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CLINICAL IMPLICATIONS OF PENILE DOPPLER ULTRASOUND IN ERECTILE DYSFUNCTION: A NARRATIVE REVIEW OF TECHNIQUE, INTERPRETATION, PITFALLS AND EMERGING APPLICATIONS

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ABSTRACT
Erectile dysfunction (ED) affects a large and growing proportion of men worldwide, and vasculogenic mechanisms account for most organic cases. Penile Doppler ultrasound (PDUS), which combines pharmacologically induced erection with high-frequency duplex imaging, is the most widely used test of penile haemodynamics, yet its technique, diagnostic thresholds and indications vary considerably between centres. This narrative review, prepared in line with the Scale for the Assessment of Narrative Review Articles (SANRA), synthesises literature from PubMed/MEDLINE, Scopus, Web of Science and Google Scholar (1985–2026) together with current international guidelines. We describe the physiological basis of the Doppler parameters, guideline positions and indications, and a rigidity-based protocol incorporating vasoactive redosing and audiovisual sexual stimulation. A peak systolic velocity (PSV) below 25–30 cm/s indicates arterial insufficiency, whereas an end-diastolic velocity (EDV) of 5 cm/s or more, in the presence of adequate PSV and complete smooth muscle relaxation, indicates corporo-veno-occlusive dysfunction. Incomplete relaxation is the principal source of error: in one prospective series, 47% of outside diagnoses of venous leak proved false on repeat testing, and only about a quarter of published protocols describe redosing. Beyond diagnosis, PDUS predicts response to non-surgical therapy, contributes to cardiovascular risk assessment and surgical planning, and is central to the diagnosis and embolisation of high-flow priapism. Controversies include heterogeneous cut-offs, absent age-adjusted reference ranges and operator dependence. Shear-wave elastography, contrast-enhanced ultrasound and artificial intelligence are promising adjuncts. Standardised, rigidity-based protocols with structured reporting are essential for reliable and comparable PDUS results.

KEYWORDS: Erectile dysfunction; Penile Doppler ultrasound; Duplex ultrasonography; Peak systolic velocity; Venous leak; Priapism

1. INTRODUCTION
Erectile dysfunction (ED), the persistent inability to attain or maintain an erection sufficient for satisfactory sexual performance, is among the most common chronic conditions of adult men. An estimated 152 million men were affected worldwide in 1995, and the number was projected to reach approximately 322 million by 2025, driven largely by population ageing and the rising burden of cardiometabolic disease [1]. Contemporary population studies report a prevalence ranging from 3% to 76.5%, a spread that reflects differences in age structure, case definition and questionnaire used, with a consistent rise in prevalence with age [2]. In the landmark Massachusetts Male Aging Study, 52% of men aged 40–70 years reported some degree of ED [3].
ED is no longer a disease of older men alone. Reviews of younger cohorts describe prevalence rates of up to 30% in men below 40 years [4], and in routine outpatient practice approximately one in four men presenting with new-onset ED is younger than 40 years [5]. In men with diabetes the pooled prevalence exceeds 50% [6]. Most importantly, ED shares risk factors and endothelial pathophysiology with atherosclerotic cardiovascular disease (CVD), and has been established as an independent marker of cardiovascular risk [7]. Because the cavernosal arteries are smaller than the coronary arteries, the same degree of atherosclerotic burden produces symptomatic penile ischaemia earlier—the "artery size hypothesis"—so that ED frequently precedes clinical coronary disease by two to five years [8, 9]. These epidemiological data are summarised in Table 1.

Table 1. Epidemiological and clinical data relevant to vasculogenic erectile dysfunction

Domain	Key data	Source
Global burden	≈152 million men in 1995; projected ≈322 million by 2025	Ayta et al. [1]

Prevalence range	3%–76.5% across population studies; rises steeply with age	Kessler et al. [2]
Men aged 40–70 years	52% report some degree of ED (MMAS)	Feldman et al. [3]
Young men (<40 years)	Up to 30% in community studies; ≈1 in 4 new ED presentations in clinic	Nguyen et al.; Capogrosso et al. [4, 5]
Diabetes mellitus	Pooled prevalence >50% (145 studies)	Kouidrat et al. [6]
Cardiovascular link	ED is an independent marker of CVD; typically precedes coronary symptoms by 2–5 years	Gandaglia et al.; Montorsi et al.; Inman et al. [7–9]
PDE5 inhibitor failure	Approximately 30%–35% of men do not respond adequately to oral therapy	McMahon et al. [10]

ED, erectile dysfunction; MMAS, Massachusetts Male Aging Study; CVD, cardiovascular disease; PDE5, phosphodiesterase type 5.

In most men ED has an organic basis, and vasculogenic mechanisms—arterial insufficiency (AI), corporo-veno-occlusive dysfunction (CVOD, "venous leak") or a combination of the two—predominate. Phosphodiesterase type 5 (PDE5) inhibitors remain first-line therapy, but roughly 30%–35% of men do not respond adequately and require second-line treatment [10]. The therapeutic landscape for these men now spans intracavernosal injection (ICI) therapy, vacuum erection devices, low-intensity shockwave therapy, regenerative approaches and penile prosthesis implantation [11]; selecting among them is far more rational when the haemodynamic phenotype is known.

Penile Doppler ultrasound (PDUS), first described by Lue et al. in 1985, combines pharmacologically induced erection with high-frequency B-mode and spectral Doppler imaging to quantify cavernosal arterial inflow and veno-occlusive competence [12]. Four decades later it is the most widely used test of penile vascular function, yet protocols, thresholds and indications remain inconsistent between centres. This narrative review aims to synthesise current evidence on the physiological basis, guideline position, indications, standardised technique, interpretation, diagnostic pitfalls and prognostic value of PDUS in ED, together with its role in priapism and the emerging technologies likely to shape its future.

