Chapter 10
Ultrasound Application for Penile Disorders: Color Doppler Ultrasound Hemodynamic Evaluation for Erectile Dysfunction and Priapism

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Color Doppler Ultrasound Hemodynamic Study for Erectile Dysfunction

Erection is achieved through hemodynamic mechanisms that involve the increase of cavernosal arterial flow, relaxation of corporal smooth muscle, and veno-occlusive function. Hemodynamic studies are important in the evaluation of patients with impotence. Among the methods of hemodynamic study, color Doppler sonography is currently the best.

In 1985, Lue et al. described Duplex ultrasonography as a noninvasive tool to study penile hemodynamics of patients with erectile dysfunction.[1] The advent of color Doppler imaging and continuous improvements in ultrasound technology have greatly enhanced the capacity of ultrasound to assess hemodynamics. Modern ultrasound equipment is also able to analyze blood flow parameters to measure velocity more quickly and more accurately. These characteristics allow the changes in various blood flow parameters be assessed in a dynamic fashion.[2]

The reported methods of performing color Doppler sonography for erectile dysfunction (or impotence) vary. The methods of early reports mostly consist of measuring peak systolic velocity (PSV) and end diastolic velocity (EDV) at 5- or 10-min intervals. The "highest PSV" is commonly used to diagnose arterial insufficiency, and an EDV-based criterion (such as resistive index or RI) is used to diagnose venous leak. However, in our early experience we noted a number of pitfalls associated with these methods. Various diagnostic criteria have also been used; early reports recommended the degree of cavernosal artery dilatation to be a key criterion, while more recent reports commonly use "highest PSV" for arterial insufficiency and resistive index for venous leak.[1–4] Meuleman and associates studied normal volunteers and found that they had a mean PSV of 41–44 cm s^{-1} during the erectile phases.[4] A "highest PSV" of 35 cm s^{-1} was subsequently accepted as normal. In addition to these criteria, we believe that a dynamic observation and interpretation of the study is desirable. The pathophysiology of erectile dysfunction is no less complicated than that of urinary dysfunction. The hemodynamic evaluation for erectile dysfunction should be performed with the same attention to detail as urodynamic studies. We believe that a dynamic study with continuous observation and frequent recording of hemodynamic parameters is preferable.[2,5,6]

Indications

Our current indications for color Doppler ultrasound hemodynamic study in patients with erectile dysfunction are as follows:

1. Primary impotence
2. Erectile dysfunction following penile, perineal, or pelvic injuries
3. Medical legal case
4. Peyronie's disease
5. Young patients (< 50 years old) suspicious for vascular cause of impotence
6. Young patients suspicious for psychogenic cause of impotence
7. Patients or their spouse desire investigation for cause of impotence

Procedure

Our current procedure for color Doppler ultrasound hemodynamic study is as follows:

1. Studies are performed in a "do not disturb" environment with only essential personnel involved.
2. We perform an intracorporeal injection using a 0.2 c.c. Papaverine/phentolamine/PGE1 (30 mg/1 mg/20 μg) mixture (Tri-Mix) or 0.3 ml of the standard Tri-Mix for most patients. We may administer a second injection in the

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opposite corpora 15–20 min later for patients with an inadequate erectile response and abnormal arterial flow of the opposite side cavernosal artery.

3. We use an ATL HDI ultrasound machine for color Doppler ultrasound studies at our Urology clinic. With the penis gently retracted toward the abdomen, the transducer is placed ventrally at the base of penis to measure blood flow parameters at a consistent proximal location. The cavernosal artery blood flow is traced continuously (switching from one side to another). The hemodynamic parameters including PSV, EDV, and RI are recorded frequently (usually every 1–3 min, depends on the change of hemodynamic parameters observed) for about 30 min. The measurement of cavernosal artery diameter before and after injection is optional.
4. The status of erection is observed and rigidity manually evaluated periodically during the study. Self-stimulation is performed if the patient does not achieve a rigid erection.

