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SPECIAL SECTION: MALE PELVIS

Utility of dynamic MRA in the evaluation of male erectile dysfunction

Alexandra Roudenko[1] · Rand N. Wilcox Vanden Berg[3] · Christopher Song[2] · Martin R. Prince[2] · Darius A. Paduch[4,5] · Daniel Margolis[2]

Abstract

Purpose To assess the efficacy of time-resolved MR angiography (MRA) in evaluating penile vasculature in patients with clinically suspected vascular anomalies contributing to their erectile dysfunction correlating with penile doppler ultrasound (PDUS) findings and clinical outcomes after surgical intervention.

Methods Men ($n=26$) with signs of early vascular shunting on PDUS underwent time-resolved, contrast-enhanced (0.1 mMol/kg gadobutrol at 1 ml/s followed by saline flush) 3-dimensional spoiled gradient echo T1-weighted MRA sequence performed over 3 min with 4.6 s frame rate after intracavernosal injection of an erectogenic agent. Additional T1- and T2-weighted sequences were performed for anatomic co-localization and tissue characterization. MRA images were evaluated for early filling of draining veins as well as arteriovenous malformations and fistulas and correlated with findings at surgery.

Results 29 MRA examinations on 26 patients (mean age 39 years) demonstrated abnormal early venous drainage ($n=22$) as well as diminutive/delayed cavernosal enhancement ($n=3$), incomplete tumescence ($n=2$), and combined arterial inflow/venous outflow disease ($n=1$). The MRA had a concordance of 85.2% at determining the presence, or lack thereof of a shunt/AVM when compared to PDUS.

Conclusions Time-resolved MRA allows for both temporal and spatial resolution with visualization of both arterial and venous abnormalities which may be suggested with a screening PDUS examination. This technique allows us to provide detailed anatomic information prior to any surgical intervention.

Keywords Erectile dysfunction · MR angiography · Time-resolved MRA · Venous leak · Dynamic MRA

Introduction

Erectile dysfunction (ED), generally defined as the consistent or recurrent inability to attain and/or maintain penile erection sufficient for sexual satisfaction [1–3], may significantly reduce quality of life [4] for as many as 30 million men in the United States [5] with 8–52% of men throughout the world experiencing some degree of ED symptoms depending on the specific population being evaluated [3, 5–7]. While historically labeled as a disease of older men, ED is experienced by men of all ages [11] with prior studies estimating 21% of men aged 30–79 and 22–39% of men aged 40 and above suffering from ED [7–9]. ED is often more distressing to younger patients at the peak of their fertility when establishing an intimate relationship and starting a family are important goals [3, 7, 8, 10].

Vascular causes of ED include arteriogenic impotence secondary to diabetes, hypertension, and atherosclerosis, especially in older men. Venous leakage also contributes to inadequate penile tumescence. Trauma, structural alterations, and acquired venous shunts are some of the causes of abnormal venous leakage [11] which can lead to ED. In one study of 948 men in Turkey with a mean age of 48 years, 34.6% had an organic etiology and of those patients, 40.5% had arteriogenic causes and venogenic

✉ Alexandra Roudenko
sasha.roudenko@gmail.com

1 Department of Radiology, Mount Sinai Health System, 1000 10th Ave, New York, NY 10019, USA

2 Department of Radiology, Weill Cornell Medicine, 1305 York Ave, New York, NY 10021, USA

3 Department of Urology, Weill Cornell Medicine/New York Presbyterian, 525 E 68 St, New York, NY 10065, USA

4 Arthur Smith Institute for Urology, Northwell Health, 1000 Northern Blvd, Ste 120, Great Neck, NY 11021, USA

5 Bioimaging Lab, Consulting Research Services, Inc, North Bergen, NJ, USA

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causes in an additional 10%; although within the cohort of patients under 40, 16.6% had venogenic etiologies [12]. Penile Doppler ultrasound (PDUS) is an excellent screening examination [5] as 49% of ED in younger males is arteriogenic or venogenic in origin [12].

Combined surgical-radiologic approaches allow for better evaluation of abnormal venous drainage for optimal surgical planning. While PDUS is the mainstay of initial minimally invasive imaging, other options include computed tomography (CT) [13] and MRI with MRI perfusion parameters previously found to correlate with self-reported ED symptoms [14]. More invasive methods such as penile angiography [15, 16] and cavernosography [16] are more useful than PDUS as they allow for a detailed investigation of anatomic variants. However, the invasiveness as well as radiation concerns for these younger patients limit penile angiography as an early imaging modality and to cases where surgical intervention is planned [17]. Our practice routinely utilizes MR angiography which provides similar or complementary information with the ability to acquire and reformat the images in optimally obliqued imaging planes for surgical guidance as well as providing temporal information about vascular inflow and outflow. Even in patients who may eventually proceed to conventional angiography, prior evaluation with MRA may decrease catheter manipulations and fluoroscopy time (radiation exposure) as part of the vascular anatomy will have been delineated beforehand. Here we describe our experience using MRA to assess ED in 26 patients with suspected vascular etiologies.

