identification of these collateral pathways is important because they may substantially affect Doppler US findings during erection and may lead to misinterpretation. For example, the peak systolic velocity of the cavernosal arteries may be substantially lower, despite a full erectile response in the presence of arterial collateral communication.

Venous drainage of the three corpora occurs via the superficial, intermediate, and deep venous systems (Fig 4). The superficial dorsal vein drains the distal portion of the cavernosa, including the skin and glans. It is located on the dorsal surface of the penis, in the dartos fascia, and drains into the external pudendal vein. The deep dorsal vein lies in the median position, underneath the Buck fascia, and receives blood from the circumflex veins of the corpus spongiosum and sinusoidal spaces through the emissary veins of the corpora cavernosa. The deep dorsal vein drains into the prostatic venous plexus and the internal pudendal vein. The superficial and deep dorsal veins are easily visualized at US in the midline of the penile shaft.

Physiology of Penile Erection

Penile erection is a complex phenomenon that is dependent on the coordinated interaction of the arterial, venosinusoidal,

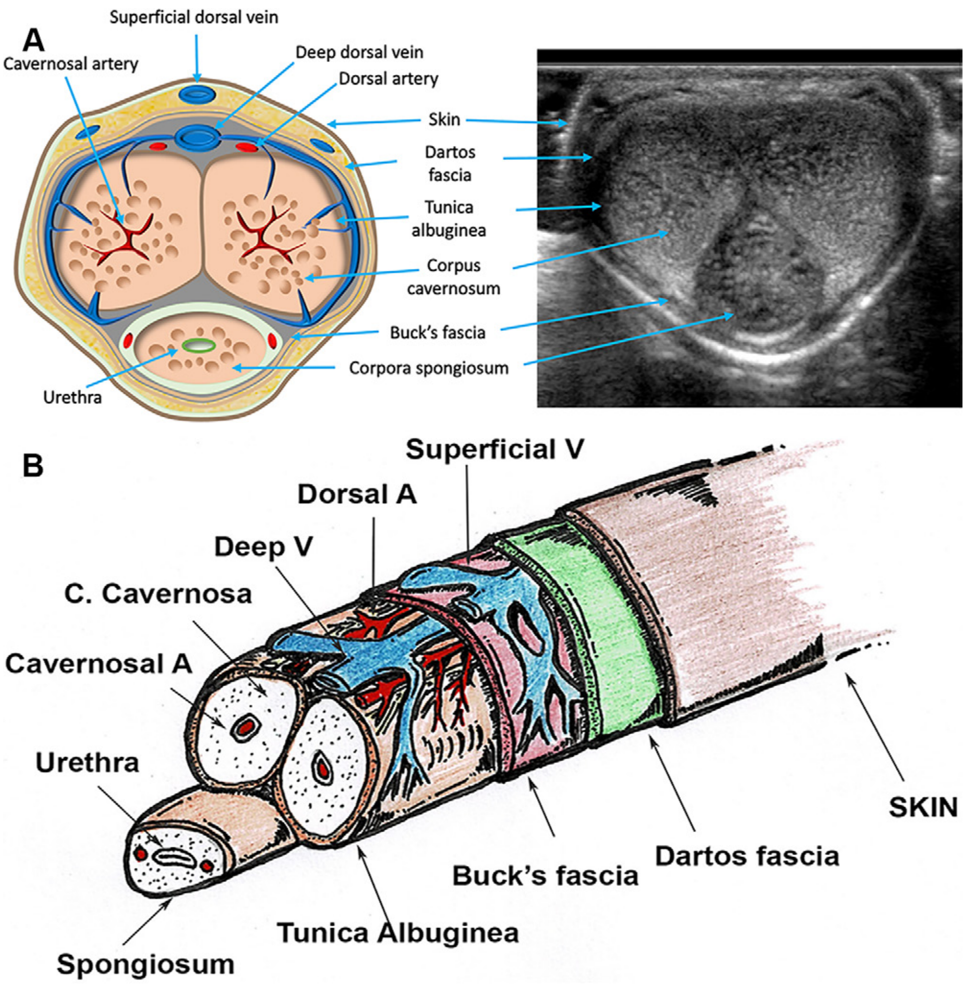


Figure 1. Normal anatomy of the penis. **(A)** Transverse illustration (left) and gray-scale US image (right) show detailed anatomy of the penis. **(B)** Longitudinal illustration of the penis shows the various layers of the penis, including the corporal bodies and vascular anatomy. *A* = artery, *C* = corpora, *V* = vein.

and autonomic nervous systems. In the flaccid state, the smooth muscles are in a tonic state, the cavernous sinusoids are collapsed, and the cavernous venules are open. The emissary veins drain the sinusoidal spaces into dorsal veins, and a low-velocity flow can be detected at US.

Erection of the penis is initiated by neuronal impulses that lead to relaxation of smooth muscle and dilatation of the cavernosal arteries, which in turn causes increased blood flow to the cavernosa. These, together with compression of cavernous venules between dilated sinusoid spaces and the unyielding tunica albuginea, results in reduction of venous outflow. This leads to an imbalance between arterial inflow and venous drainage that causes and maintains turgidity of the corpora and rigid erection. Five stages of erection have been defined: latency, tumescence, full erection, rigid erection, and detumescence (Fig S1). Specific physiologic and Doppler US changes and spectral waveforms (Fig 5) occur during each of these stages. A thorough understanding of the stages facilitates accurate interpretation of the Doppler US findings in patients with penile abnormalities, including suspected ED.

US Protocol and Technique

US is performed in a quiet, warm, and darkened room, so that the patient is relaxed and comfortable. The penis is evaluated in both flaccid and erect states, especially in patients with ED. These studies involve intracavernosal injection of vasoactive drugs. Before starting the procedure, it is mandatory to have a detailed discussion with the patient about the study, including the potential complications (eg, hematoma and priapism) and contraindications (eg, penile implants, significant penile deformity, blood disorders such as sickle cell anemia, and known drug allergies) to intracavernosal injection of vasoactive drugs. In addition, written consent should be obtained. At the authors' institution, the intracavernosal injection is performed by the radiologist performing the US study. In some centers, the referring urologist is usually on site to help with the intracavernosal injection, and the radiologist performs the US study. The latter arrangement may be useful for managing acute complications that may arise from the injection and may also help with clinical evaluation during the study. However, it is important to be cognizant of the additional costs and stress on resources.

The scan is performed with the patient in the supine position, and the penis in anatomic position (ie, lying against the anterior abdominal wall). However, anatomic positioning may not be suitable for patients with obesity or those with smaller genitalia. In such cases, patients can be advised to gently pull the tip of the penis toward their head to achieve the appropriate position for the US study. A high-frequency linear transducer (7–12 MHz) is used, with warm coupling gel. The scan is typically performed on the ventral surface of the penis, but the US probe can be placed on the dorsal

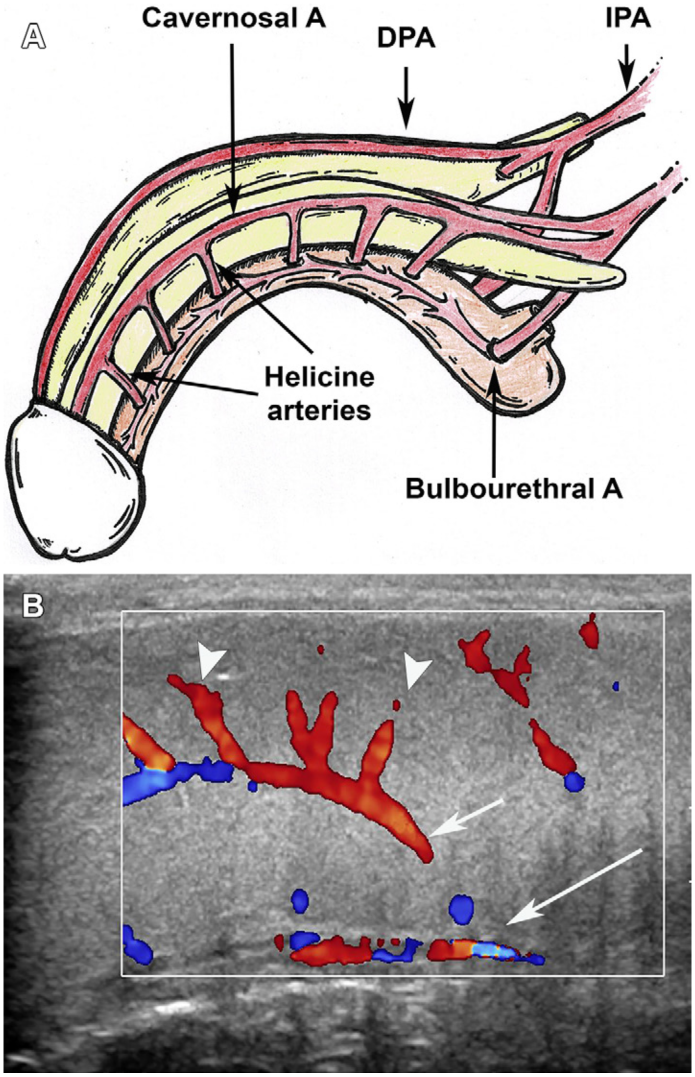


Figure 2. **(A)** Illustration shows the three main arteries supplying the penis: the cavernosal artery, dorsal penile artery *(DPA)*, and bulbourethral artery. These are branches of the internal pudendal artery *(IPA)*. *A* = artery. **(B)** Longitudinal color Doppler US image shows the helicine branches (arrowheads) arising from the cavernosal artery (short arrow). Note the bulbourethral artery (long arrow) in the spongiosum.