2. METHODS

This narrative review was prepared in accordance with the Scale for the Assessment of Narrative Review Articles (SANRA) [13]. PubMed/MEDLINE, Scopus, Web of Science and Google Scholar were searched for articles published between January 1985 and September 2026 using combinations of the terms "penile Doppler", "penile duplex ultrasound", "PDUS", "erectile dysfunction", "vasculogenic", "arterial insufficiency", "veno-occlusive dysfunction", "venous leak", "peak systolic velocity", "end-diastolic velocity", "elastography" and "priapism". Current guidelines of the American Urological Association (AUA), European Association of Urology (EAU), Sexual Medicine Society of North America (SMSNA), International Society for Sexual Medicine (ISSM) and the Italian Society of Andrology and Sexual Medicine (SIAMS) were reviewed, and reference lists of key articles were hand-searched. Original studies, systematic reviews, consensus statements and guidelines in English that reported PDUS methodology, diagnostic thresholds, diagnostic accuracy, prognostic value or emerging applications were included; animal-only studies, duplicate publications and abstracts without extractable data were excluded. Preference was given to peer-reviewed, accessible (open-access or widely indexed) sources. Evidence was synthesised thematically (Figure 1).

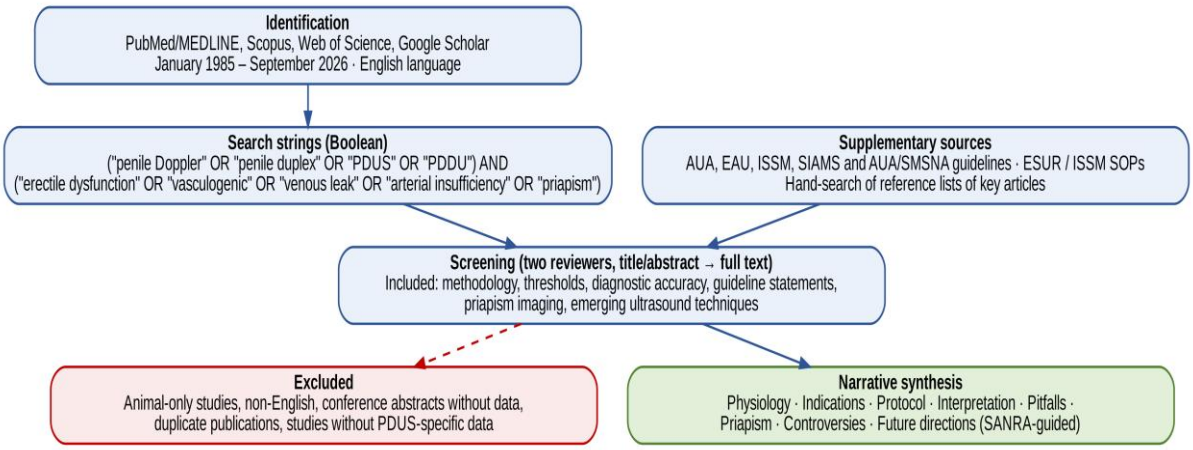


Figure 1. Literature identification and synthesis approach used for this narrative review. AUA, American Urological Association; EAU, European Association of Urology; ISSM, International Society for Sexual

Medicine; SIAMS, Italian Society of Andrology and Sexual Medicine; SMSNA, Sexual Medicine Society of North America; ESUR, European Society of Urogenital Radiology; SOP, standard operating procedure; SANRA, Scale for the Assessment of Narrative Review Articles.

3. Physiological Basis of Erection and Its Doppler Correlates

Erection is a neurovascular event. Sexual stimulation triggers release of nitric oxide (NO) from non-adrenergic, non-cholinergic (nitrergic) nerve terminals and from the sinusoidal endothelium; NO activates soluble guanylate cyclase, raising cyclic guanosine monophosphate (cGMP) and lowering intracellular calcium in cavernosal and arterial smooth muscle [14]. The resulting smooth muscle relaxation (SMR) dilates the cavernosal and helicine arteries, increasing arterial inflow several-fold, while expansion of the sinusoidal spaces compresses the subtunical venular plexus against the relatively inextensible tunica albuginea, restricting venous outflow. Intracavernosal pressure then rises towards systolic pressure and the penis becomes rigid [15]. Recent work has added a further cellular layer: corpus cavernosum fibroblasts regulate local noradrenaline availability and thereby the degree of penile relaxation, and their number increases with repeated erections [16].

PDUS measures the two haemodynamic limbs of this process (Figure 2). Peak systolic velocity (PSV) in the cavernosal artery reflects the adequacy of arterial inflow; end-diastolic velocity (EDV) reflects the efficiency of veno-occlusion, falling to zero or becoming negative once intracavernosal pressure exceeds diastolic pressure. The corollary is critical: both parameters are valid only when complete SMR has been achieved. Incomplete relaxation—commonly caused by anxiety-driven sympathetic tone in the clinical setting or by an inadequate drug dose—lowers PSV and keeps EDV artificially high, mimicking arterial insufficiency and venous leak respectively.

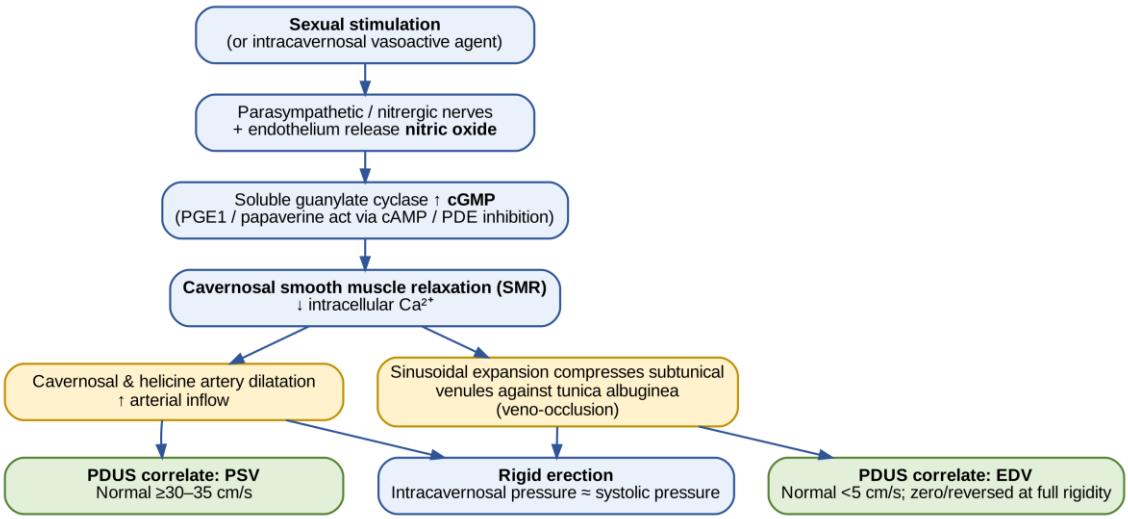


Figure 2. Physiology of penile erection and the corresponding penile Doppler ultrasound (PDUS) parameters. cGMP, cyclic guanosine monophosphate; cAMP, cyclic adenosine monophosphate; PDE, phosphodiesterase; PGE1, prostaglandin E1; PSV, peak systolic velocity; EDV, end-diastolic velocity.