MRA provides advantages over PDUS as it is able to assess patients with mixed arterial and venous causes of ED. While a prior study investigated the utility of MRA in evaluating penile arteries prior to revascularization in patients with ED secondary to arterial insufficiency, their conclusion was that conventional digital angiography was essential and they were not able to differentiate dorsal, cavernosal, and perforating arteries [14]. However, with current technology, MRA penile evaluation is able to achieve exquisite temporospatial resolution, further enhancing its utility over CT angiography where potentially only one or two useful time points would be obtained due to ionizing radiation concerns as well as its technical limitations. At our institution, we have developed a magnetic resonance angiography (MRA) protocol that makes it possible to elucidate anatomic variants suggested by PDUS or clinical history without subjecting patients to an invasive procedure or ionizing radiation. The objective of this study was to retrospectively analyze MRA in the evaluation of young men with suspected aberrant vascular anomalies contributing to ED with correlation with PDUS findings and clinical outcomes after surgical intervention.

Methods

Patient selection

All ED patients presenting from January 2017 to May 2019 with early shunting of blood on PDUS or other suggestion of a vascular etiology were investigated with dynamic MRA. A HIPAA-compliant retrospective review was approved by the institutional review board with informed consent waived.

Inclusion criteria include all adult men with ED and suggestion of abnormal vascular inflow and/or shunting on PDUS. Exclusion criteria include not being able to undergo MRI or receive gadolinium-based intravenous contrast agents.

Patient examinations cannot be delayed due to the time sensitive nature of the intracavernosal injection and therefore are required to be scheduled at MRI scanners in close proximity to the urology office where the erectogenic agent is administered prior to the MRA. Additionally, evaluation of patients who fail to achieve and maintain tumescence during the MRA is a relative contraindication as well as those where the exam cannot be adequately performed due to patient interruption or premature termination of the acquisition.

Penile Doppler ultrasound evaluation

PDUS was performed in the clinic by a urologist with 17 years of experience and expertise in treating ED. The initial PDUS measured the diameter of the cavernosal arteries (CAs) prior to pharmacologic therapy. Subsequently, patients underwent intracavernosal injection with 10 units of an erectogenic agent (Trimix or Super-Trimix); if after 15 min there was incomplete tumescence, the dose was escalated and injection repeated until adequate tumescence was achieved. The amount of erectogenic agent required for tumescence during PDUS was used to guide amount for MRA. Spectral Doppler analysis measured the peak systolic velocity (PSV), the end diastolic velocity (EDV), and the resistive index of the CAs during stimulated tumescence. Patients that did not detumesce within 30 min of PDUS were given 120 mg of oral pseudoephedrine; if they did not detumesce within another 15 min, they were injected intracavernosally with 500 µg of phenylephrine. Early vascular shunting was suspected when there was an abnormal arterial course of the CAs (e.g., branching, premature termination) or abnormal vascular connections visualized (Fig. 1). PSV values less than 25 cm/s were considered suggestive of arterial insufficiency and lack of reversal of flow during diastole, a resistive index < 0.70, and/or persistent EDV over 5 cm/s suggested the presence of venous leak.

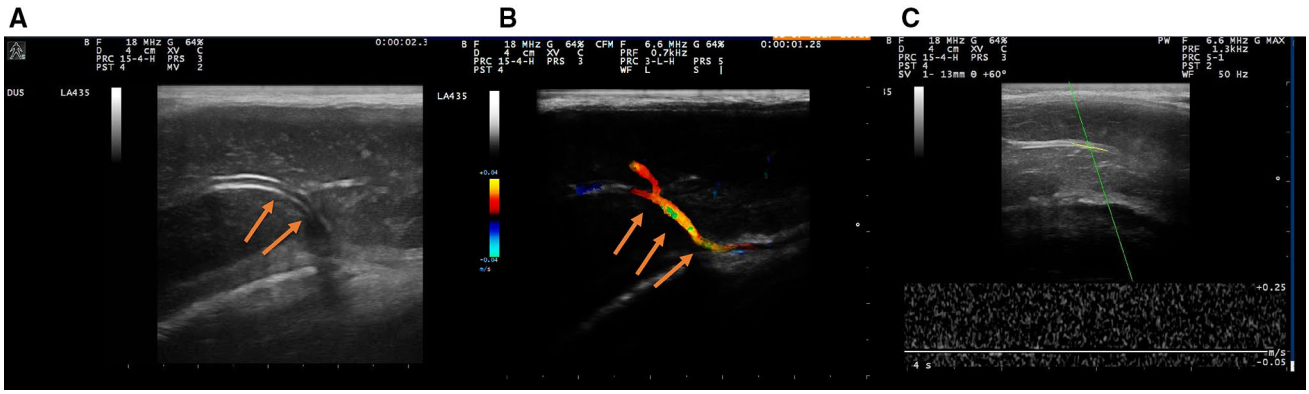

Fig. 1 Abnormal course of right cavernosal artery connecting with a superficial vessel compatible with shunt before and after Hsu venous ligation of fistula and venous stripping. **a** Grayscale longitudinal ultrasound image with right cavernosal artery deviating from its normal course through the corpus cavernosum (arrows). **b** Color Doppler ultrasound of cavernosal artery demonstrating abnormal course. **c** Power Doppler ultrasound with no more flow detected through shunt postoperatively