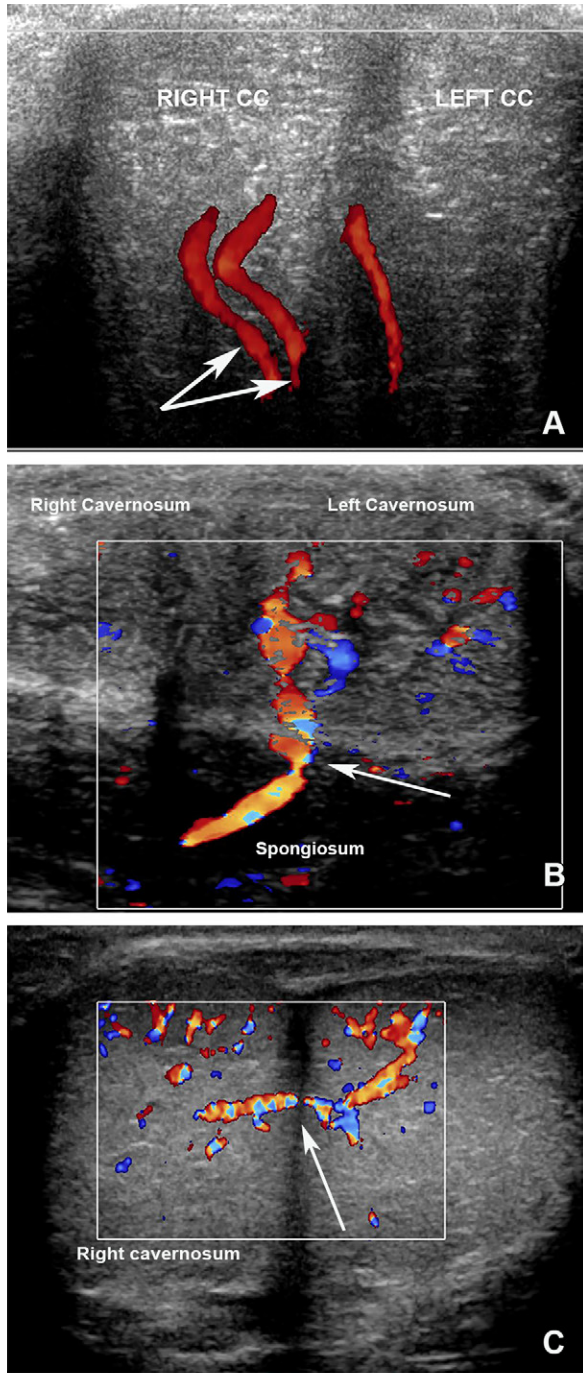


Figure 3. Arterial anatomic variants. Transverse color Doppler US views at the root of the penis show an intracavernosal bifid right cavernosal artery (arrows in **A**), spongiosal-cavernosal arterial communication coursing from the spongiosum into the cavernosa (arrow in **B**), and arterial communication between the right and left cavernosa (arrow in **C**). *CC* = corpus cavernosum.

or lateral surface, if needed. Scanning is performed in both the longitudinal and transverse planes from the base of the penis to the glans (Fig S2).

The US transducer should be applied gently, with minimal compression on the penis, because firm pressure leading to vessel compression can impede blood flow and affect the accuracy of velocity measurements, especially during diastole. In addition, using a copious amount of coupling gel as a standoff gel pad reduces the pressure placed on the skin, which in turn minimizes the compression of the superficially located dorsal vein (Fig 6).

The initial assessment is performed with gray-scale US to assess the anatomy, including cavernosal artery diameter, and to evaluate for the presence of tumors, plaques, focal arterial stenosis, fibrosis, discontinuity of the tunica albuginea, and hematoma. Dynamic assessment such as compression of the superficial dorsal vein is used to differentiate artifacts or sluggish flow from thrombosis. Also, gentle palpation to induce the motion of internal echoes to differentiate between a solid mass and a cyst with internal echoes or an abscess may be useful.

Color Doppler US allows assessment for the presence of blood flow and its direction. The color Doppler US gain and

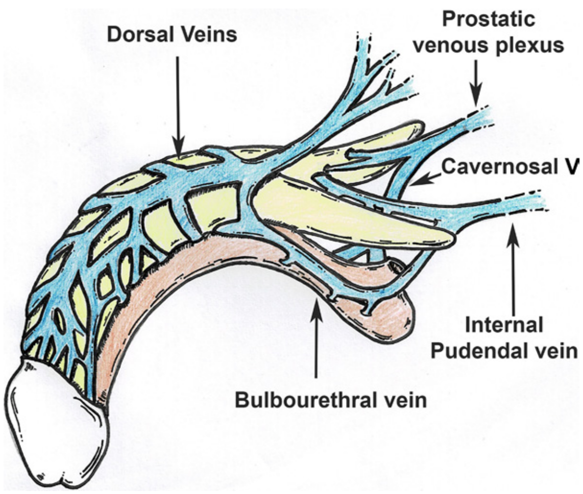


Figure 4. Longitudinal illustration of venous anatomy of the penis shows three main veins draining into the periprostatic plexus and internal pudendal veins. *V* = vein.

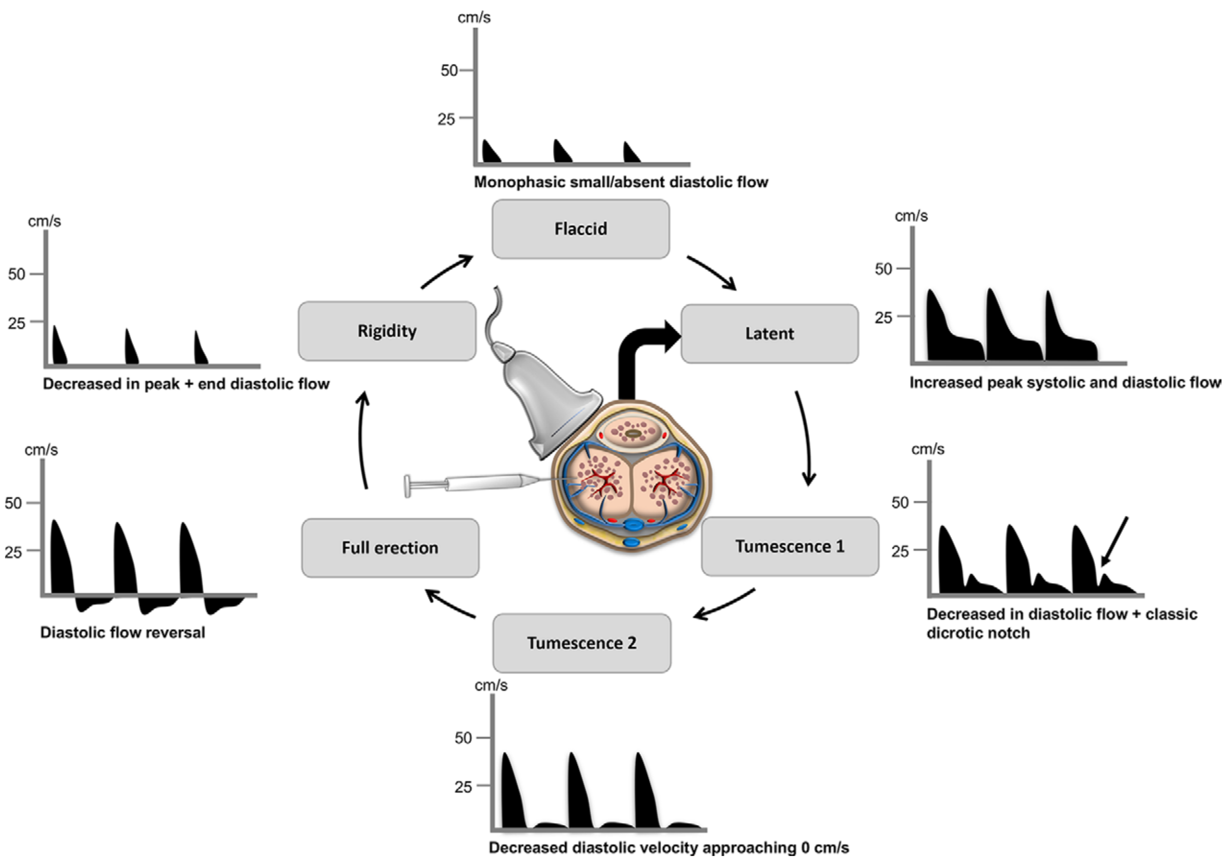


Figure 5. Illustration shows the different phases of erection and the corresponding changes to the spectral Doppler US waveforms during each of these phases.

velocity scale should be optimized to allow detection of slow flow. Beam steering is adjusted to keep the incident angle less than 90° for better color Doppler US flow sensitivity.

Spectral Doppler US filters are set to the lowest level without causing substantial artifacts. For measurement of peak systolic velocity and end diastolic velocity, it is critical that the Doppler US sample angle be kept at less than 60° to avoid erroneous readings (Fig 7A). Although this may be challenging, a possible way to achieve this is by placing the transducer at the base of the penis and performing a heel-toe maneuver using the transducer to obtain the optimal angle required. Finer adjustment can be made using Doppler US angle correction to align the caliper along the longitudinal axis of the vessel for accurate velocity measurements (3,4) (Fig 7B).

Classification of Penile Abnormalities

A wide range of nonvascular and vascular pathologic conditions can involve the penis, including inflammatory, infectious, traumatic, and vascular conditions and those related to ED (Table 1). Some of the abnormalities such as trauma, priapism, and Fournier gangrene need urgent treatment to prevent irreversible ED, and hence, these cases warrant a rapid and accurate imaging diagnosis. Many of these conditions have typical clinical and US presentations. US, with its color and spectral Doppler US capabilities, can facilitate a timely diagnosis.