4. Position of PDUS in Current Guidelines

International guidelines agree that PDUS is not a routine first-line test for every man with ED but a second-level investigation reserved for situations in which knowledge of vascular status will change management, prognosis or counselling (Table 2). The AUA guideline recommends specialised testing, including PDUS, when it is required to guide treatment or to inform the patient and partner [17]. The EAU guideline places PDUS among specific diagnostic tests for selected patients and defines a normal study as PSV >30 cm/s, EDV <3 cm/s and resistive index (RI) >0.8 [18]. The SIAMS guideline, endorsed by ten Italian scientific societies, is more liberal and suggests penile colour Doppler ultrasound, at least in the flaccid state, for all men with ED as a tool for cardiovascular risk stratification (weak recommendation, moderate-quality evidence) [19]. The ISSM standard operating procedures (SOP) set out a uniform technique [20], and an andrological review proposed PDUS mainly for non-responders to oral therapy and for men requiring precise cardiovascular risk stratification [21]. Specialist sexual-medicine centres emphasise that the value of PDUS is "entirely predicated on achieving complete cavernosal smooth muscle relaxation" [22], and a recent editorial comparing guidelines highlighted the persisting heterogeneity of recommendations [23]. Notably, a 2023 health-technology reference review found no diagnostic test accuracy studies of PDUS against a contemporary reference standard [24], underlining that much of the evidence base remains observational.

Table 2. Position of penile Doppler ultrasound in major guidelines and consensus documents

Guideline / body	Year	Position on PDUS	Thresholds stated

AUA guideline [17]	2018	Specialised testing (incl. PDUS) when it may alter management or for patient/partner counselling; not routine	Not specified
EAU guideline [18]	2021	Specific diagnostic test for selected patients (e.g., suspected vasculogenic ED, before vascular surgery, Peyronie's disease, medicolegal)	Normal: PSV >30 cm/s, EDV <3 cm/s, RI >0.8
SIAMS + 10 Italian societies [19]	2023	Suggests penile colour Doppler (at least flaccid) in all men with ED for CV risk stratification (weak)	Flaccid and dynamic parameters
ISSM SOP [20]	2013	Standardised technique: high-frequency linear probe, ICI, rigidity documentation, bilateral measurement at penoscrotal junction	PSV <25 cm/s abnormal; EDV >5 cm/s suggests CVOD
Andrology review [21]	2021	Non-responders to oral therapy; men needing CV risk stratification	PSV <35 (severe <25) cm/s; EDV >4.5–5 cm/s or RI <0.75
MSKCC protocol [22]	2024	Rigidity-based protocol with redosing; scan at full rigidity or maximal dose	PSV >30 cm/s normal; EDV <5 cm/s normal

AUA, American Urological Association; EAU, European Association of Urology; SIAMS, Italian Society of Andrology and Sexual Medicine; ISSM, International Society for Sexual Medicine; SOP, standard operating procedure; MSKCC, Memorial Sloan Kettering Cancer Center; CV, cardiovascular; ICI, intracavernosal injection; PSV, peak systolic velocity; EDV, end-diastolic velocity; RI, resistive index; CVOD, corporo-veno-occlusive dysfunction.

5. Indications for PDUS

The principal indication is to distinguish vasculogenic from non-vasculogenic ED and to phenotype vasculogenic ED when the result will influence treatment. Young men with suspected focal arterial occlusion after pelvic or perineal trauma are the classic example, because isolated stenoses in non-smoking, non-diabetic men younger than 55 years may be amenable to microvascular arterial bypass surgery, for which PDUS is the screening test before selective pudendal arteriography [25]. Before and after radical pelvic surgery, the haemodynamic profile helps predict recovery: men with arterial insufficiency or venous leak after radical prostatectomy have a lower likelihood of spontaneous return of function [26]. In Peyronie's disease, PDUS is recommended before invasive intervention to document plaque characteristics and vascular status, which influences the choice between plication, grafting and prosthesis [27]. Flaccid and dynamic PSV have also been proposed as markers of systemic atherosclerosis: a flaccid PSV below approximately 13 cm/s was associated with arteriogenic ED and silent coronary artery disease in one cohort [28], and reduced cavernosal velocities have been linked with future cardiovascular events [29]. Indications are summarised in Table 3.

Table 3. Indications for penile Doppler ultrasound in clinical practice

Indication	Clinical rationale
Failure of, or contraindication to, PDE5 inhibitors	Defines haemodynamic phenotype; guides choice between ICI, VED, Li-ESWT and prosthesis
Young man with trauma (pelvic fracture, perineal/straddle injury)	Screens for focal arterial lesions suitable for microvascular arterial bypass
Suspected primary CVOD (e.g., lifelong ED, loss of rigidity during intercourse)	Confirms or refutes venous leak before considering ICI therapy or prosthesis
Peyronie's disease before surgery	Documents plaque, calcification and vascular status; informs choice of surgical technique
Before/after radical pelvic surgery or radiotherapy	Baseline and prognostic counselling; detects accessory pudendal artery injury
Cardiovascular risk stratification	Reduced flaccid/dynamic PSV associated with systemic atherosclerosis
Medicolegal assessment	Objective documentation of vascular injury
Research and trials	Objective haemodynamic end-points for novel ED therapies
Priapism (see Section 10)	Differentiates ischaemic from non-ischaemic priapism; localises fistula; guides embolisation

PDE5, phosphodiesterase type 5; ICI, intracavernosal injection; VED, vacuum erection device; Li-ESWT, low-intensity extracorporeal shockwave therapy; CVOD, corporo-veno-occlusive dysfunction; PSV, peak systolic velocity.