Phases of Erection and Hemodynamic Events

Cavernosal arteries at a flaccid state prior to penile injection usually have a low and intermittent flow (Fig. 10.1). After injection of pharmacologic agent, we typically observe the following five phases of hemodynamic events:

In Phase I, both systolic and diastolic flows increase and become continuous. Patients begin to have penile engorgement (Fig. 10.2).

In Phase II, with an increase in intracorporeal pressure, a progressive decrease in EDV occurs. The PSV remains high. In this phase, partial erection is achieved (Fig. 10.3).

In Phase III, when the intracorporeal pressure increases to near systemic diastolic blood pressure, the EDV reaches 0 and the PSV remains high. Patients usually have a full erection with modest rigidity at this phase (Fig. 10.4).

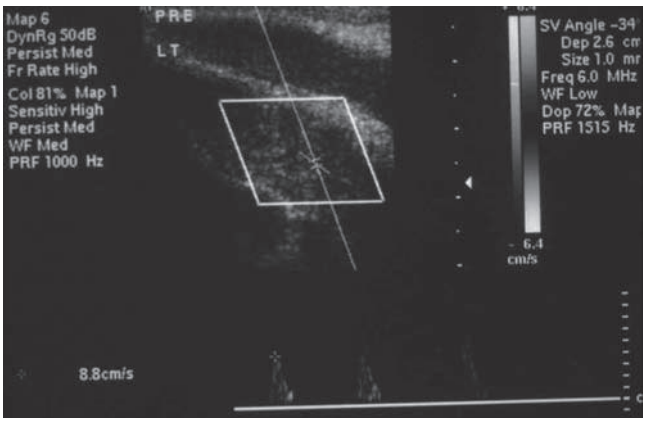

Fig. 10.1. Cavernosal arteries at a flaccid state prior to penile injection usually have a low and intermittent flow with zero end diastolic velocity

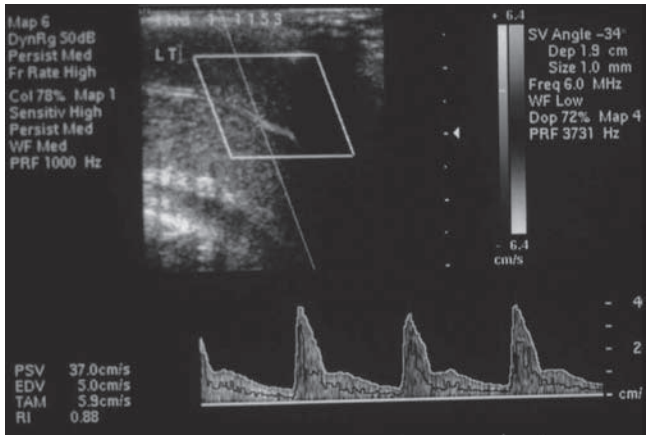

Fig. 10.2. In Phase I of pharmacologic erection, both systolic and diastolic flows increase and become a continuous flow

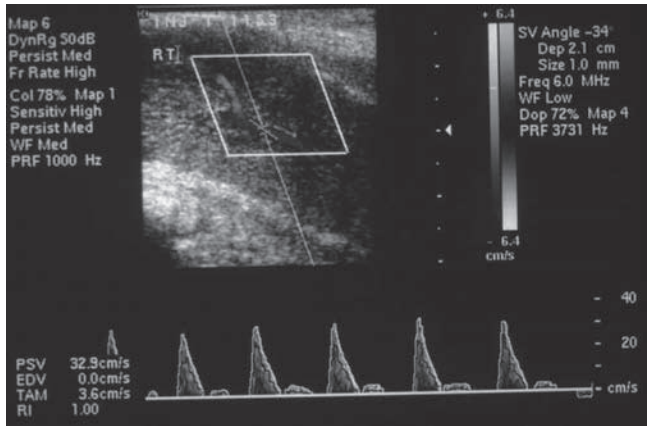

Fig. 10.3. In Phase II of pharmacologic erection, with increase in intracorporeal pressure, a progressive decrease in EDV occurs. The PSV remains high. In this picture, some diastolic flow remains, but the EDV has become zero (phase III)