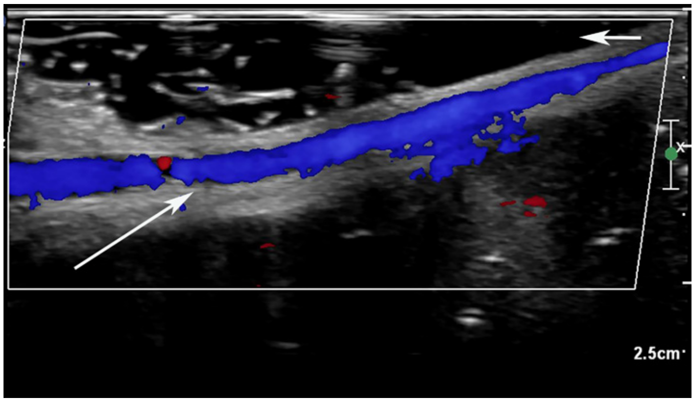


Figure 6. Color Doppler US longitudinal view of a normal dorsal penile vein (long arrow). Note that a copious amount of coupling gel (short arrow) acts as a standoff gel pad to minimize compression of the superficially located vein.

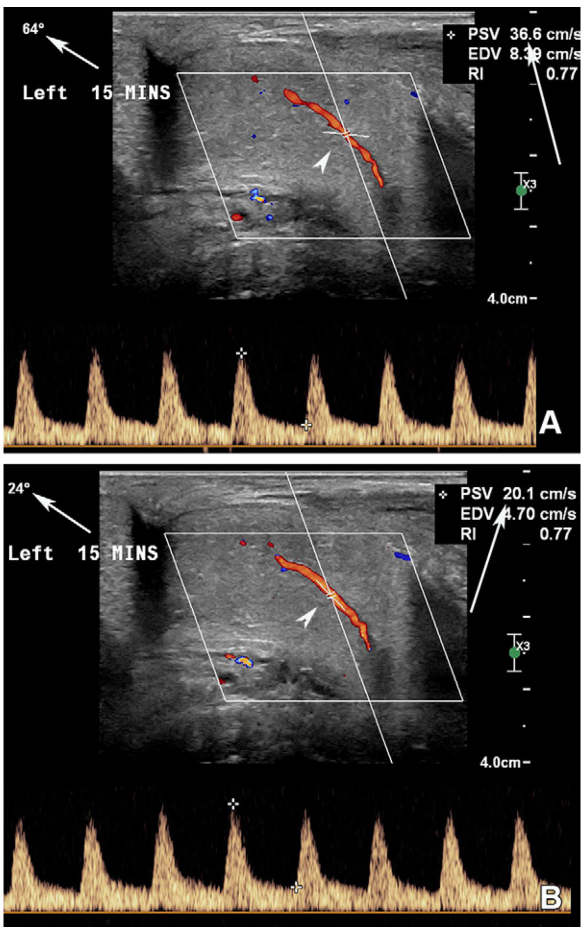


Figure 7. Spectral Doppler US tracing of left cavernosal artery at 15 minutes after intracavernosal injection. **(A)** Note the uncorrected Doppler US angle (arrowhead) of 64° (short arrow), resulting in an apparent normal peak systolic velocity of more than 35 cm/sec (long arrow). **(B)** Doppler US image shows the angle corrected (arrowhead) to 24° (short arrow) by using the heel-toe maneuver of the transducer, resulting in a more accurate peak systolic velocity reading of 20 cm/sec (long arrow) indicative of arterial insufficiency in this patient with ED.

Table 1: Classification of Penile Abnormalities

Nonvascular		
	Peyronie disease	
	Trauma	
		Fracture
		Hematoma
		Arteriovenous fistula
	Infection	
	Tumor	
		Benign tumor
		Malignant tumor
		Tumorlike conditions
	Foreign body	
Vascular		
	Vasculogenic erectile dysfunction	
		Arterial insufficiency
		Venous incompetence
	Venous thrombosis	
	Priapism	
		High flow
		Low flow

Nonvascular Abnormalities

Peyronie Disease

PD, also known as induratio penis plastica, is an idiopathic connective tissue disorder characterized by the formation of fibrous plaques in the tunica albuginea, with induration of the corpora cavernosa or a fibrous cavernositis. Although the exact cause is unknown, in most cases (primary PD), it has been reported to be associated with diabetes, Dupuytren contracture, and cardiac diseases. In addition, repeated trauma to the erect penis is thought to cause localized microtears in the tunica albuginea, resulting in proliferation of fibroblasts, leading to plaque formation within the bilaminar tunica layers (5). Two phases of PD are recognized: the acute inflammatory phase, which is associated with pain and increasing deformity, and the chronic phase, which is associated with ED and deformity but without substantial pain.

The incidence of PD increases with age, and it typically manifests with penile pain, curvature (Fig S3A), and an hourglass deformity. It may be associated with psychologic issues such as depression and poor self esteem (6). In a small minority of patients (10%), there may be spontaneous resolution, but more commonly (50%), it is a progressive deformity in the absence of therapy. In addition to abnormal shaft curvature, other complications include loss of shaft length (with septal fibrosis), veno-occlusive dysfunction (due to intracavernosal fibrosis) and even arterial compromise from larger plaques, which can result in ED.

Diagnosis is frequently based on clinical examination, but US allows confirmation of the diagnosis in doubtful cases. US can be used to localize, determine the activity of,

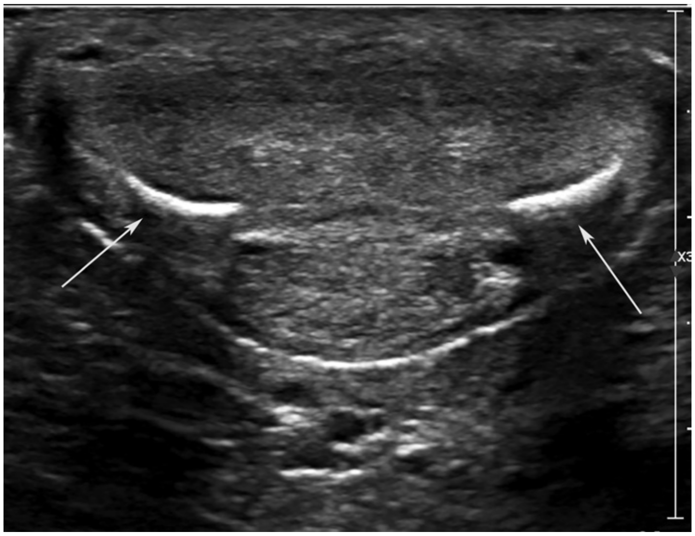


Figure 8. Suspected PD in a 54-year-old man with diabetes and ED. Transverse US image shows echogenic calcified plaque with posterior acoustic shadowing in the paramedian ventral aspect of the tunica albuginea (arrows).

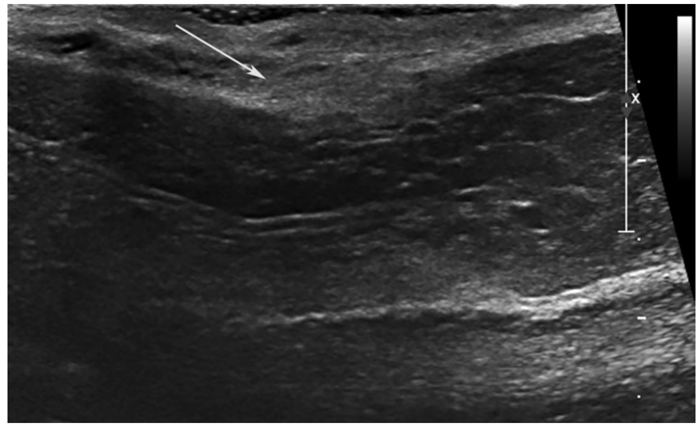


Figure 9. PD in a 48-year-old man with a history of painful erection who presented with a clinically palpable nodule. Longitudinal US image shows a hypoechoic or isoechoic focal nodular thickening of the tunica albuginea (arrow) compared to the adjacent normal portion of the tunica albuginea, consistent with a plaque that is seen in the acute inflammatory phase.

quantify, and estimate the extent and depth of the plaques (7). These factors can help determine the timing and type of treatment. US is comparable to MRI in its ability to show plaques. However, MRI is more accurate for assessing plaque location and thickness and also disease extent and activity (8). Plaques may be seen in the tunica albuginea or intercavernosal septum, which during the chronic phase is often calcified (Fig 8) or may be hypo-, hyper-, or isoechoic (to the normal portion of the tunica albuginea) (Fig 9) in acute to subacute phases. Liu et al (9) reported that identification of plaque at US is improved when the penis is erect compared with identification of it in the flaccid state. Furthermore, pharmacologic induction of erection can be used in patients suspected of having PD when the lesion is not easily identified at clinical examination or at US of the flaccid penis.

Doppler US in patients with PD is performed to assess for any associated vascular abnormalities due to fibrous plaques (10). Doppler US can help to differentiate between veno-occlusive disease (considered to be the primary vascular cause of impotence in PD) and arterial insufficiency, which can direct correct treatment (11). Treatments for plaques include intralesional injections, prosthesis, mechanical shock wave therapy, and surgical interventions such as penile plication (ie, the Nesbit procedure) (Fig S3B) (12). Patients with arterial inflow disease that is confirmed to be due to plaque at Doppler US can benefit from surgical plaque excision and grafting of bovine pericardial tissue.