Patient preparation for dynamic MRA

15 min prior to scheduled MRA, patients underwent intracavernosal injection with an erectogenic agent (Trimix or Super-Trimix); the amount was dictated by the amount used for the PDUS, which on average was equal to 4–6 times their regular amount of erectogenic agent used at home (Trimix, or Super-Trimix). Erection grade was assessed subjectively by the urologist 10 min later and if adequate, they proceeded to the MRA. Furthermore, the radiology technicians were trained to alert the urologist and radiologist if the patient began to detumesce during image acquisition. After the completion of MRA image acquisition, the patient was again examined by the urologist to assure that the erection was adequately maintained as the study is significantly limited when tumescence is incomplete. Patients that did not detumesce within 30 min of returning to the urologist's office (approximately 1.5 h after initial injection), were given 120 mg of oral pseudoephedrine; if they did not detumesce within another 15 min, they were injected intracavernosally with 500 µg of phenylephrine.

MRI protocol

Patients were scanned at 1.5 Tesla ($n=1$) or 3 Tesla ($n=28$) (Siemens Magnetom Aera and Skyra, respectively) using the body coil for signal transmission and a 32-channel phased array coil for signal reception. 3D spoiled gradient echo time-resolved imaging with stochastic trajectories (TWIST) was acquired in the coronal plane using the parameters listed in Table 1. After acquisition of a mask data set, imaging was begun simultaneously with injecting 0.1 mMol/kg gadobutrol at 2 ml/s followed by 20 ml saline flush at the same injection rate. Both mask subtracted and unsubtracted 3D image data sets were reconstructed on a computer workstation (TeraRecon Inc, California, USA) to obtain reformations and subvolume maximum intensity projections (MIPs) optimized for evaluation of arterial supply and venous drainage from the penis. Anatomic co-localization and tissue characterization was performed with axial and sagittal T2-weighted turbo spin-echo images, axial T2-weighted turbo spin-echo images with fat saturation, and axial and coronal 3-dimensional gradient-recalled echo (Siemens VIBE-DIXON) pre- and post-contrast images. The duration of the MRI examination was approximately 30 min with 15 min of scan time prior to administration of gadolinium contrast.

The imaging field of view extended superiorly to include the aortic bifurcation and sufficiently posteriorly to include

Table 1 MRA protocol parameters

TWIST MRA	
Parameter	Value
TR	2.64
TE	1
Flip angle	19°
FOV	36 cm
Matrix	352 × 194
Slice thickness	1.25 mm
Temporal resolution	2.36 s
Pixel bandwidth	790 Hz
Temporal update rate	4.6 s
Voxel size	1 mm × 2 mm × 1.25 mm
Voxel volume	2.3 mm^3
Acquisition time	2.31 min
# of phases	30

the internal iliacs as well as pudendal artery origins. Anterior extent of field of view included penile arteries. The anatomic imaging delineates ventral or dorsal location of the vascular abnormalities and characterized findings that were not simple vascular malformations such as fibrosis with Peyronie's disease, benign and malignant penile masses, partial cavernosal thrombosis, and sequelae of trauma [18–20].

Image analysis

All MRA time-resolved MRA studies were reviewed in consensus by 2 radiologists (DM—a fellowship trained GU radiologist with 14 years post fellowship experience—and AR—a fellowship trained body radiologist with 6 years of radiology experience) blinded to patient information. Observers noted qualitative enhancement and timing of the cavernosal and dorsal penile arteries, any areas of abnormal enhancement prior to enhancement of the systemic veins, as well as the location (right/left, superficial/deep, ventral/dorsal).

Statistical analysis

Descriptive statistics only were performed, as this was a single-arm, retrospective study. The correlation between venous shunt identified on PDUS and MRA is computed with the McNemar Chi Square correlation. The frequency of outcome is provided based on initial and final diagnoses.