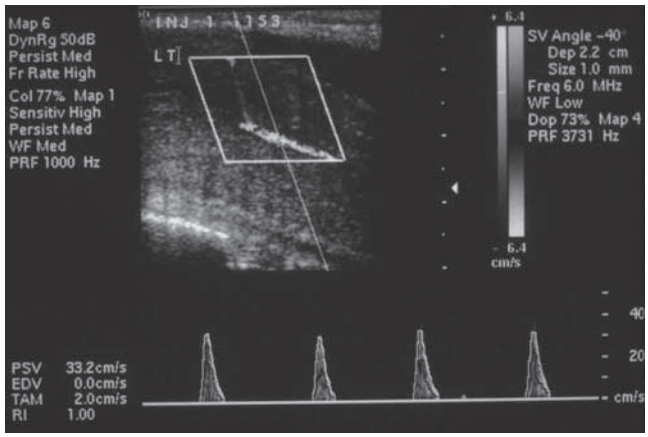

Fig. 10.4. In Phase III of pharmacologic erection, when the intracorporeal pressure increases to near systemic diastolic blood pressure, the EDV reaches 0. PSV remains high

In Phase IV, EDV becomes negative and PSV remains high. The penis further increases in its rigidity (Fig. 10.5).

In Phase V, with further increases in intracorporeal pressure and rigidity, PSV also decreases. EDV remains negative.

Hemodynamic Patterns

The hemodynamic events vary among individual patients. We stratify the color Doppler hemodynamic findings into the following eight patterns[1,2]:

I. Normal maximal PSV (≥35 cm s^{-1}), sustained (≥5 min)
Ia. EDV ≤0 with complete erectile response
Ib. EDV >0 or incomplete erectile response
II. Normal maximal PSV (≥ 35 cm s^{-1}), transient (<5 min)
IIa. EDV ≤0 with complete erectile response
IIb. EDV > 0 or incomplete erectile response
III. Borderline maximal PSV (30–35 cm s^{-1})
IIIa. EDV ≤0 with complete erectile response
IIIb. EDV > 0 or incomplete erectile response
IV. Low maximal PSV (<30 cm s^{-1})
IVa. EDV ≤0 with complete erectile response
IVb. EDV > 0 or incomplete erectile response

Interpretation of Color Doppler Ultrasound Hemodynamic Studies

We interpret the entire dynamic study and consider the maximum PSV, erectile response, and injection dose required. The dosage of pharmacologic agents used in color Doppler ultrasound studies varies among investigators. We used a modest dose (as described in procedure) for the first injection since most normal individuals respond to such dose with a complete erection. Patients responding only to higher doses are likely to have abnormal hemodynamics, and their hemodynamic abnormalities may be masked if a high dose is used from the beginning. A smaller dose also decreases the possibility of priapism. Using a modest dose priapism can still occur. All patients were informed of this possibility before the study and we emphasized the prompt and appropriate treatment for priapism. Patients were asked to call our emergency contact number if an erection lasted longer than 3 h. The option of giving a second injection to the opposite side helps avoid misdiagnosing a low PSV in the contralateral cavernosal artery.

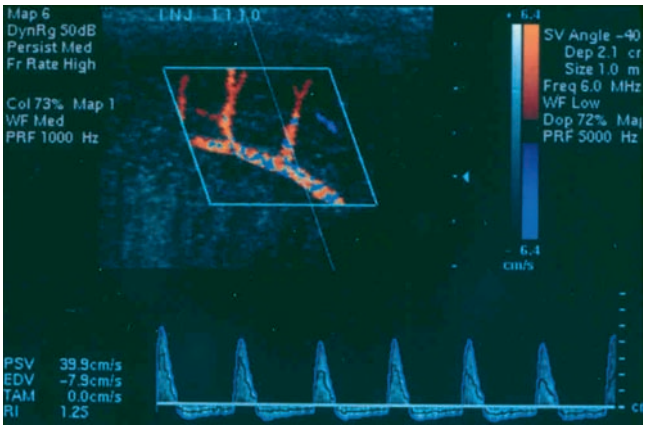

FIG. 10.5. In Phase IV of pharmacologic erection, EDV becomes negative. PSV remains high