Differential diagnosis considerations of calcified plaques include vascular calcifications, which when extensive can cause diagnostic confusion, but the location and appearance at US can help to clarify the diagnosis (Fig 10A). In unconfirmed cases, correlative imaging with plain radiography (Fig 10B) or cross-sectional imaging (Fig S4) can help. Furthermore, gas within the penile tissue from intracavernosal injection or due to gas-forming infections can mimic calcified plaques. However, the typical appearance of gas at US (Fig 10C), the clinical history, or a short-term follow-up scan can allow clarification in inconclusive cases.

Trauma

The most common trauma to the penis is acute bending of the erect shaft during sexual intercourse. In the acute setting, patients typically present with a history of a sudden “pop” or “crackling” sensation followed immediately by detumescence, pain, and swelling. US examination may reveal a subcutaneous or intracorporeal hematoma, a hypoechoic breach in the tunica albuginea, a urethral injury, or arterial fistulas to the sinusoid spaces or veins. High-resolution US is the best modality to identify subtle tunica tears, although pharmacologic tumescence with intracavernosal prostaglandin-E1 injection is rarely required (Fig 11A, 11B) to confirm penile fracture. Color Doppler US with squeezing of the penile shaft during the examination forces blood from the cavernosa through the small tear and makes the injury more obvious (13). MRI, when available, can add value in identifying the site and extent of injury to the tunica albuginea and also is useful in differentiating penile fracture from a less serious contusion, which is defined by an intact tunica (14).

Rapid diagnosis and treatment are important to prevent long-term sequelae such as segmental fibrosis, which can result in permanent ED, mainly due to failure of the veno-occlusive mechanism (15). In addition, traumatic injuries can also result in arterial insufficiency due to posttraumatic stenosis leading to vasculogenic impotence. In these patients, Doppler US may show a dampened waveform on the affected side, a peak systolic velocity of less than 25 cm/sec, or asymmetric velocities greater than 10 cm/sec between the two sides.

Treatment is usually surgical evacuation of the hematoma and repair of the tear (Fig 11C), which also reduces the risk of delayed curvature and ED.

Infection

Infective presentations of the penis are wide, ranging from mild balanitis to life-threatening Fournier gangrene. The

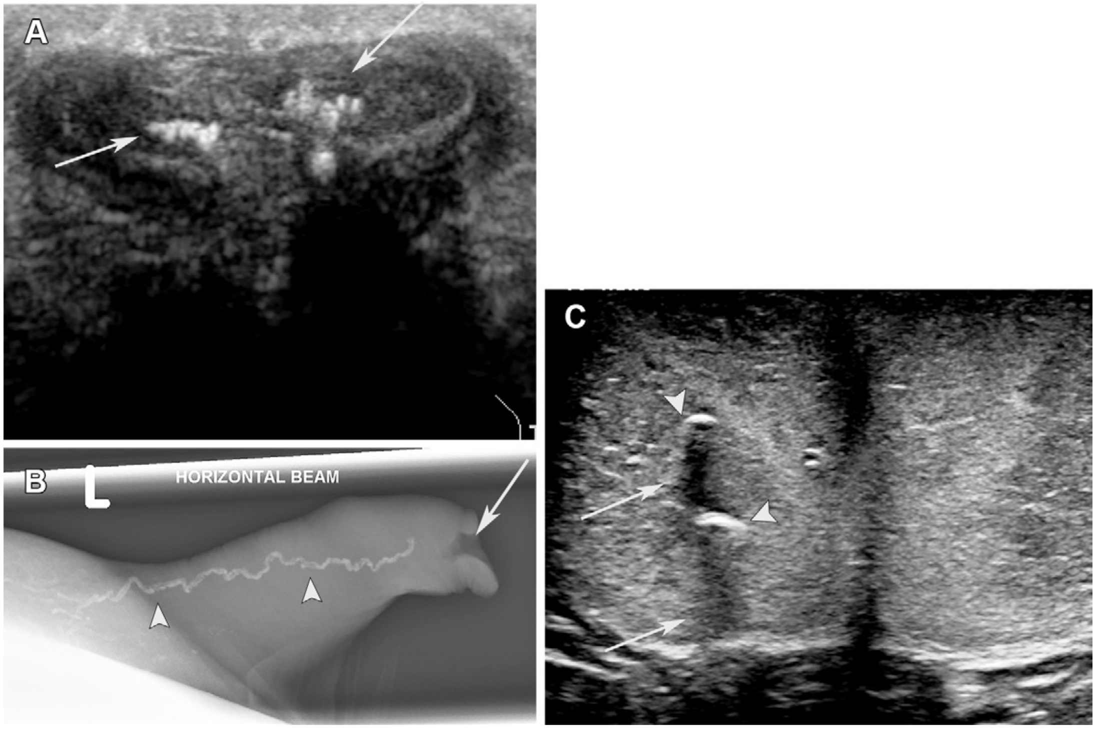


Figure 10. Considerations in differential diagnosis of calcified plaques of PD. **(A)** Transverse US image in a 63-year-old man shows extensive calcifications in the corpora cavernosa on both sides (arrows). The central location and contiguous alignment along and involving the cavernosal artery are indicative of vascular calcifications. **(B)** Radiograph acquired with a mammographic unit in the same patient as in **A** shows vascular calcification (arrowheads). Note the small ischemic ulcer at the glans (arrow). **(C)** Transverse US image shows that gas locules (arrowheads) in the cavernosa from intracavernosal injection can mimic calcified plaque, but the location, reverberation artifacts, and dirty posterior shadowing (arrows) can help to differentiate between them.

Figure 11. Focal tear of the tunica albuginea in a 69-year-old man who presented to the emergency department after hearing a "pop" sound during sexual intercourse, followed by pain and swelling of the penis. **(A)** Transverse US image shows a focal hematoma (arrow) overlying the lateral aspect of the left corpus cavernosum with a possible 2–3-mm breach of the tunica albuginea (arrowhead). **(B)** Transverse US image of the same site after administration of pharmacologic tumescence shows a 6-mm defect (calipers) due to a focal tear of the tunica albuginea, resulting in focal herniation of the cavernosal tissue (arrow). **(C)** Intraoperative photograph shows a 4-mm defect (arrow) in the tunica, which was repaired. Good recovery with no ED was reported at clinical follow-up..

latter may occur as a secondary spread from sexually-transmitted infections, cavernositis, or balanitis but more frequently manifests as the primary idiopathic fulminating gangrene type. Fournier gangrene results in extensive necrotizing inflammation involving the superficial and deep subcutaneous layers, extending beyond the penis, and represents a urologic emergency that is associated with high morbidity and mortality. Risk factors include diabetes mellitus, immunocompromised state, and retained foreign bodies (including iatrogenic and self-implanted foreign bodies).

Diagnosis is usually made on the basis of clinical examination, but US may allow the diagnosis to be established before it is clinically obvious. In the early stage, US may demonstrate edema, hyperemia, and echogenic foci with dirty posterior

Figure 12. Sepsis in an 81-year-old man with diabetes who presented with swelling of the penis and scrotum. **(A)** Longitudinal color Doppler US image shows marked subcutaneous edema with hypervascularity (short arrows) and foci of gas (long arrow) consistent with Fournier gangrene due to gas-forming organisms. **(B)** Axial CT image shows the extent of infection and the distribution of the subcutaneous gas (arrows).

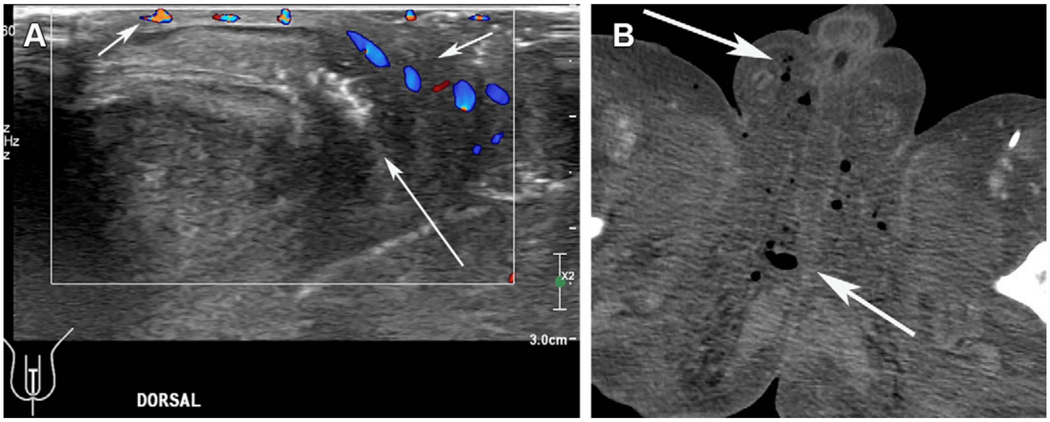
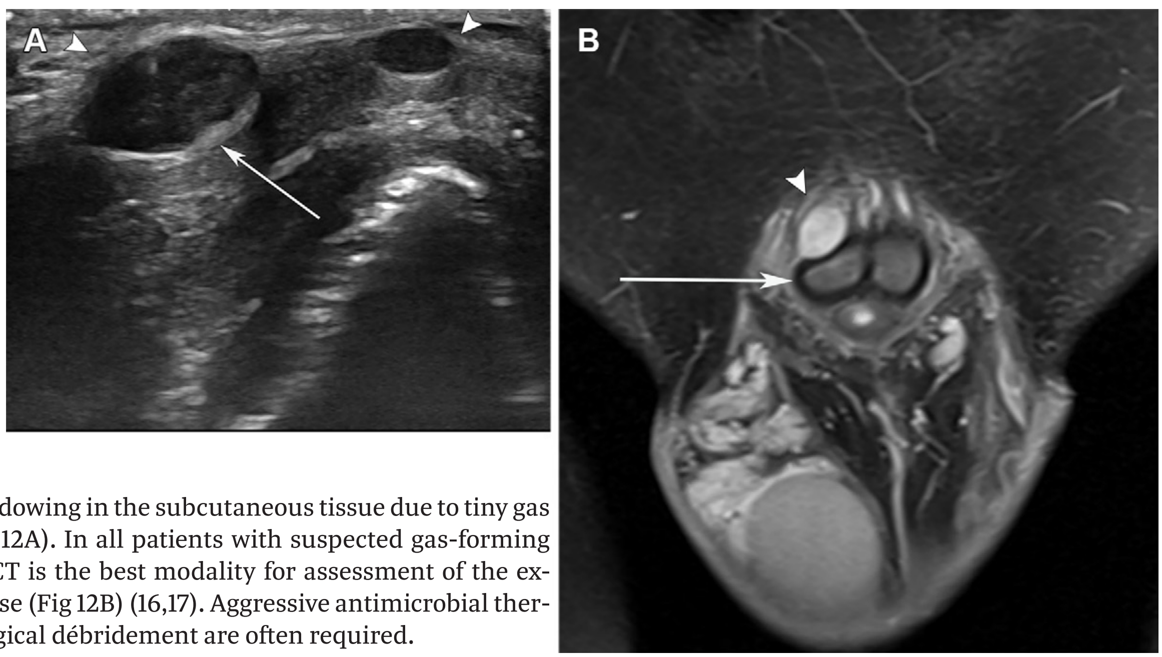