Results

Patient demographics

A total of 29 MRA examinations were performed on 26 patients at our institution during the period of retrospective review; the baseline characteristics are presented in Table 2. Average patient age at initial evaluation was 39 years (range 18–73; median 36). Average length of ED symptoms was 9.3 ± 7.1 years. The Male Sexual Health Questionnaire (MSHQ), a validated questionnaire [21], was given to all patients at initial evaluation and the relevant portions are reported: on average patients scored low in the erection scale (6.41 ± 3.41 out of a max of 15), in the ED bother scale (1.63 ± 0.79 out of a max of 5), and in the satisfaction scale (19.35 ± 7.15 out of a max of 30). The most common comorbidity was the presence of a varicocele (58.6%), followed by hypogonadism (31%), Peyronie's (13.8%), and hypertension (13.8%). Of the 29 MRA examinations, 2 patients demonstrated incomplete tumescence during the MRA examination limiting its diagnostic utility (Table 3) with one of the patients brought back for a repeat study. The other patient had clearly demonstrated abnormalities bilaterally despite

Table 2 Baseline characteristics

	Average (years)	Range (years)
Age at initial evaluation	39.27 ± 12.1	18–73
Age of onset	30.33 ± 11.3	15–59
Duration	9.3 ± 7.1	1–30
Comorbidities		*n* (%)
Hypertension		4 (13.8)
Diabetes mellitus		1 (3.5)
History of priapism		0 (0)
Peyronie's		4 (13.8)
Coronary artery disease		0 (0)
Hypogonadism		9 (31.0)
Varicocele		17 (58.6)
Tobacco use		3 (10.3)
Timing		Median (IQR)
PDUS to MRI, days, $n = 26$		89 (41.25–284)
MRI to surgery, days, $n = 11$		64 (56.5–92.5)
MSHQ at initial evaluation		Total
Erection scale (max 15)		6.41 ± 3.41
ED bother scale (max 5)		1.63 ± 0.79
Satisfaction scale (max 30)		19.35 ± 7.15

Table 3 Abnormalities on MRA examinations

Summary of MRA findings
Of 29 MRA examinations
2 with incomplete tumescence
22 demonstrated abnormal early venous drainage
3 delayed/diminutive cavernosal enhancement
1 combined arterial inflow and venous outflow
3 with a vascular plexus without early venous drainage
1 blush of contrast in corporeal tissues without early venous drainage

partial detumescence with ED for the past 30 years and a history of multiple pelvic surgeries.

Ultrasound evaluation

All patients underwent PDUS evaluation prior to evaluation with MRA (Table 4). Average PDUS values were PSV 43.66 ± 21.22 cm/s, EDV − 1.63 ± 7.86 cm/s, CA diameter 1.3 ± 0.3 mm, and RI 0.99 ± 0.19. Venous leak was present in 9 patients (32.1%), arterial deficiency in 11 (39.3%), and both venous leak and arterial deficiency in 3 patients (11%). 22 (84.6%) had vasculature concerning for a shunt or arteriovenous malformation (AVM). Furthermore, the PDUS reports which mentioned a possible shunt/AVM when visualized by the operator and the presence or lack thereof had a concordance of 85.2% when compared to the MRA reads. MRA and PDUS were concordant in 22 patients for the presence of a shunt and 2 in the absence thereof; MRA was more sensitive than PDUS ($p = 0.027$). However, the McNemar Chi Square correlation demonstrated a two tailed p value of 0.48, with Chi square statistic of 0.5 for a Yates correction of 1.0.

Of the 4 patients who had discordant results between PDUS and MRA, one had early venous drainage suggesting an arteriovenous fistula seen on MRA but not PDUS; another patient had a shunt suggested on PDUS but no early venous drainage and primary arterial inflow disease on MRA; the third patient had a possible shunt suggested on PDUS but no findings to suggest one on MRA; and the last patient had PDUS suggesting a shunt but MRA was notable for tortuous and dilated left arterial inflow.

MR angiography

Arterial inflow

Iliac arteries were visualized on average 33.3 s after contrast injection (Table 5; range 13.3–52.6 s; median 32.5 s) with common penile arteries visualized on average 5.7 s later (range 0–21.4 s; median 4.9 s). There was a slightly earlier average time to visualization of dorsal penile arteries compared to cavernosal enhancement (average 9.1 s vs. 11.4 s; range 3.5–21.4 s for dorsal and 3.5–45.2 s for cavernosal; median 8.8 s vs. 9.7 s) secondary to the patients with arterial inflow disease.

Of our patient cohort, 4 patients had delayed and diminutive cavernosal enhancement suggesting inflow disease including one patient with combined arterial inflow and venous outflow disease (Table 3). One patient with a dominant dorsal artery demonstrated vascular supply from the superficial inferior epigastric artery.

Venous outflow

Of the 29 MRA examinations, 22 demonstrated abnormal early venous drainage. An additional 3 patients were noted to have a prominent vascular plexus at the penoscrotal junction without abnormal early venous drainage as well as one patient with blush of contrast in the corporeal tissues after visualization of the systemic veins (Table 3).