6. Procedural Protocol and Technical Considerations

6.1 Setting and equipment

PDUS should be performed in a private, quiet room by a clinician trained in both the technique and its interpretation. A high-frequency (≥7.5 MHz; ideally 10–18 MHz) linear-array transducer with B-mode, colour/power Doppler and pulsed-

wave spectral Doppler is required [30]. A preliminary flaccid B-mode survey assesses the tunica albuginea, corpora and spongiosum for plaques, calcification, fibrosis or masses, and records the diameter of the cavernosal arteries [31]. The transducer is placed on the ventral or lateral aspect of the shaft near the penoscrotal junction, where the cavernosal arteries run parallel to the skin and the angle of insonation can be kept at or below 60° [32].

6.2 Vasoactive agent selection

Practice is strikingly heterogeneous. In a review of 86 PDUS studies, 50% used prostaglandin E1 (PGE1) alone, 16% papaverine, 12% trimix (papaverine, phentolamine and PGE1) and 7% bimix, while 12% did not report the agent at all; among PGE1 studies, 44% used 20 µg and 35% used 10 µg. The same review found that only 26% of studies described a redosing protocol, 59% used a purely time-based scanning schedule, 56% made no mention of rigidity assessment, published "normal" EDV thresholds ranged from 3 to 7 cm/s, and approximately one-quarter did not report the cut-offs used at all [33]. Combination agents act on complementary pathways and produce more complete relaxation at lower individual doses. In a dynamic colour power Doppler study of 116 men, redosing with PGE1 plus phentolamine upgraded the haemodynamic diagnosis in 35% of patients, compared with 15% when PGE1 alone was repeated, without an increase in prolonged erections [34]. Agents, doses and redosing logic are summarised in Table 4.

6.3 Redosing: the critical element

Haemodynamic measurements obtained under incomplete SMR are unreliable. Pharmacocavernosometric work demonstrated that apparently abnormal haemodynamics frequently normalise once trabecular smooth muscle relaxation is maximised [35]. Applying this principle to Doppler, Mulhall et al. showed that a structured vasoactive redosing schedule corrected a substantial proportion of abnormal initial results, converting many presumed diagnoses of venous leak or arterial insufficiency to normal [36]. Despite this, redosing remains the exception rather than the rule in published protocols (Section 6.2).

Table 4. Commonly used vasoactive agents and a rigidity-based redosing protocol

Item	Details	Practical notes
PGE1 (alprostadil)	10–20 µg ICI	Most widely used; injection pain in some men; lowest priapism risk
Bimix	Papaverine 30 mg/mL + phentolamine 0.5–1 mg/mL	Useful when PGE1 pain anticipated
Trimix	Papaverine 30 mg/mL + phentolamine 1 mg/mL + PGE1 10 µg/mL	Most potent; dose individualised by age, comorbidity and prior response
Initial dose	Low–moderate dose	Assess rigidity at 5–10 min; offer audiovisual stimulation
Second dose	Repeat or escalate if rigidity < EHS 3–4 (<80%) or EDV elevated	Reassess after ~10 min
Third dose	Final dose up to the centre's maximum	Scan at full rigidity or report "maximal pharmacological stimulation"

Agent concentrations and redosing logic adapted from the studies discussed in Sections 6.2–6.3. PGE1, prostaglandin E1; ICI, intracavernosal injection; EHS, Erection Hardness Score; EDV, end-diastolic velocity.

6.4 Rigidity-based versus time-based assessment

Traditional protocols scan at fixed intervals after injection, most often 5, 10 and 20 minutes, and this remains the commonest approach in the literature (Section 6.2). A rigidity-based approach, in which spectral Doppler is recorded only once a functional erection has been achieved (or the maximum dose has been given), maximises the probability of complete SMR. Rigidity is graded with the Erection Hardness Score (EHS 1–4), where EHS 3 corresponds to an erection hard enough for penetration and EHS 4 to full rigidity [37], or with a 0–100% scale. Rigidity should be recorded separately at the time each cavernosal artery is sampled, because detumescence during scanning artificially raises EDV.

6.5 Audiovisual sexual stimulation

Audiovisual sexual stimulation (AVSS) counteracts the sympathetic inhibition of the clinical environment. Early work showed that AVSS delivered through head-mounted "virtual glasses" improved erectile response during colour duplex Doppler [38]. A recent randomised crossover trial in 60 men confirmed the effect: with three-dimensional virtual glasses, a functional erection (EHS ≥3) was achieved in 83.6% of sessions versus 43.3% with a desktop monitor, mean PSV increased from 29.3 to 35.3 cm/s and EDV decreased from 3.65 to 3.36 cm/s [39].

6.6 Doppler signal acquisition

Spectral waveforms are obtained from both cavernosal arteries with angle correction, a small sample volume placed in the vessel lumen and at least three consecutive uniform cardiac cycles. Location matters: PSV declines progressively from the penile base to the distal shaft, so measurements obtained at different sites are not interchangeable [40]. The recommended technical parameters are listed in Table 5 and the complete workflow in Figure 3.

Table 5. Recommended technical parameters for penile Doppler ultrasound

Parameter	Recommendation	Rationale
Transducer	Linear array, 10–18 MHz	Spatial resolution of 0.5–1 mm cavernosal arteries

Patient position	Supine; penis on abdominal wall	Cavernosal arteries parallel to skin
Sampling site	Proximal shaft / penoscrotal junction, both sides	Velocities fall distally; ensures reproducibility
Angle of insonation	≤60°, angle-corrected	Velocity error rises steeply above 60°
Sample volume	1–2 mm, centred in lumen	Avoids wall artefact
Velocity scale / wall filter	Scale adjusted to avoid aliasing; low wall filter (≈50 Hz)	Preserves low diastolic and reversed flow
Timing	Rigidity-based (EHS 3–4 / ≥80%) or after maximal dose	Maximises smooth muscle relaxation
Parameters recorded	PSV, EDV, RI, acceleration time, rigidity per side, dose used	Complete, reproducible report

Based on the ISSM standard operating procedure (Section 4) and the technique reviews cited in Section 6.1. EHS, Erection Hardness Score; PSV, peak systolic velocity; EDV, end-diastolic velocity; RI, resistive index.