Figure 13. Schwannoma in a 39-year-old man who presented with a painless penile lump of 10 years' duration, with diagnosis confirmed at histopathologic examination of a percutaneous biopsy sample. **(A)** Longitudinal US image shows elliptical hypoechoic lesions (arrowheads) involving or impressing on the tunica albuginea (arrow). **(B)** Coronal contrast-enhanced fat-saturated T1-weighted MR image shows a hyperenhancing lesion (arrowhead) involving or impressing on the tunica (arrow), which remains intact.



acoustic shadowing in the subcutaneous tissue due to tiny gas locules (Fig 12A). In all patients with suspected gas-forming infections, CT is the best modality for assessment of the extent of disease (Fig 12B) (16,17). Aggressive antimicrobial therapy and surgical débridement are often required.

Tumors and Tumorlike Lesions

Various malignant and benign lesions can involve the penis. The most common benign lesion is an epidermoid cyst. Others include median raphe cysts, cysts of the Cowper or Littré glands, schwannomas (Figs 13, S5), and hemangiomas. Malignant tumors include the rare primary squamous cell carcinoma and metastatic lesions of urogenital or rectal origin.

US is more accurate and superior to clinical examination in assessment of the extent of the tumor and identification of pathologic lymph nodes (18). However, MRI is better than US for differentiation of benign from malignant lesions or pseudotumors, assessment of tumor extent, and locoregional tumor staging (14).

US features of benign disease include the presence of an intact tunica albuginea and a lesion that is well circumscribed. Cysts can be unilocular or multilocular (Fig 14) with or without internal echoes. Malignant primary tumors with ulceration can demonstrate hyperechogenic foci due to entrapped gas bubbles. Metastatic lesions of the penis (Fig 15) tend to be located in the middle of the cavernosa or spongiosum and appear irregular and slightly heterogeneous. Infiltration of the tunica albuginea with malignant tumors is seen as an interruption of the otherwise thin echogenic line.

Tumor mimics such as inflammatory lesions of PD, foreign body granulomas, calcinosis cutis, gouty tophi (19) (Fig

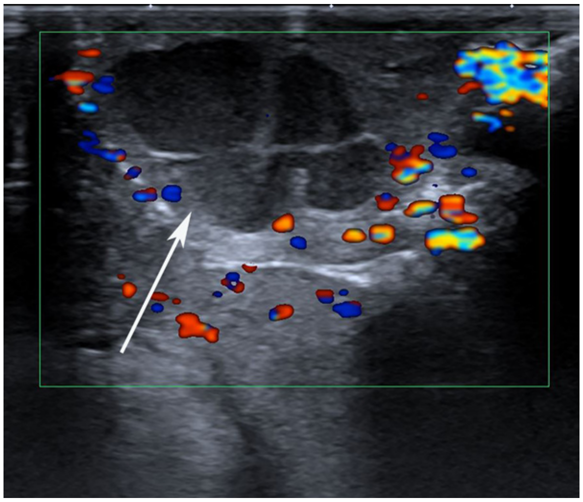


Figure 14. Incidental penile painless mass of a few years' duration in a 94-year-old man. Transverse color Doppler US image shows a multilocular cyst (arrow), with no internal color flow, within the right corpus cavernosum. The nature of the lesion was not confirmed because the patient declined intervention.

16), and posttraumatic fibrosis are some of the differential diagnosis considerations. Accurate differentiation is usually achieved on the basis of clinical history and physical examination alone, with US rarely necessary for diagnosis.

Foreign Body

A wide variety of foreign bodies and inflammatory changes related to the implanted foreign body can be encountered on US studies. The foreign body can be iatrogenic (urinary catheters, urethral stents, or erection devices) or self-implanted under the skin of the penis for sexual enhancement, a practice known as "pearling" (20). Clinical history may be absent to minimal in the latter situation but more obvious in iatrogenic cases. US can help to localize, characterize, and also guide removal (self-implanted) or repositioning (malpositioned urinary catheter) of the foreign body. Self-implanted foreign bodies are often inserted under nonsterile conditions, and patients can present with an acute infection, abscess, or inflammatory granuloma (Figs 17, S6).

At US, the subcutaneous foreign body is typically seen as an echogenic focus with posterior acoustic shadowing (21). At color Doppler US, there may be increased vascularity in the adjacent subcutaneous tissue due to inflammation. Conditions to consider in the differential diagnosis include PD plaques, fibrosis, calcinosis cutis, and rarely, gouty tophi. The patient's clinical history typically suggests the diagnosis; however, US can be complementary when the patient is unable to provide a complete history.

Vascular Abnormalities

Vascular abnormalities that can affect the penis include vasculogenic ED (due to arterial insufficiency, venous incompetence, or mixed disease), priapism, and thrombosis, especially venous thrombosis.

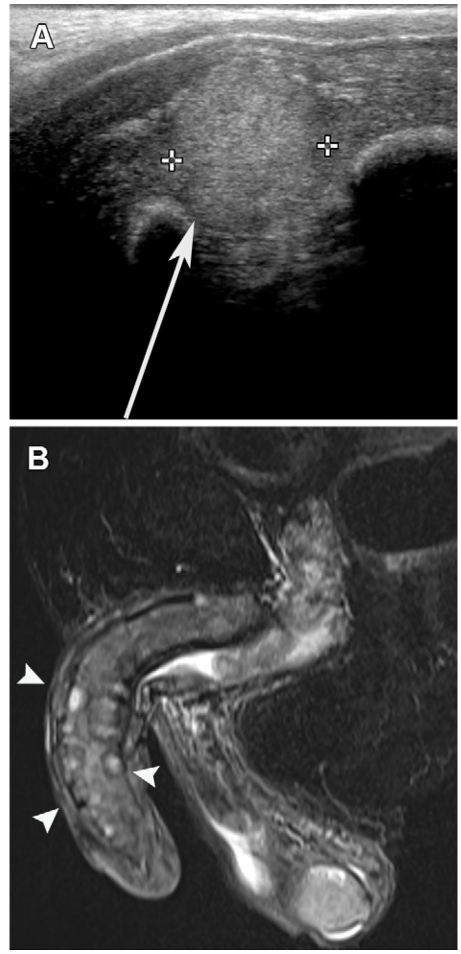


Figure 15. Metastatic mucinous adenocarcinoma of the urinary bladder in a 69-year-old man who presented with painless penile lumps of few months' duration. **(A)** Longitudinal US image shows an echogenic well-defined nodule within the corpus cavernosum (arrow). Several other mixed echogenic lesions were also demonstrated (not shown), some with mass effect on the tunica. **(B)** Coronal short-tau inversion-recovery MR image shows multiple mixed-signal-intensity metastases (arrowheads).

Venous Thrombosis

Venous thrombosis of the penis can involve the superficial or the deep dorsal vein or, in rare cases, there may be partial segmental involvement of the corpus cavernosum. Thrombosis of the superficial vein is more common and is well reported as penile Mondor disease. Penile Mondor disease is typically benign and was first reported by Helm et al (22) in 1958. It manifests as a painless palpable cordlike induration on the dorsal and dorsolateral aspects of the penis due to thrombophlebitis of the superficial vein (23). In most cases, no obvious cause is demonstrated. However, some of the risk factors include penile trauma, vigorous sexual activity, vasculitis, prolonged sitting, hypercoagulation, and urogenital infection.