Patients with a normal maximum PSV and a rigid erection (patterns Ia, IIa) with one injection are considered *normal*. Patients with a sustained normal maximum PSV but an incomplete erection (patterns Ib) are diagnosed as having *veno-occlusive dysfunction*. Patients with a transient normal maximum PSV but an incomplete erection (patterns IIb) may have *arterial insufficiency* and/or *veno-occlusive dysfunction*. Patients with a borderline or low maximal PSV yet complete erectile response (patterns IIIa, IVa) probably have arterial insufficiency that is being compensated for by good veno-occlusive function. Those who have both low maximal PSV and an incomplete erection have *arterial insufficiency*, but their veno-occlusive function cannot be isolated by the study. Patients requiring a large dose of intracorporeal agent to achieve a normal maximal PSV and complete erection have some combination of abnormal erectile tissue, borderline arterial insufficiency, and/or veno-occlusive dysfunction.

Pitfalls of Hemodynamic Studies

In performing a color Doppler ultrasound hemodynamic study, it is important to watch for the following pitfalls:

1. Some authors reported using 5- or 10-min intervals for PSV measurements. Such measurement methods may not be reliably detect the highest PSV. The hemodynamic of an erection is truly a dynamic event. Many patients reach their peak response in less than 5 min. A falsely low maximal PSV could be recorded if measurements do not start within 2–3 min after the injection. Furthermore, the PSV may not be sustained in a normal range for longer than 5 min. A dynamic observation rather than a spot check is preferable.[2,5]
2. PSV values differ with varying sites of measurement. We find that the PSV is generally highest at the proximal cavernosal artery and decreases with more distal sites of measurement. We noted that the PSV at the midshaft is, on average, 68% of that at the penoscrotal junction. Additionally, only 25% of patients having a normal PSV at the proximal penile shaft also have a normal value at the midshaft.[5] Thus, measuring distal sites may give a false low value, making it preferable to measure hemodynamic parameters at a consistent proximal site. We find it technically more difficult to measure the hemodynamic parameters at the proximal crura through the scrotum; therefore, the penoscrotal junction is our preferred site of measurement.

3. Consider the impact of varied vascular anatomy on the measurement of hemodynamic parameters. The cavernosal artery anatomy varies among patients. Some anatomical variations have impact on the hemodynamic parameters.[7] Patients with a bifurcated cavernosal artery or a cavernosal artery that gives out major branches at the proximal shaft tend to have a lower PSV after the bifurcation or branch. Thus, it is better to measure the hemodynamic parameters proximal to the branch. The majority of patients with bifurcated arteries or multiple arteries have different PSV values in each. If it is not possible to measure the hemodynamic parameters proximal to a large branch or bifurcation, it is desirable to measure the hemodynamic parameters from both branches of the artery and interpret the findings cautiously.

   By carefully assessing vascular anatomy, puzzling hemodynamics may be explained. For example, in a patient with a substantially higher PSV at the midpenile shaft than in more proximal sites, we noted a crosscorporal artery at the midshaft which supplies blood flow from the opposite corpora. This helped us to understand the unusual finding.
4. Do not diagnose contralateral arterial insufficiency when only one side of the penis is injected. The pharmacologic agents injected into one side of corpora may have a lower concentration in the opposite corpora. We have noted that patients with low PSV on the contralateral side following the first injection may convert to a normal PSV after an injection is administered to that side.[1,5,6]
5. Be careful in interpreting EDV and RI. An EDV of 0 (or RI of 1) is commonly used as an indicator of adequate veno-occlusive dysfunction. High EDV suggests venous leak. However, such diagnostic criteria should be used with caution. Since RI = (PSV – EDV)/PSV, the resistive index result depends on the EDV. When the EDV is 0, the RI is 1. When the EDV is >0, the RI is <1. In general, EDV reflects the intracorporal pressure. Schwartz et al. studied the correlation of EDV and the intracorporal pressure.[3] By placing needles in the corpora to directly measure intracorporeal pressure, they found that the EDV of the cavernosal arteries decreases with increasing intracorporeal pressure. When the pressure reached near systemic diastolic blood pressure, the EDV decreased to 0 (RI = 1). However, we believe that the EDV can also be affected by other factors, such as the status of the corporal artery and poor sinusoidal smooth muscle relaxation. We observed some patients have an EDV of zero, but have a soft penis. In these patients, the 0 EDV (and RI of 1) cannot be explained by the intracorporeal pressure. An EDV of zero with a flaccid or semierect penis is probably caused by an arterial factor rather than intracorporeal pressure, making it a mistake to conclude that a patient has adequate veno-occlusive function based on EDV and RI alone. Furthermore, at a flaccid state of penis, we commonly observe an intermittent cavernosal artery flow with a zero EDV. It reflects the contracted state of the cavernosal artery and does not indicate that the patient has an adequate veno-occlusive function. Thus it is advisable to record the status of the erection to avoid misinterpretation of EDV and RI An EDV of negative value is usually more reliable in reflecting on a high intracavernosal pressure and an adequate veno-occlusive function.[5]