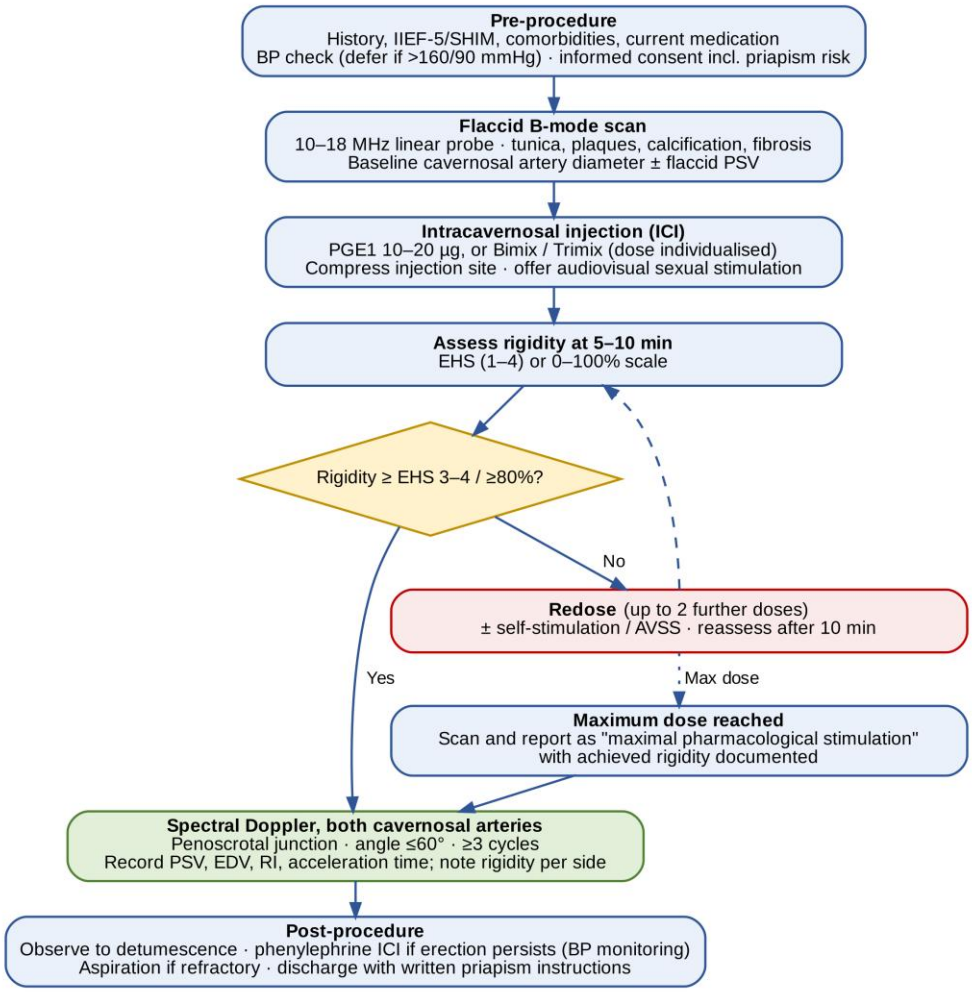


Figure 3. Rigidity-based penile Doppler ultrasound protocol with vasoactive redosing. BP, blood pressure; IIEF-5, five-item International Index of Erectile Function; SHIM, Sexual Health Inventory for Men; ICI, intracavernosal injection; PGE1, prostaglandin E1; EHS, Erection Hardness Score; AVSS, audiovisual sexual stimulation; PSV, peak systolic velocity; EDV, end-diastolic velocity; RI, resistive index.

7. Interpretation of Haemodynamic Parameters

7.1 Peak systolic velocity

PSV is the most robust index of arterial inflow. In early correlative work, PSV ≥35 cm/s indicated normal arterial function, 25–34 cm/s was borderline, and <25 cm/s indicated severe arterial insufficiency [41]. Against selective internal pudendal arteriography, a PSV below 25 cm/s identified significant arterial disease with close to 100% sensitivity and approximately 95% specificity [42]. Most centres now use a single threshold of 25–30 cm/s, and a side-to-side difference of more than 10 cm/s, or a prolonged acceleration time (>100–110 ms), suggests unilateral or proximal stenosis. Flaccid PSV is attractive because it avoids injection, but it correlates only weakly with post-injection PSV ($r = 0.21$) and no flaccid cut-off between 10 and 15 cm/s achieved both sensitivity and specificity above 80% for predicting a normal dynamic PSV [43]; it should therefore be regarded as a screening or cardiovascular-risk marker rather than a substitute for dynamic testing.

7.2 End-diastolic velocity and resistive index

EDV reflects veno-occlusion. With full rigidity, diastolic flow should be absent or reversed. Persistent EDV ≥5 cm/s, in the presence of adequate PSV and documented complete SMR, indicates CVOD, a threshold supported by correlation with cavernosometry [44]. As noted in Section 6.2, the EDV threshold used in the literature varies widely. The RI, calculated as (PSV − EDV)/PSV, rises towards 1.0 with effective veno-occlusion; values >0.9 are normal and <0.75 suggest venous leak. However, RI is a derived ratio and can mask abnormality: a PSV of 90 cm/s with an EDV of 10 cm/s yields an RI of 0.89 despite a clearly elevated EDV, so direct interpretation of PSV and EDV is preferred. Diagnostic thresholds and the supporting accuracy data are summarised in Table 6, and the characteristic combinations in Table 7 and Figure 4.