Penile Mondor disease is usually diagnosed clinically, but when there diagnostic uncertainty, US can help to exclude

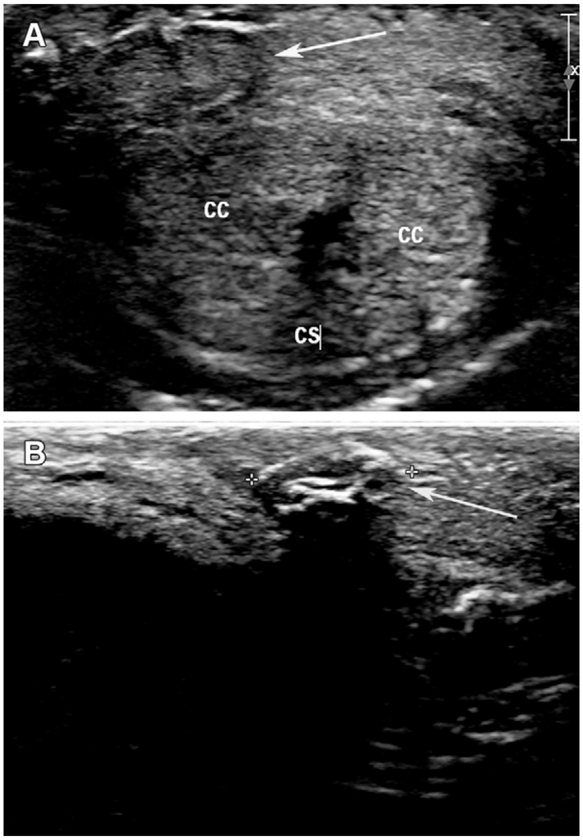


Figure 16. Painless hard lumps of a few years' duration in a 72-year-old man with a history of chronic gout, with marked skeletal manifestations. No histologic evaluation was performed because the patient declined intervention. **(A)** Transverse US image shows a mixed echogenic nodule (arrow) within the subcutaneous tissue or Buck fascia on the right dorsal aspect of the penis abutting the underlying tunica albuginea. **(B)** Longitudinal US image shows another nodule but with calcification in the subcutaneous tissue (arrow). *CC* = corpus cavernosum, *CS* = corpus spongiosum.

Figure 17. Multiple hard palpable penile nodules in a 44-year-old man who had a history of injecting unknown foreign material many years earlier. Transverse US image shows several echogenic foci (arrows) in the Buck fascia, some with posterior acoustic shadowing, that were suspected to be chronic inflammatory nodules related to previous self-injections for augmentation.

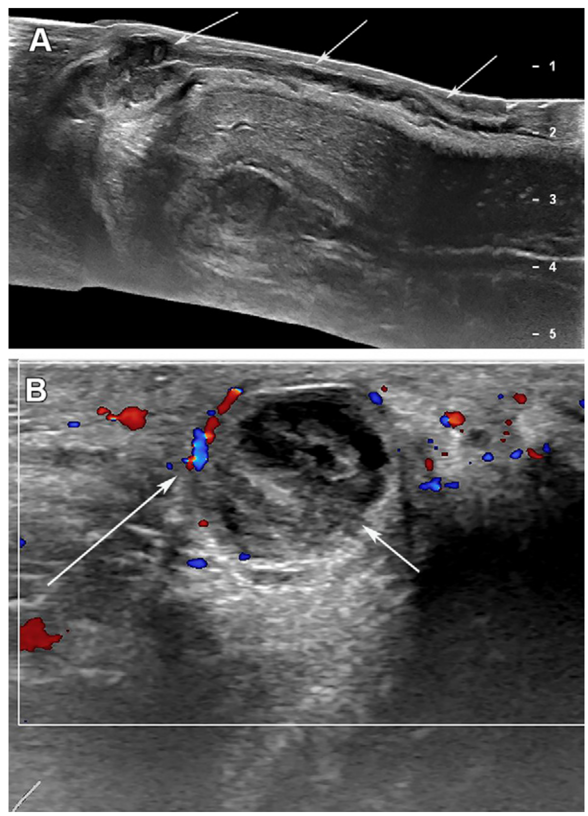


Figure 18. Thrombophlebitis in a 47-year-old man who presented with a mildly tender lump at the base of the penis of 2 weeks' duration. **(A)** Longitudinal panoramic US image shows a markedly distended superficial dorsal penile vein with an occlusive thrombus (arrows). **(B)** Transverse color Doppler US image shows an occlusive thrombus (short arrow) within the distended thick-walled dorsal vein and perivenular hypervascularity (long arrow) suggestive of thrombophlebitis.

mimics such as PD and malignancy or can be used in patients who do not respond to initial conservative management. Findings on US images include a noncompressible vein and echoes within the vein and absent color flow, but increased color flow within the perithrombosed vein from active inflammation may be found (Fig 18).

In addition, US can help to assess for tears of the corpora cavernosa or tunica albuginea in patients with a history of trauma. Penile Mondor disease is usually managed conservatively, with no medications, and typically resolves in 4–8 weeks, but occasionally, nonsteroidal anti-inflammatory drugs (NSAIDs) are prescribed for 4–6 weeks. Antimicrobial and anticoagulation therapies have limited to no role in treatment.

Deep dorsal vein thrombosis is uncommon compared with superficial vein thrombosis (24) and usually manifests as pain during erection. With delayed diagnosis and treatment, it can cause serious complications such as ischemia and priapism. Potential causes include coagulation disorders and malignancy, and more recently, COVID-19–related cases

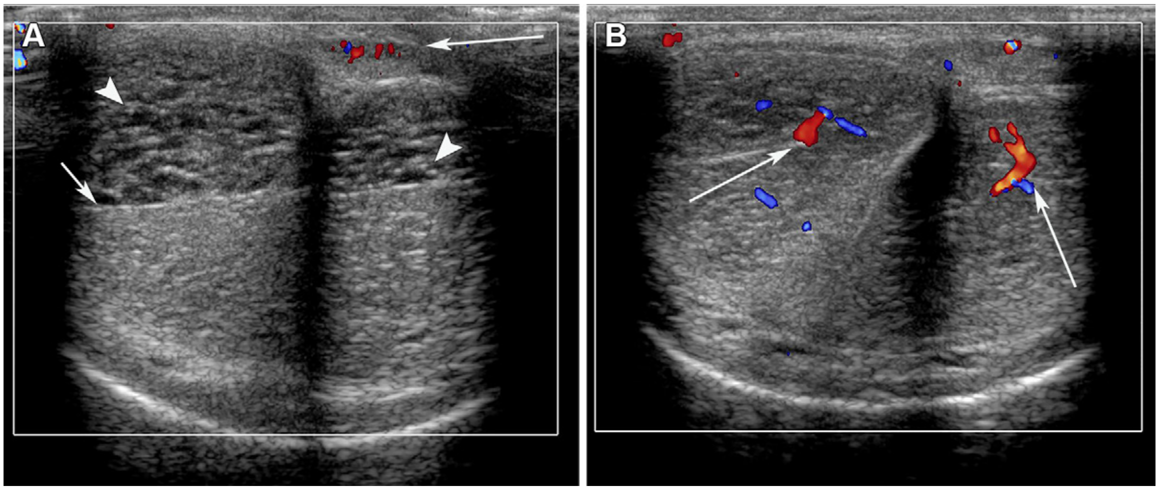


Figure 19. Priapism, increasing pain, and a rigid penis in a 37-year-old man 3 hours after pharmacologic induction of erection with intracavernosal injection of prostaglandin E1 for evaluation of ED. **(A)** Transverse color Doppler US image shows absent color flow in the dilated sinusoids (arrowheads) of the corpora cavernosa and a hematocrit level (short arrow) from stagnant blood. Note preserved flow in the dorsal penile artery (long arrow). **(B)** Transverse color Doppler US image acquired immediately after aspiration of 2–3 mL of blood from the cavernosa using a 25-gauge needle shows return of vascularity in the corpora cavernosa (arrows) and decompressed sinusoidal spaces. Immediate detumescence occurred after the aspiration.

have been reported as extrapulmonary manifestations due to hypercoagulopathy (25,26). US can easily be used to identify deep vein thrombosis, and the features are similar to those seen in patients with superficial vein thrombosis.

Partial segmental thrombosis of the corpus cavernosum is rare and predominantly occurs in young men. Most reported cases are idiopathic in nature. However, bicycle riding, perineal trauma, and hematologic conditions have been reported as risk factors. Patients typically present with severe pain and perineal swelling. Thrombosis is often unilateral and located in the proximal portion of the cavernosum. Ilicki et al (27) postulated that, first, a transverse membrane or fibrous connective tissue septum dividing the corpus into a proximal and distal portion acts as a mechanical barrier to the venous drainage resulting in stasis, and second, a triggering event (microtrauma) is required for thrombosis. On US images, the affected proximal segment of the cavernosum is enlarged, with heterogeneous echoes and absent color flow in the thrombus. Contrast-enhanced MRI allows confirmation of the diagnosis because it is better than other modalities at delineating the segmental thrombosis, helps in determining the age of the thrombus, and may also demonstrate a thickened septum in the affected cavernosum (28).

Priapism

Priapism is defined as persistent erection of the penis lasting for more than 4 hours. It is broadly classified as low flow (ie, veno-occlusive or ischemic) or high flow (ie, arterial or nonischemic) priapism.

The low-flow or venous type is more common and manifests as painful erection. It is a medical emergency caused by reduced or absent venous drainage. A blood clot in the corpora can often be visualized on US images. Low-flow priapism is often idiopathic but is also often associated with hypercoagulability states such as sickle cell anemia, spinal cord stenosis, the use of a variety of drugs including sildenafil (phosphodiesterase inhibitors), or occasionally, as a complication of intracavernosal injection of prostaglandin E1 for assessment and treatment of ED (Fig 19). Malignant tumors (Fig 20), due to either direct invasion from the bladder or prostate or metastatic disease, can also result in low-flow priapism. US may demonstrate distention of the whole or part of the corpora by a relatively hyperechoic clot. On color Doppler US images, there is a persistent absence of blood flow or a high-resistance flow pattern in the cavernosal arteries (29) or a resistive index greater than 1 (absent diastolic flow), which has been shown to be an objective predictor of priapism (30,31). However, imaging appearances do not usually influence management of low-flow priapism, and US is not routinely employed. Initially, these patients may respond to fine-needle aspiration of a small amount of blood from the corpora cavernosa to decompress the sinusoid spaces or pharmacologic reversal with injection of an α-adrenergic agonist, which can relieve the venous outflow obstruction. If this fails, surgical decompression is performed by means of cavernosal shunting. If treatment is delayed or if low-flow priapism is left untreated, degeneration of the penile tissue and even widespread necrosis occurs, resulting in irreversible ED and scarring (32).