Table 4 Baseline PDUS results: peak systolic velocity (PSV), end diastolic velocity (EDV), cavernosal artery (CA), resistive index (RI), arteriovenous malformation (AVM)

	Mean (standard deviation)
PSV (cm/s)	43.66 (21.22)
EDV (cm/s)	− 1.63 (7.86)
CA diameter (cm)	0.13 (0.03)
RI	0.99 (0.19)
Post-PDUS diagnosis	*n* (%)
Venous leak present	9 (32.1)
Arterial deficiency	11 (39.3)
Suggested AVM/shunt	22 (84.6)

Table 5 Patient age and timing of visualization of vascular structures

	Average	Median	Minimum	Maximum
Patient age (years)	39.3	36	18	73
Vascular visualization				
Iliac arteries (s)	33.3	32.5	13.3	52.6
Δ Common penile arteries (s)	5.7	4.9	0	21.4
Δ Dorsal arteries (s)	9.1	8.8	3.5	21.4
Δ Cavernosal arteries (s)	11.4	9.7	3.5	45.2
Δ Abnormal venous drainage (s)	14.0	12.0	3.5	32.9
Δ Systemic veins (s)	22.91	20.1	9.5	55.3

Early venous drainage was noticed on average 14 s after opacification of the iliac arteries (Table 5; range 3.5–32.9 s; median 12 s) with systemic veins visualized on average 22.9 s after iliac artery opacification (range 9.5–55.3 s; median 20.1 s).

Surgical findings and outcomes data

Surgical correction was pursued for all patients where the MRA suggested a vascular abnormality amenable to surgery. To date, 11 patients have undergone venous ligation. For patients who underwent surgical repair of suspected vascular causes of ED, the operative findings were noted at the time of surgery and were significant for sustained erections after penile vascular surgery was completed. For our very short term simple outcomes post-operative ED severity has been assessed subjectively through interview with all subjects reporting subjective improvement of ED and no immediate complications. Additionally, one patient has undergone repeat PDUS showing resolution of venous leak (Fig. 1).

Discussion

Vasculogenic ED can be due to a variety of factors ranging from atherosclerosis and venous leak, to congenital or trauma-induced anatomical variations, and is suggested when oral medications for ED such as phosphodiesterase-5 (PDE5) inhibitors or intracavernosal injections fail [5]. In our cohort of young men with an average age of 39 years, MRA allowed us to identify and describe these vascular variations in a non-invasive manner with 85% concordance rate between PDUS and MRA findings. All men had symptoms of erectile dysfunction with an average duration of 9 years. Common penile arteries were visualized on average 5.7 s after the iliac arteries with dorsal arteries at 9.1 s and cavernosal arteries at 11.4 s post iliac artery opacification. In the 22 MRI examinations with early venous drainage visualized, abnormalities were seen on average 14 s after the iliac arteries.

Detailed arterial characterization evaluates patency of cavernosal and dorsal arteries as well as their supply from the internal pudendal and common penile arteries [18] (Figs. 2 and 3) as abnormal arterial inflow may be the etiology of clinical symptoms. Abnormalities that may be visualized include diminutive or delayed enhancement of the cavernosal arteries, predominantly superficial arterial inflow, and abnormal arterial supply to the cavernosal arteries which implies the presence of a shunt and steal syndrome, potentially the cause of patients ED. Of our patient cohort, 4 had delayed and diminutive cavernosal enhancement as well as one patient with the superficial inferior epigastric artery supplying a dominant dorsal artery. Previously described normal arterial variations include dominant laterality of the cavernosal artery or the presence of an accessory pudendal artery [22, 23], cavernosal artery arising from superficial dorsal artery, bifurcating cavernosal arteries, double and triple cavernosal arteries, and dorso-cavernosal anastomoses [24–26].

While dorsal and cavernosal arteries should enhance similarly, diminutive and delayed cavernosal enhancement may be visualized, which is compatible with the presence of impaired penile perfusion with a subsequent decrease in oxygen tension leading to overall increased time to achieve maximal erection and decreased rigidity of the erect penis [27]. Diffuse cavernosal arterial insufficiency may reflect systemic processes such as atherosclerosis, while focal abnormalities are more often seen in younger patients who have a history of blunt pelvic and perineal trauma [27].

Venous outflow is via emissary veins which perforate through the tunica albuginea and drain into a venous plexus and then into the deep dorsal veins [5, 18]. Cavernosal veins have also been described which span the length of the corpus cavernosum with a communicating vein to the deep dorsal vein and numerous emissary veins to the corpora cavernosa [28]. Abnormal venous outflow may be visualized as one or more focal areas of early and persistent venous enhancement within the penis prior to the visualization of enhancement within the iliac veins (Fig. 4). This early venous drainage is a connection not subject to normal erectile dynamics and may be accounting for patients symptoms as blood entering has