Table 6. Diagnostic thresholds and reported accuracy of penile Doppler ultrasound parameters

Parameter	Threshold	Accuracy / evidence	Reference standard / study
Dynamic PSV	≥35 cm/s normal; 25–34 borderline; <25 cm/s severe AI	Graded association with arterial disease	Quam et al. [41]
Dynamic PSV	<25 cm/s	Sensitivity ≈100%, specificity ≈95% for significant arterial disease	Pudendal arteriography; Benson et al. [42]
Flaccid PSV	10, 13 and 15 cm/s tested	Weak correlation with dynamic PSV (r = 0.21); no cut-off reached >80% sensitivity and specificity	Dynamic PDUS; Souper et al. [43]
EDV	≥5 cm/s (with adequate PSV and full SMR)	Correlated with cavernosometric venous leakage	Cavernosometry; Bassiouny & Levine [44]

PSV, peak systolic velocity; EDV, end-diastolic velocity; AI, arterial insufficiency; SMR, smooth muscle relaxation.

Table 7. Interpretation of penile Doppler ultrasound patterns and their clinical implications

Pattern	PSV	EDV	Clinical implication
Normal haemodynamics	≥30–35 cm/s	<5 cm/s (zero/negative)	Non-vasculogenic ED (psychogenic, neurogenic, endocrine); only valid if complete SMR achieved
Arterial insufficiency	<25–30 cm/s	<5 cm/s	Cardiovascular risk assessment; risk-factor modification; PDE5i, Li-ESWT; revascularisation in selected young men
Corporo-veno-occlusive dysfunction	≥30 cm/s	≥5 cm/s, bilateral	Poorer response to oral agents; ICI or VED; penile prosthesis if refractory
Mixed vasculogenic	<25–30 cm/s	≥5 cm/s	Most severe phenotype; ICI or penile prosthesis
Unilateral low PSV	Asymmetry >10 cm/s	Variable	Incomplete SMR on that side, true unilateral lesion (e.g., post-prostatectomy) or anatomical variant
Unilateral high EDV	Normal	≥5 cm/s on one side	Usually loss of rigidity during scanning; CVOD is not a side-specific diagnosis

PSV, peak systolic velocity; EDV, end-diastolic velocity; SMR, smooth muscle relaxation; PDE5i, phosphodiesterase type 5 inhibitor; Li-ESWT, low-intensity extracorporeal shockwave therapy; ICI, intracavernosal injection; VED, vacuum erection device; CVOD, corporo-veno-occlusive dysfunction.

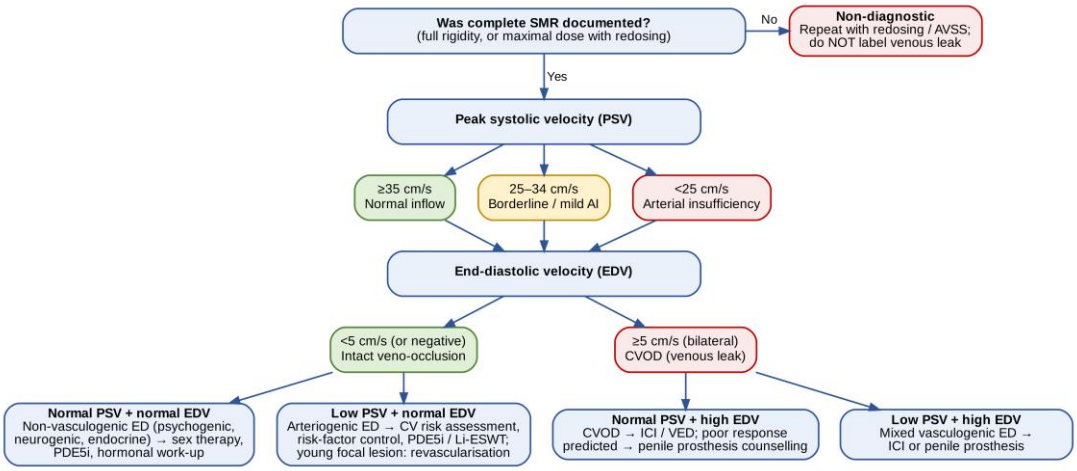


Figure 4. Diagnostic and management algorithm based on penile Doppler ultrasound parameters. SMR, smooth muscle relaxation; AVSS, audiovisual sexual stimulation; AI, arterial insufficiency; CVOD, corporo-veno-occlusive dysfunction; CV, cardiovascular; PDE5i, phosphodiesterase type 5 inhibitor; Li-ESWT, low-intensity extracorporeal shockwave therapy; ICI, intracavernosal injection; VED, vacuum erection device.

8. Diagnostic Pitfalls and the Problem of False Diagnosis

The most consequential error in PDUS is the false diagnosis of venous leak. In a prospective study of 292 men referred with a diagnosis of venous leak made on an outside Doppler, repeat PDUS with redosing and, where indicated, cavernosometry showed that 47% had completely normal haemodynamics and only 43% had confirmed venous leak; younger age (<45 years), failure to achieve an adequate erection during the original study, and fewer than two vascular risk factors predicted a false diagnosis [45]. A false label of CVOD may lead to unnecessary prosthesis surgery, whereas a false label of arterial insufficiency may trigger unnecessary cardiovascular investigation. Common pitfalls and their remedies are listed in Table 8.

Table 8. Common pitfalls in penile Doppler ultrasound and how to avoid them

Pitfall	Consequence	Remedy
Incomplete smooth muscle relaxation (anxiety, low dose)	Falsely low PSV; falsely high EDV ("venous leak")	Redosing, AVSS, privacy, self-stimulation; scan at full rigidity
Time-based scanning only	Measurement before peak response or after detumescence	Rigidity-based protocol; document EHS per side
Angle of insonation >60° or no angle correction	Velocity over- or under-estimation	Angle ≤60° with correction; heel–toe probe manoeuvres
Distal sampling site	Lower PSV than at penile base	Sample at penoscrotal junction, same site at follow-up
Multiple or anomalous cavernosal arteries	Asymmetric or misleading velocities	Colour survey of whole shaft; report anatomical variants
Reliance on RI alone	Normal RI masking elevated EDV	Interpret PSV and EDV directly
Unreported cut-offs and dose	Non-comparable results across centres	Standardised report: agent, dose, redosing, rigidity, PSV, EDV, RI

Compiled from the studies discussed in Sections 6–8. PSV, peak systolic velocity; EDV, end-diastolic velocity; RI, resistive index; AVSS, audiovisual sexual stimulation; EHS, Erection Hardness Score.