High-flow or arterial priapism is caused by increased arterial flow and is typically due to an arteriosinusoidal, arteriolacunar, or arteriovenous fistula resulting from severe pelvic trauma or surgery. As the venous outflow is preserved from the cavernosal space, the patient develops only a partial erection with no substantial acute pain. Persistent venous outflow prevents complete erection, stasis, and hypoxia. If high-flow priapism is suspected, Doppler US studies can demonstrate the characteristic color blush from the lacerated (Fig 21A) cavernosal artery and high-velocity turbulent flow (33). However, to date and to our knowledge, no large published studies are available, and it is likely that not all fistulas are detected at

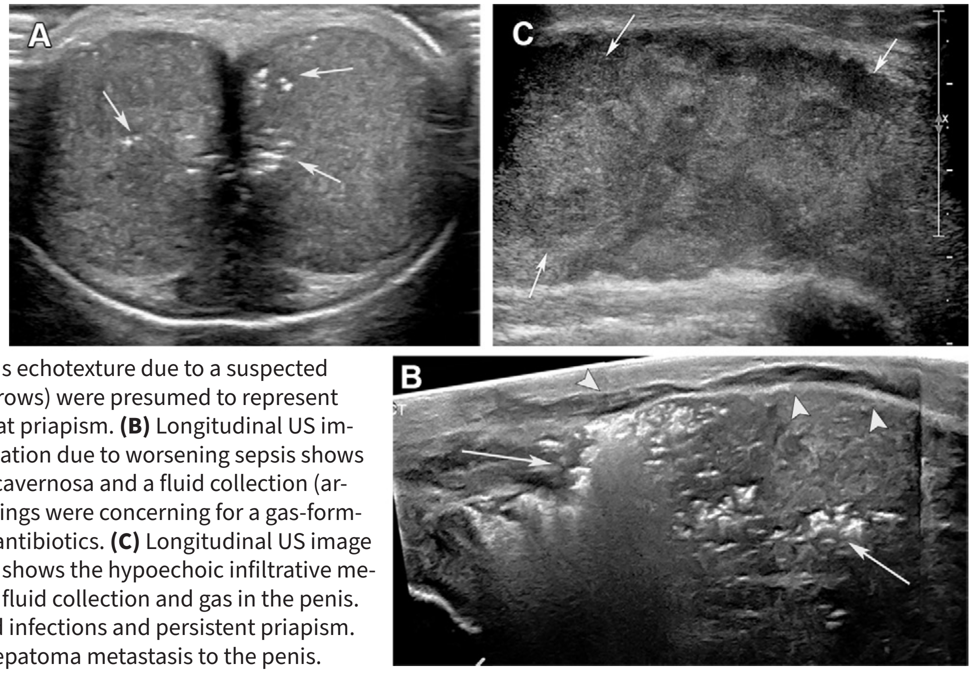


Figure 20. Metastasis of hepatoma to the penis in a 70-year-old man who presented with a 3-day history of painless priapism. **(A)** Transverse US image shows markedly enlarged corpora cavernosa with heterogeneous echotexture due to a suspected metastatic infiltrative tumor. Echogenic foci (arrows) were presumed to represent iatrogenic gas from attempted aspiration to treat priapism. **(B)** Longitudinal US image acquired 12 days after the initial US examination due to worsening sepsis shows extensive gas (arrows) in the enlarged corpora cavernosa and a fluid collection (arrowheads) in the subcutaneous tissue. The findings were concerning for a gas-forming infection, and the patient was treated with antibiotics. **(C)** Longitudinal US image acquired 2 months after the initial examination shows the hypoechoic infiltrative metastasis (arrows) and resolution of the previous fluid collection and gas in the penis. The patient underwent penectomy for repeated infections and persistent priapism. Histologic examination confirmed infiltrative hepatoma metastasis to the penis.

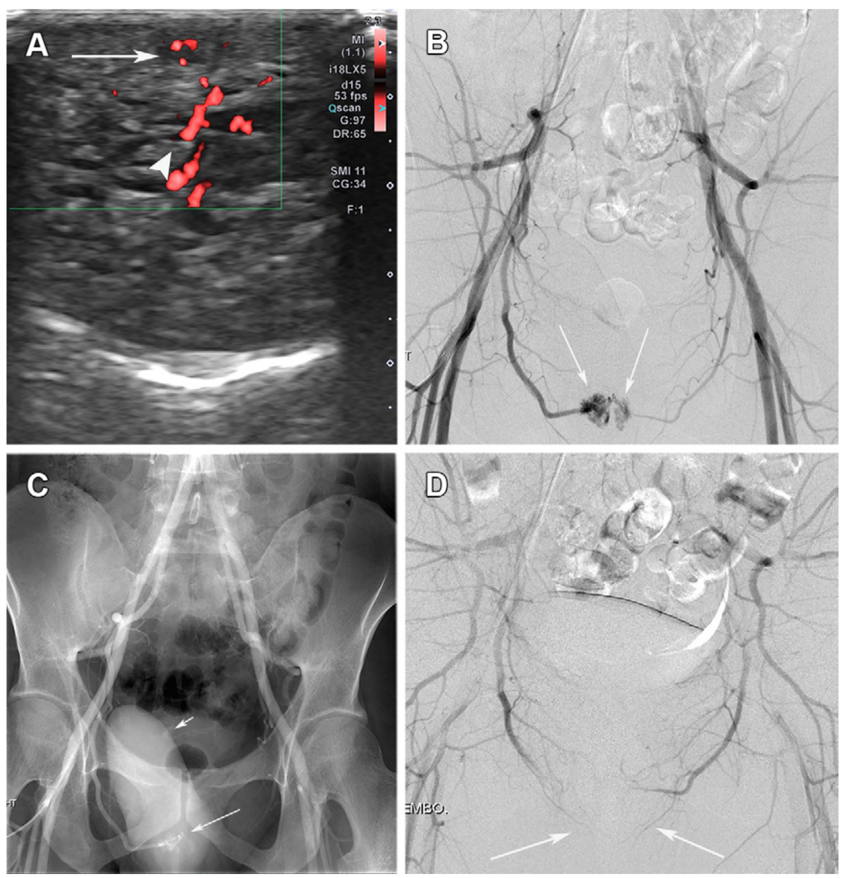


Figure 21. Lacerated right cavernosal artery in a 30-year-old man with a history of injury to the perineum while playing cricket who presented with a 3-day history of painless priapism. **(A)** Transverse color Doppler US image shows a leash of vessels (arrowhead) in the corpora cavernosa suspicious for an arteriosinusoidal fistula (arrow). **(B)** Digital subtraction pelvic angiogram shows the blush from lacerated vessels on both sides (arrows). **(C)** Coronal unsubtracted conventional pelvic angiogram shows a blush due to contrast material leakage from a lacerated right cavernosal artery (long arrow). Also, note that the penis is in an erect state (short arrow). **(D)** Digital subtraction pelvic angiogram was obtained after superselective embolization of the cavernosal arteries with gelfoam slurries resulted in hemostasis (arrows). Substantial detumescence occurred immediately on the table.

Doppler US, and many may spontaneously resolve. Conventional arteriography (Fig 21B, 21C) remains the standard of care for diagnosis, and transarterial embolization (Fig 21D) is the treatment of choice (34) and can be performed using autologous blood clots or temporary embolic agents such as gelatin foam (Gelfoam; Pfizer). Follow-up color Doppler US allows confirmation of successful embolization by demonstrating the disappearance or reduction in size of the fistula.

Erectile Dysfunction

ED has a high prevalence and incidence worldwide and can substantially affect physical and psychosocial health. ED can

Table 2: Doppler US Diagnostic Criteria for Vasculogenic Erectile Dysfunction

Doppler US Parameters and Criteria	Interpretation
Peak systolic velocity (cm/sec)	
>35	Normal arterial inflow
25–35	Indeterminate
<25	Arterial insufficiency
Differential of >10 between sides	Arterial insufficiency on the side with lower peak systolic velocity
End-diastolic velocity (cm/sec)	
<5	Normal veno-occlusive mechanism
>5	Venous incompetence, no arterial inflow disease (peak systolic velocity >35 cm/sec)
Resistive index	
>0.9	Normal
<0.8	Venous incompetence with other supportive findings
Complementary: parvus tardus waveform	Suspect proximal arterial stenosis

have vascular and nonvascular causes (eg, neurogenic, psychogenic, or hormonal), and penile US with Doppler US is an excellent tool for identification and classification of organic causes of ED. However, with the introduction of oral phosphodiesterase inhibitors, Doppler US studies for evaluation of ED are used substantially less frequently and are indicated mainly in patients who do not respond to a trial of medication or for whom there is high suspicion for a remediable vascular cause that is amenable to intervention (35–37).

In addition, penile Doppler US may suggest the presence of silent coronary artery disease in men presenting with ED, because ED has been reported to be a marker of endothelial dysfunction and an early manifestation of cardiovascular disease (38,39).

Doppler US assessment can accurately suggest the diagnosis of vasculogenic impotence due to arterial or venous disease or can exclude a vascular cause. Pharmacologic induction of erection is necessary for accurate assessment of the hemodynamic changes that occur during erection that are reflected on the Doppler US images.