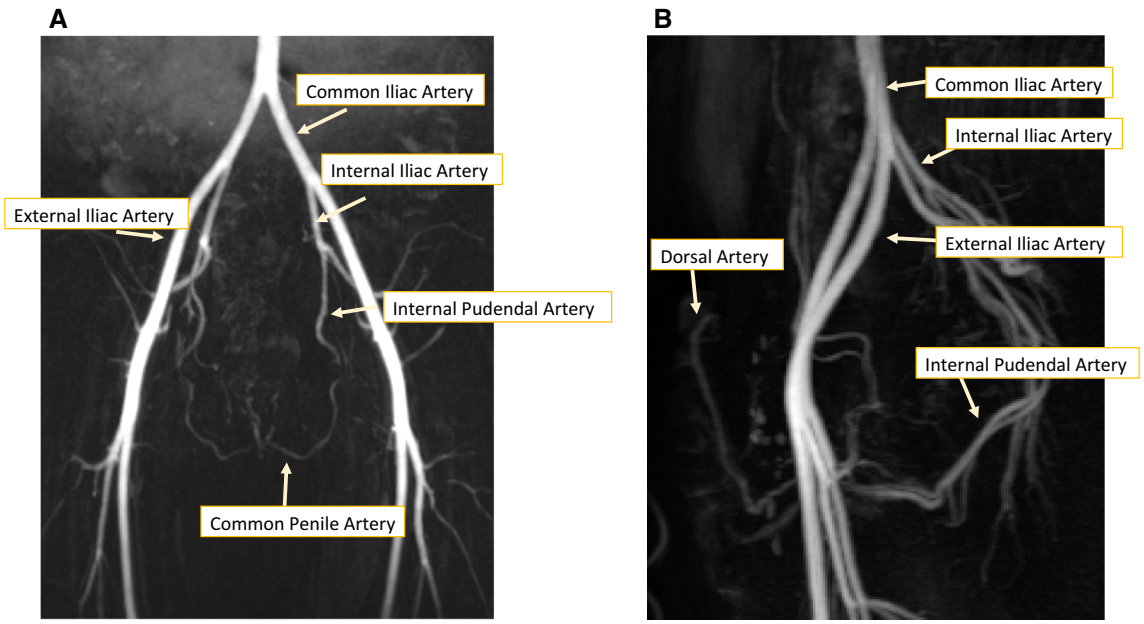

Fig. 2 Normal arterial anatomy on MR angiography (**a** coronal, **b** sagittal)

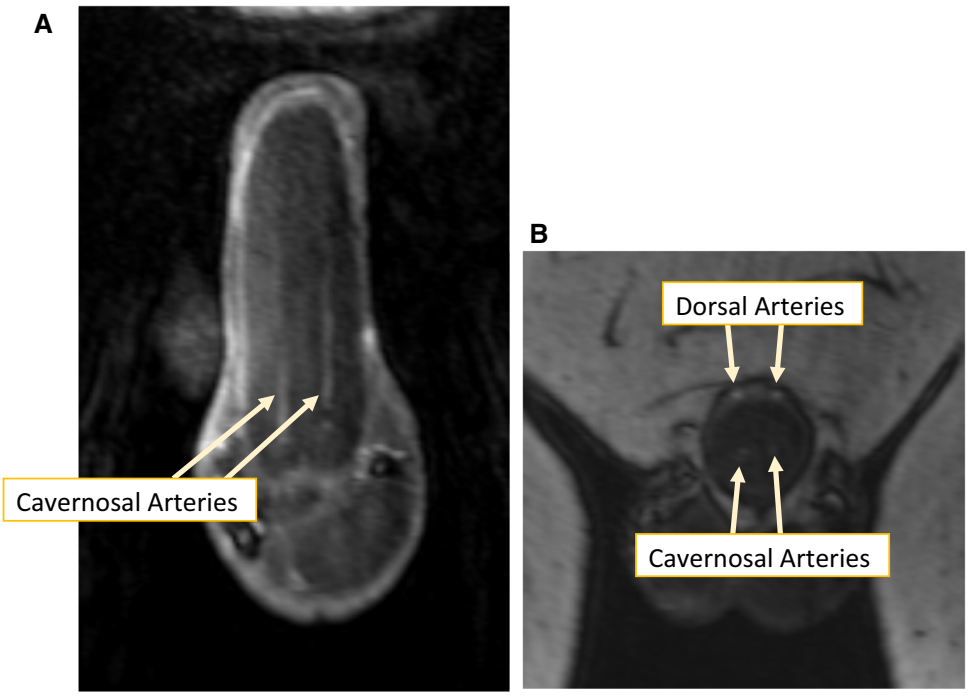

Fig. 3 Cavernosal and dorsal arteries on MR angiography: **a** Coronal GRE through the penile shaft. **b** Coronal GRE posteriorly at the level of penoscrotal junction

a path of less resistance through which it can exit. Differentiation of superficial versus deep, and ventral versus dorsal, early venous drainage is performed with co-localization of the vascular malformation visualized on MRA with location on the anatomic images.