To diagnose veno-occlusive dysfunction using color Doppler ultrasound, we assess the hemodynamic pattern and erectile status rather than relying solely on EDV or RI. It is reasonable to suspect the presence of veno-occlusive dysfunction if a patient has normal arterial flow but an incomplete erectile response and a high EDV after intracorporeal injection of pharmacologic agents. With a careful analysis of the hemodynamic pattern, color Doppler ultrasound provides a global assessment of veno-occlusive dysfunction in a noninvasive manner. For patients with sonographic evidence of veno-occlusive dysfunction further study dynamic infusion or gravity cavernosometry may be necessary to have a more complete evaluation before considering venous ligation surgery.[8–10]

In summary, an erection is a complex and dynamic process. Color Doppler ultrasound studies for erectile dysfunction are best performed with the involvement of a urologist who has a thorough understanding of the hemodynamics of erection. Dynamic studies and careful interpretation of blood flow parameters are necessary to provide an accurate assessment of the hemodynamic abnormalities of erectile dysfunction. Penile arterial anatomy varies among individuals. The value of hemodynamic parameters differs with varied sites of measurement. To obtain a reliable result, hemodynamic parameters should be measured at a consistent proximal site. The variation in vascular anatomy and cavernosal artery pathology should be considered when interpreting color Doppler studies.

Color Doppler Ultrasound Evaluation for Priapism

The literature on color Doppler ultrasound study of priapism is limited. Most reports are related to patients with high flow priapism as a result of cavernosal artery injury. Color Doppler ultrasound is the primary diagnostic tool for the differentiation of high flow (nonischemic) and low flow (ischemic) priapism. However, the diagnostic criterion for high flow vs. low flow priapism is poorly defined. To our knowledge, color Doppler ultrasound hemodynamic studies for priapism patients following surgical shunt treatment have not been previously reported. We found that penile hemodynamic characteristics are important not only for the initial evaluation of priapism but also for the treatment decisions after initial intervention.[11,12]

Procedure

For the evaluation of priapism, color Doppler ultrasound evaluation is performed before penile injection or aspiration. Hemodynamic assessment may be repeated after therapeutic

aspiration and penile injection of alpha adrenergic agent or shunt surgery to examine the restoration of cavernosal blood flow which indicates the adequate relief of priapism. With the penis placed toward the abdomen and the transducer placed at the ventral surface of penis, we examine the cavernosal arteries from the penoscrotal junction to the midpenile shaft and measure hemodynamic parameters (PSV, EDV, and resistive index). With the transducer pushing down the scrotum, we also examine the cavernosal arteries at the crura.

Color Doppler Ultrasound Findings and Interpretation for Priapism

Priapism is traditionally divided into ischemic (low flow) and nonischemic (high flow) categories. Color Doppler ultrasound is a useful tool to categorize priapisms. Penile blood gas has also been used to help the diagnosis. It is generally recommended that a low flow (or ischemic) priapism is a medical emergency and requires urgent management for detumescence, while a high flow (nonischemic) priapism does not require urgent management. However, this categorization and the treatment strategies based on such classification have many caveats.