After the initial gray-scale and Doppler US evaluation of the penis, erection is induced by intracavernosal injection of a vasoactive drug into the lateral aspect of one of the cavernosa along the proximal one-third of the penis. Prostaglandin E1 is the most common vasoactive agent used, with a dosage of 10–20 µg (40).

The color and spectral Doppler US interrogation of the cavernosal arteries should be initiated within 2 minutes of injection of prostaglandin E1, and assessment should be performed every 5 minutes, up to 20–25 minutes (Fig S7). Assessment at 30 minutes or more is sometimes indicated to ensure that the maximum pharmacologic effect has been reached. Sampling the cavernosal arteries at the base of the penis where the vessels angle posteriorly toward the penis is recommended, and readings at this site have been shown to be more accurate than those at other sites.

The expected hemodynamic changes and the associated spectral Doppler US waveforms must be correlated with the phase of erection to improve the diagnostic accuracy of the study (Figs 5, S1). Peak systolic and end-diastolic velocity in centimeters per second and resistive indices are measured and recorded meticulously in a structured reporting template. There are defined Doppler US criteria for normal and vasculogenic ED (Table 2). The peak systolic velocity corresponds to the maximum flow rate during systole and is the most accurate indicator of arterial disease. A peak systolic velocity reading of more than 35 cm/sec allows exclusion of significant arterial stenosis. A reading of less than 25 cm/sec is suggestive of arterial insufficiency, but a reading of 25–35 cm/sec is nonspecific and considered to be indeterminate. In addition, a difference in peak systolic velocity of greater than 10 cm/sec between the two cavernosal arteries is considered to be abnormal, and an underlying arterial disease is assumed on the side with the lower reading (6,41,42). A parvus tardus pattern of flow or systolic flow reversal in the cavernosal artery is suggestive of a more proximal arterial stenosis such as that in the internal pudendal artery. This should be highlighted in the Doppler US report because some of these patients may be suitable for endovascular treatment. Endovascular balloon angioplasty or stenting of the internal pudendal artery (Fig 22) has been shown to be a feasible and safe treatment option that leads to sustained improvement of ED in highly selected patients, according to some studies (43). Furthermore, Doppler US can be used as a noninvasive follow-up tool for early identification of stent stenosis or occlusion (Fig 22).

Venous leakage as the cause of vasculogenic impotence can be diagnosed on Doppler US images, with end-diastolic velocity being the best indicator. In a normal erectile response, minimal to absent flow should be detected with the cavernosal arteries during diastole at 15–20 minutes after injection of vasoactive drugs. In addition, a flow reversal during diastole virtually excludes the possibility of a clinically significant venous leak. In the presence of a normal arterial response (peak systolic velocity >35 cm/sec), a persistent end-diastolic velocity reading of more than 5 cm/sec during all phases of erection is suggestive of venous incompetence (44). With an increase in end-diastolic velocity, a decrease in the resistive index to below 0.80 is also seen in patients with

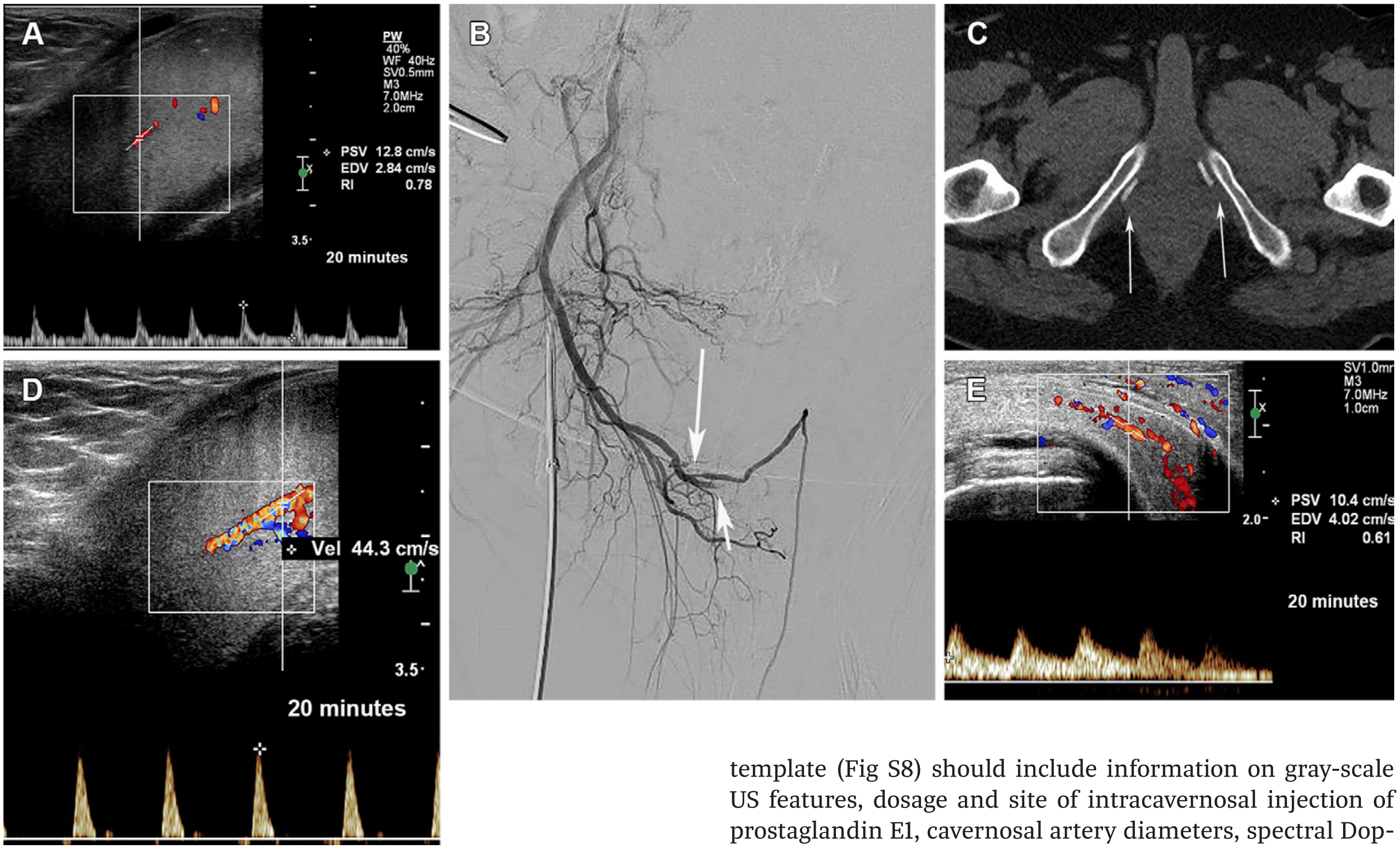


Figure 22. ED in a 69-year-old man with diabetes, ischemic heart disease, and hypertension who underwent an unsuccessful trial of sildenafil treatment. **(A)** Longitudinal spectral Doppler US tracing image at 20 minutes shows features of arterial insufficiency. **(B)** Digital subtraction angiogram of the right internal iliac artery shows an occluded inferior branch (short arrow) and 80% stenosis of the superior branch (long arrow) of the internal pudendal artery. Similar findings were seen on the left side (not shown). The stenosis was treated with drug-eluting stents on both sides. **(C)** Axial CT image shows bilateral stents in the internal pudendal artery (arrows). **(D)** Longitudinal spectral Doppler US tracing image acquired 2 months after stent placement shows a normal finding with peak systolic velocity of greater than 35 cm/sec. The patient reported satisfactory erectile function. **(E)** Longitudinal spectral Doppler US tracing performed 6 months after stent placement shows a markedly reduced peak systolic velocity, which was persistently less than 25 cm/sec, and a parvus tardus pattern suggestive of stent occlusion or stenosis. The patient reported a return of ED similar to that at presentation. *EDV* = end-diastolic velocity, *PSV* = peak systolic velocity, *RI* = resistive index.

a venous leak. In addition, a continuous flow in the deep dorsal vein can be seen in all phases in these cases, but this is not mandatory for making a diagnosis. It is important to be aware of a potential false-positive diagnosis of venous leakage in young men with anxiety, because an increase in the sympathetic drive can result in inadequate sinusoidal smooth muscle relaxation, resulting in failure of the veno-occlusive mechanism. Additional injection of an intracavernosal α-adrenergic antagonist such as phentolamine may help to avoid this pitfall (45).

Some patients have mixed arterial and venous disease leading to ED. However, diagnosis of mixed vasculogenic impotence on Doppler US images is challenging, because poor arterial inflow or arterial response (peak systolic velocity <25 cm/sec) does not fully engage the veno-occlusive mechanism, and hence these patients may have persistent high end-diastolic flow, even in the absence of a substantial venous leak.

Standardized structured reporting for Doppler US studies of ED is essential to ensure high diagnostic accuracy and communication with the referring clinician. The reporting template (Fig S8) should include information on gray-scale US features, dosage and site of intracavernosal injection of prostaglandin E1, cavernosal artery diameters, spectral Doppler US waveform patterns, Doppler US parameters recorded at regular intervals, subjective scoring of tumescence by the patient on a scale of 1–10, objective gradation of penile rigidity, deformities, and complications related to the study.

Conclusion

US is typically the first-line imaging tool to evaluate the penis. It provides valuable information for detection, characterization, and management of penile pathologic conditions. Penile Doppler US studies with pharmacologic induction of erection continue to be crucial in the evaluation of patients with suspected vasculogenic impotence who have not responded to medical treatment. Furthermore, Doppler US can be important in the follow-up of patients to assess response to treatment and identify treatment failure. Radiologists should be familiar with Doppler US techniques, understand the limitations of the modality, and be able to interpret the wide spectrum of vascular and nonvascular abnormalities that are encountered on US images.

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