PDUS is best utilized as a screening examination that can suggest a vascular abnormality and presence of a shunt as well as a preliminary understanding of the patient's anatomy. This technique, however, is subject to issues common to ultrasound including significant operator variability [26] and difficulty with reconstructions and image manipulation as well as studies suggesting confounding with false positive results on duplex ultrasound alone [17]. MRA is necessary for confirmation of findings (Fig. 5), sometimes

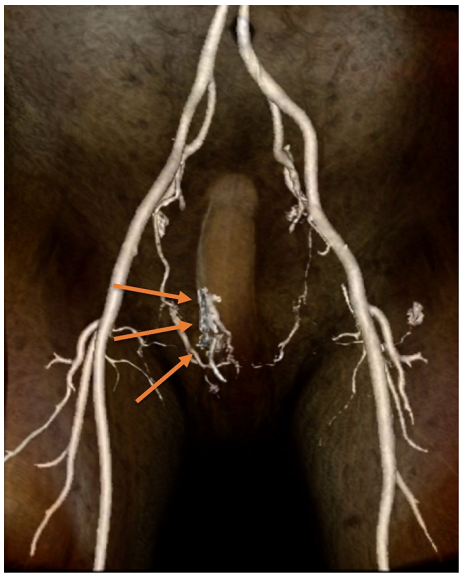

Fig. 4 Volume-rendered coronal MRA MIP demonstrating a vascular malformation at the right penoscrotal junction extending almost to the level of the glans with superficial early venous drainage (arrows)

clarifying points of confusion after PDUS. The MRA serves as a confirmation of such vascular abnormalities and allows the surgeon to visualize where along the course of the penile vasculature the abnormality originates and where to focus during surgical planning. With such confidence, the patient and surgeon can undergo a more informed consent and proceed with surgery.

Given the excellent spatial and temporal data achieved with MRA, we can now provide more detailed anatomic information prior to any potential surgical intervention. Primary inflow deficiency can be corrected via bypass from the internal pudendal artery or via stenting [10]. Furthermore, venous stripping procedures can address venous leak, with newer techniques addressing initial shortcomings [27, 29, 30]. After the implementation of our current workup strategy, at our institution, surgery is only performed once patients have undergone evaluation with MRA with the confirmed presence of a vascular malformation inhibiting the function of the normal veno-occlusive mechanism. This confirmation allows us to address the historical shortcoming of venous surgery for ED by adding a screening test to find the most suitable patients as previous iterations of penile vascular surgery have been fraught with poor outcomes which now appear to be secondary to an incomplete knowledge of penile vascular anatomy [13]. While PDUS can show anatomy and course of the CAs and raise the suspicion of a shunt, it is a screening examination and confirmation must be performed with another test such as MRA, which can help elucidate unclear findings on PDUS, confirm suspicions prior to undertaking any interventions, and help determine the dominant leak. While initial data are promising, long-term data will be necessary as patients are reassessed over the course of at least 1 year for improvement in ED symptoms.

Upon PDUS in our workflow, the patients were screened for anatomic abnormalities that could contribute to their ED. While PDUS cannot directly measure a shunt, it can suggest the presence of one with decreased PSV, no reversal of flow during diastole in the CAs, and persistent EDV over 5 cm/s [21]. For arterial disease, PSV is most accurate with values less than 25 cm/s strongly suggestive of arterial insufficiency [31]. In our cohort, 39.3% had values on PDUS suggestive of arterial insufficiency. Furthermore, PDUS showed that 32.1% of our cohort met the diagnostic parameters for venous leak and in 82.1% there was an anatomic suggestion of a shunt or AVRM.

Another potential influence on surgical planning is a visualized varicocele. It has been previously shown that when a varicocele is present in a patient with ED, correction of the varicocele improves erectile function [32]. Therefore, if a patient has a varicocele, it would be fixed before penile vascular surgery is proposed with careful attention placed on ligating veins originating from the penis and terminating in spermatic cord structures.

Prior imaging modalities for full pelvic vascular anatomy have either been invasive (angiography, cavernosography) or representing only one or two time points (contrast-enhanced MRI, CT angiography). Given the younger age of our patient population, techniques without ionizing radiation may be preferable. Time-resolved MRA allows for a better temporal and spatial resolution and has proven to be a versatile non-invasive technique. We have customized a protocol specific for evaluation of vascular etiologies of ED which allows for imaging of intrapenile vasculature as well as evaluation of abnormal inflow and outflow as an etiology of ED. Patient preparation is a key component as incomplete tumescence limits visualization especially of the cavernosal arteries which may necessitate bringing patients back for repeat examinations.