9. Prognostic Value, Treatment Selection and Safety

PDUS findings inform counselling about the likelihood of response to non-surgical therapy. In a five-year follow-up of 69 men who underwent ICI testing with PDUS, 18.8% developed ED refractory to non-surgical treatment; EDV (AUC 0.730) and RI (AUC 0.714) predicted refractoriness better than PSV (AUC 0.613), although the EHS achieved during testing performed at least as well (AUC 0.820) [46]. Haemodynamic phenotyping is also used to select candidates for restorative treatments such as low-intensity shockwave therapy, which shows the greatest benefit in men with vasculogenic ED of mild to moderate severity [47].

PDUS is safe when performed with appropriate precautions. In a recent cohort of 292 men undergoing dynamic PDUS with alprostadil (mean dose ≈9 µg), no episodes of priapism occurred, although high-risk groups—young men, men with neurological or haematological disorders, and men on priapism-associated medications—were well represented [48]. Higher-potency combinations carry greater risk, and every centre should have a reversal pathway. Patients are observed until detumescence; an erection that persists is treated with intracavernosal phenylephrine (typically 100–500 µg aliquots with blood pressure monitoring) and, if necessary, corporal aspiration, in accordance with the AUA/SMSNA guideline on

acute ischaemic priapism [49]. Men should be discharged with written instructions on what to do if a prolonged erection recurs.

10. Penile Doppler Ultrasound in Priapism

Priapism is a full or partial erection lasting more than four hours unrelated to sexual stimulation. Distinguishing ischaemic (low-flow, veno-occlusive) from non-ischaemic (high-flow, arterial) priapism is essential because the former is a compartment-syndrome emergency while the latter is not [50, 51]. Corporal blood gas analysis remains the first-line discriminator, with PDUS performed alongside it, provided imaging does not delay decompression in ischaemic cases (Figure 5).

A systematic review of 12 studies found that PDUS was comparable with blood gas analysis in differentiating low-flow from high-flow priapism; against pudendal arteriography it showed 40%–100% sensitivity and 73% specificity for localising vascular injury, and it was used to guide embolisation and to follow patients after treatment [52]. In ischaemic priapism, cavernosal arterial flow is absent or minimal. In non-ischaemic priapism, PDUS shows high-velocity arterial inflow with persistent diastolic flow and low RI, and frequently identifies an arterio-lacunar fistula or pseudoaneurysm ("arterial blush"); mean velocity and PSV help separate the two entities [53]. Since the description of PDUS-guided diagnosis and management of arterial high-flow priapism [54], PDUS has been used to target superselective embolisation and to monitor fistula closure and restoration of erectile haemodynamics; in a recent series of 25 patients with non-ischaemic priapism, Doppler findings informed both diagnosis and the choice between conservative management and embolisation [55]. One-year colour Doppler follow-up after embolisation has documented durable fistula occlusion with preserved erectile function in most cases [56]. PDUS may also predict pharmacologically induced priapism: after ICI of papaverine/phentolamine, a PSV >66 cm/s with an EDV of 0–1 cm/s accurately identified men who would develop prolonged erection, allowing pre-emptive reversal [57]. Characteristic findings are summarised in Table 9.

Table 9. Penile Doppler ultrasound findings in ischaemic versus non-ischaemic priapism

Feature	Ischaemic (low-flow)	Non-ischaemic (high-flow)
Pathophysiology	Veno-occlusion with stasis, hypoxia, acidosis	Unregulated arterial inflow via arterio-lacunar fistula
Typical cause	ICI agents, drugs, sickle cell disease, idiopathic	Perineal/penile trauma; post-shunt surgery
Clinical picture	Painful, fully rigid	Painless, partially rigid
Corporal blood gas	pO_2 <30 mmHg, pCO_2 >60 mmHg, pH <7.25	Arterial-like values
Cavernosal arterial flow	Absent or minimal	High velocity, turbulent
PSV / EDV / RI	Not measurable or very low	High PSV, persistent positive EDV, low RI
Additional findings	Thrombus, corporal oedema, later fibrosis	Fistula or pseudoaneurysm ("blush")
Role of PDUS	Adjunct; must not delay decompression	Diagnosis, fistula localisation, embolisation guidance, follow-up

Compiled from the guidelines and studies cited in Section 10. ICI, intracavernosal injection; PSV, peak systolic velocity; EDV, end-diastolic velocity; RI, resistive index.

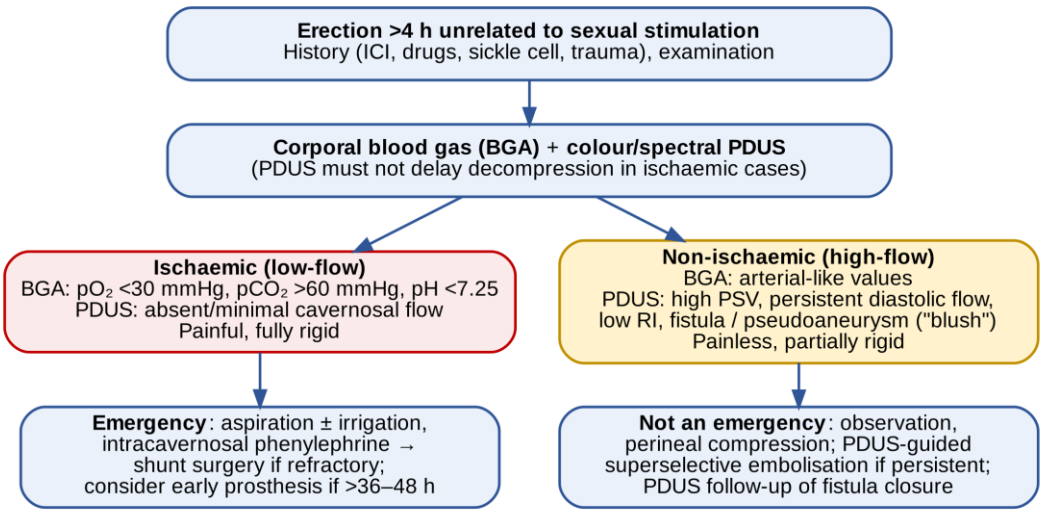


Figure 5. Role of penile Doppler ultrasound in the evaluation and management of priapism. BGA, blood gas analysis; ICI, intracavernosal injection; PDUS, penile Doppler ultrasound; PSV, peak systolic velocity; RI, resistive index.