Priapism is a dynamic event and the hemodynamic characteristics may vary at different phases of the condition. Additionally, the hemodynamic characteristics change after therapeutic intervention. For example, a patient who receives an intracavernosal injection of papaverine or prostaglandin E1 typically has high blood flow initially, with their high flow status lasting for a varied length of time. If remains untreated, it progresses to a low flow and ischemic status.[11,13] Metawea et al. noted that if the PSV is greater than 66 cm s^{-1} and the EDV is 0 cm s^{-1} after an intracavernous injection of papaverine/phentolamine, patients have high risk for priapism lasting for >6 h.[14] Secil et al. reported that if the cavernosal arterial flow reaches a phase of undetectable flow by color Doppler ultrasound after intracavernous injection of papaverine, the patient has high risk for persistent priapism.[15] Pharmacologically induced priapism usually go through phases of hemodynamic response, and it is not clear how long and at what point the priapism becomes ischemic.[2,5] When patients are presented at 4–6 h after injection, and a color Doppler ultrasound shows a high cavernosal arterial flow, it would not be safe to inform patients that the cavernosal blood flow is high and they require no treatment until low flow ensues.

Priapism of other etiologies probably has various phases of hemodynamic events as well. To obtain an erection, a high cavernosal arterial flow is usually required. In the case of priapism, it is not clear at what point the high cavernosal arterial flow becomes low. When these patients present for management with 24 h or longer of priapism, most patients show little detectible cavernosal blood flow in the color Doppler ultrasound.

Another caveat of categorizing patients into high flow and low flow priapism is our observation that some patients with low flow priapism may develop high cavernosal blood flow after a successful shunt surgery. Clinically, these patients may appear to have persistent priapism. However, other patients with similar clinical findings may have persistent low flow status if the shunt surgeries have not achieved their goal. We find that the CDU hemodynamic characteristics are important for subsequent treatment decisions following the initial shunting procedure.[11–14] One patient's CDU, who previously failed Winter shunt and Quakle shunt treatments before being referred to us, showed undetectable cavernosal blood flow. We performed a penile cavernosa-dorsal (CD) vein shunt, and his CDU study showed high cavernosal blood flow following surgery (Fig. 10.6). It is not uncommon following initial shunt surgery for patients to have some degree of persistent erections. This could be due to ineffective shunt surgery or postischemic hyperperfusion. If patients have ineffective shunt surgeries without further intervention, they are likely to be impotent subsequently. Thus, color Doppler ultrasound confirmation of priapism resolution is desirable.[11–13]

With these considerations, we believe that to understand the basic hemodynamic abnormality during various phases of priapism is of critical importance in the management of priapism. We believe that the traditional classification of "high flow"/low flow or ischemic/nonischemic requires modification. We classify priapisms according to the hemodynamic abnormality and underlying pathophysiology as follows:

1. *Arteriogenic priapism.* These patients typically have perineal trauma that causes cavernosal artery injury. Color Doppler ultrasound typically shows the presence of arteriosinusoidal malformation (Fig. 10.7). The cavernosal blood flow varies, but a pure arteriogenic priapism without veno-occlusive component seldom has the EDV <0 cm s^{-1}.
2. *Veno-occlusive priapism.* The veno-occlusive mechanism of erection is initially a result of passive compression by

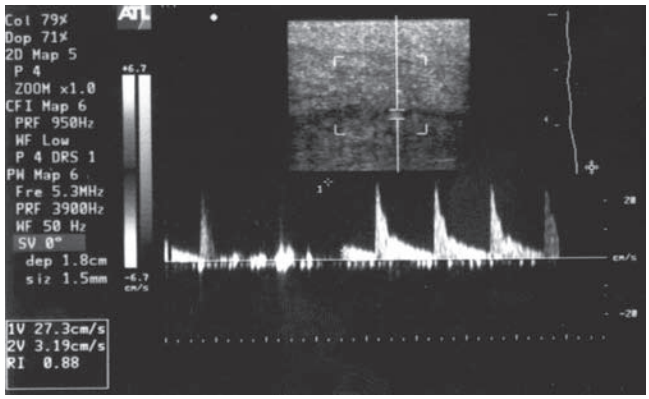

Fig. 10.6. In a patient who previously failed Winter shunt and Quakle shunt, initial CDU shows undetectable cavernosal blood flow. We performed penile cavernosa-dorsal (CD) vein shunt, and his CDU study showed high cavernosal blood flow after surgery