11. Controversies and Unresolved Questions

Threshold heterogeneity. PSV cut-offs for arterial insufficiency range from 25 to 35 cm/s and EDV cut-offs for CVOD from 3 to 7 cm/s, many studies do not state the threshold used (Section 6.2), and protocols differ in agent, dose, redosing and timing. These inconsistencies make inter-study comparison difficult and probably explain part of the variability in reported prevalence of venous leak.

Absence of age-adjusted normative data. Younger men generally have higher PSV and lower EDV, yet no validated age-specific reference ranges exist. Borderline values in older men may therefore reflect normal vascular ageing rather than disease.

Operator dependence and reproducibility. Probe position, angle correction, sample volume placement and the timing of measurements relative to rigidity all influence results, and there is no formal training curriculum or certification for PDUS. Structured reporting that records agent, dose, redosing, rigidity per side and all velocities would substantially improve reproducibility.

Reference standard. Pharmacocavernosometry and selective pudendal arteriography, the historical reference standards, are invasive and now rarely performed, so contemporary diagnostic accuracy data are scarce. Prospective studies linking PDUS phenotypes to hard outcomes—treatment response, prosthesis requirement and cardiovascular events—are the most realistic way to validate thresholds.

12. Future Directions

Several technologies may extend or refine PDUS (Table 10). Shear-wave elastography (SWE) quantifies corporal tissue stiffness, which reflects the smooth muscle-to-collagen ratio. In 131 men with ED, post-injection SWE differed between arteriogenic and non-arteriogenic ED; SWE alone was modest (AUC 0.656), but a model combining SWE with red cell distribution width achieved an AUC of 0.870 for arteriogenic ED [58]. Contrast-enhanced ultrasound (CEUS) with intracavernosal or intravenous microbubbles can delineate corporal communication, septal anomalies and perfusion defects, and may improve fistula characterisation in high-flow priapism [59]. Artificial intelligence (AI) has been applied to ED diagnosis through questionnaires, image-based classifiers and predictive models, but most studies lack external validation [60]; automated waveform analysis and probe-guidance tools could reduce operator dependence and standardise measurement. Finally, as regenerative therapies for ED mature, PDUS will be needed to select patients and to provide objective haemodynamic end-points in clinical trials.

Table 10. Emerging ultrasound-based and computational techniques complementary to penile Doppler ultrasound

Technique	What it adds	Current evidence / limitations
Shear-wave elastography	Quantifies corporal stiffness (fibrosis, smooth muscle loss)	AUC 0.656 alone; 0.870 combined with RDW for arteriogenic ED; retrospective, no healthy controls
Contrast-enhanced ultrasound	Microvascular perfusion; corporal communication; fistula delineation	Small series and case reports; off-label intracavernosal use
Artificial intelligence	Automated waveform analysis, risk prediction, decision support	30 studies reviewed; most lack external validation
3D virtual-reality AVSS	Improves rigidity and reduces false-positive results	Randomised crossover trial: functional erection 83.6% vs 43.3% (Section 6.5)

Sources as cited in Sections 6.5 and 12. AUC, area under the receiver operating characteristic curve; RDW, red cell distribution width; ED, erectile dysfunction; AVSS, audiovisual sexual stimulation.

13. CONCLUSIONS

Penile Doppler ultrasound is the most practical and informative test of penile vascular function. It distinguishes vasculogenic from non-vasculogenic ED, separates arterial insufficiency, veno-occlusive dysfunction and mixed disease, supports prognostic counselling and treatment selection, and is indispensable in the evaluation of high-flow priapism. Its accuracy, however, depends entirely on achieving complete cavernosal smooth muscle relaxation. A rigidity-based protocol with vasoactive redosing and audiovisual stimulation, bilateral angle-corrected measurement at the penoscrotal junction, and direct interpretation of PSV (abnormal <25–30 cm/s) and EDV (abnormal ≥5 cm/s) minimise false diagnoses—particularly the over-diagnosis of venous leak. Standardised thresholds, age-adjusted reference ranges, structured reporting and formal training are the main priorities for the field, while elastography, contrast-enhanced ultrasound and artificial intelligence are likely to broaden its role in the era of personalised sexual medicine.

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Key Messages

- PDUS is a second-level test indicated when knowledge of penile vascular status will change management, prognosis or counselling.
- Its accuracy depends entirely on complete cavernosal smooth muscle relaxation; a rigidity-based protocol with redosing and audiovisual stimulation is recommended.
- PSV <25–30 cm/s indicates arterial insufficiency; EDV ≥5 cm/s with adequate PSV and full relaxation indicates veno-occlusive dysfunction.
- Inadequate technique produces false diagnoses of venous leak in nearly half of referred men.
- PDUS is essential in high-flow priapism for fistula localisation, embolisation guidance and follow-up.

Abbreviations

AI, arterial insufficiency; AUA, American Urological Association; AUC, area under the curve; AVSS, audiovisual sexual stimulation; CVD, cardiovascular disease; CVOD, corporo-veno-occlusive dysfunction; ED, erectile dysfunction; EAU, European Association of Urology; EDV, end-diastolic velocity; EHS, Erection Hardness Score; ICI, intracavernosal injection; ISSM, International Society for Sexual Medicine; PDE5, phosphodiesterase type 5; PDUS, penile Doppler ultrasound; PGE1, prostaglandin E1; PSV, peak systolic velocity; RI, resistive index; SIAMS, Italian Society of Andrology and Sexual Medicine; SMR, smooth muscle relaxation; SMSNA, Sexual Medicine Society of North America; SWE, shear-wave elastography.

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