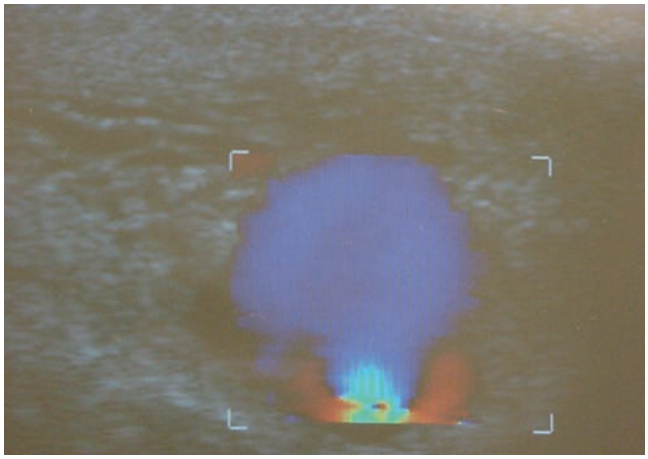

FIG. 10.7. Color Doppler ultrasound typically shows the presence of arterio-sinusoidal malformation

the dilated sinusoids which is induced by smooth muscle relaxation and increased cavernosal arterial blood flow. We hypothesize that after a certain time period of passive compression, thrombosis of emissary veins may develop causing primarily veno-occlusive priapism.

3. *Combined arteriogenic and veno-occlusive priapism*. Priapism induced by an intracorporal injection of erection inducing pharmacological agents typically has both an arteriogenic component and a veno-occlusive component during the initial phases. When the effect of pharmacologic agents on the cavernosal artery subsides, persistent priapism may become solely the veno-occlusive component.

In the course of priapism in an individual patient, the hemodynamics may change at the different phases of their priapism, and they should be managed differently according to their hemodynamic pattern.

The recognition of hemodynamics in priapism is also important in deciding whether priapism patients should receive a second shunt surgery. We believe that an effective shunt should relieve the veno-occlusive status of priapism. In color Doppler ultrasound, restoration of cavernosal blood flow with a positive or zero EDV is usually observed. A negative value of EDV and/or undetectable cavernosal blood flow usually indicates the persistence of veno-occlusive priapism. Patients who were referred to us after having failed previous shunt surgeries typically have veno-occlusive priapism in color Doppler ultrasound study. After we carry out penile CD shunt surgeries for these patients, we commonly observe a restoration of cavernosal arterial blood flow. With our technique of penile CD shunt, the patency of shunt can usually be detected by color Doppler ultrasound.[11–13] Some patients may have a period of high cavernosal blood flow after their penile CD shunt surgery. This is likely related to postischemic hyperperfusion and may be one of our body's repairing mechanisms for the damaged cavernosal tissue. This observation has two significant clinical implications. First, if the color Doppler ultrasound study, performed after a surgical shunt procedure, shows the persistence of undetectable blood flow, one should suspect that that shunt has not achieved its intended purpose to adequately drain the cavernosal blood. Second, if the patient appears to have a persistent priapism following a shunt procedure, but the color Doppler ultrasound reveals high cavernosal blood flow and a patent shunt, it may be part of a recovery phase for priapism after a successful shunt surgery. Thus observation rather than further intervention is recommended. With a management strategy that utilizing penile CD shunt and incorporating color Doppler ultrasound studies before and after shunt surgery, we have noted high rate of potency preservation for priapism patients.[13]

In summary, the hemodynamic of priapism appears to have various phases. Color Doppler ultrasound is useful not only to differentiate arteriogenic priapism from veno-occlusive priapism, but also in monitoring the success of shunt surgery. If color Doppler ultrasound shows a recovery phase of hemodynamics with high cavernosal blood flow and a patent shunt, further surgery is not necessary. In contrast, if following a surgical shunt procedure the cavernosal blood flow remains undetectable or has not improved since before the shunt surgery, it is likely that the shunt surgery has not achieved its purpose and further intervention should be performed without undue delay.

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