Time-resolved MRA has given us a better understanding of the anatomy of the male erection in this patient population, but it has more applications that can be considered. This technology will further allow us to explore other connections between vascular systems to explain functional problems that have been previously described. Prior studies have shown an improvement in erectile function after varicocelectomy and suggested this is due to increased Leydig cell function; however, time-resolved MRA could help look for functional explanations caused by possible connections between the penile vasculature and gonadal vessels as can be seen intraoperatively [32]. This technology could also be applied to elucidating

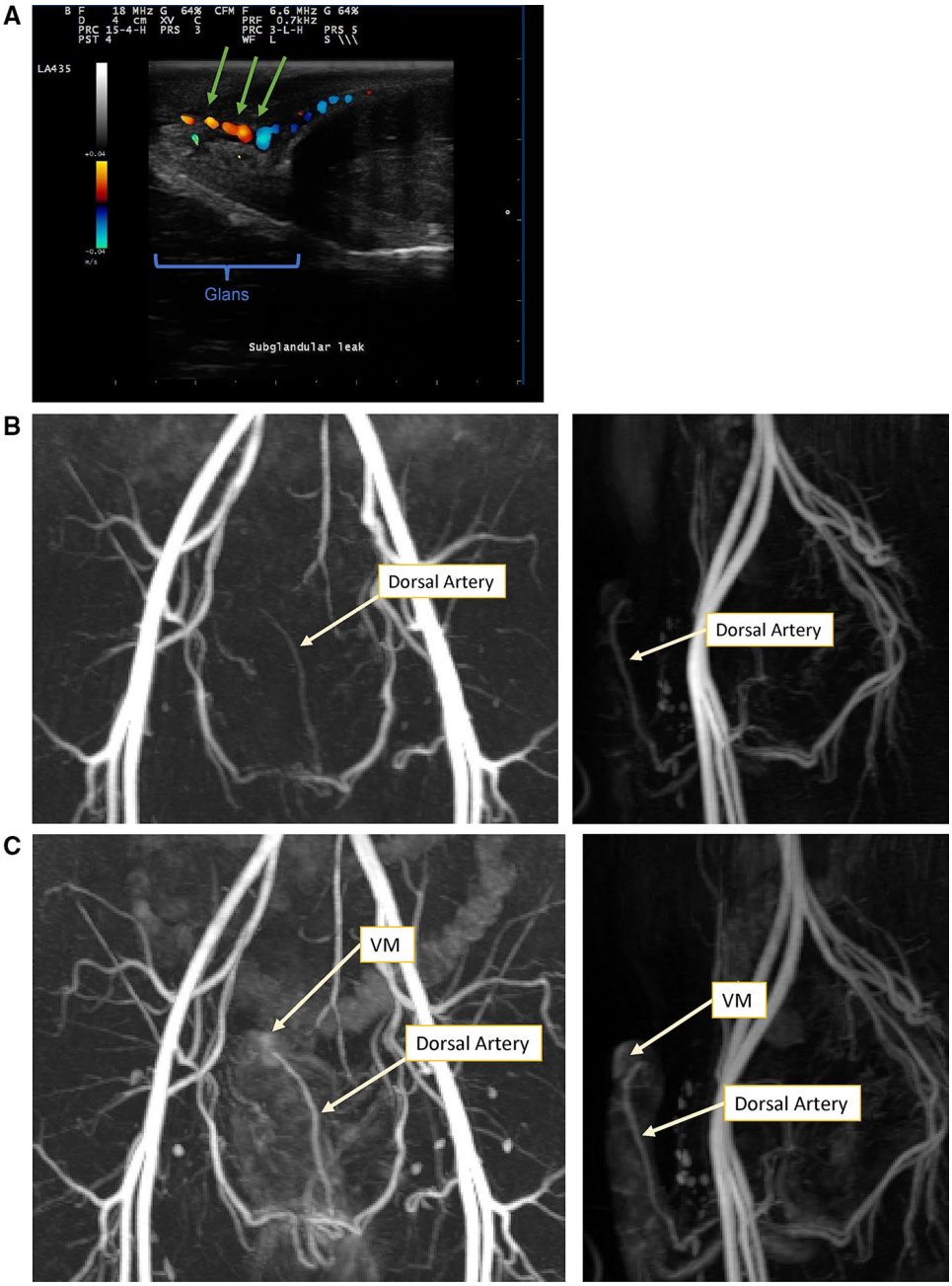

Fig. 5 Early venous drainage unilateral, unifocal. **a** PDUS with abnormal subglandular vessel concerning for leak (arrows) on longitudinal color Doppler ultrasound. **b** Coronal and sagittal time-resolved MRA MIPs in the arterial phase with asymmetrically prominent left dorsal artery. **c** Coronal and sagittal time-resolved MRA MIP at a slightly later time point demonstrating early venous enhancement of vascular malformation (VM) at the left ventral glans of the penis. Iliac veins are not yet visualized

functional outcomes after prostate artery embolization and pelvic surgery/interventions in general.

Furthermore, several additional populations may uniquely benefit including veterans and those undergoing gender affirming surgery. Veterans already have an increased risk of ED compared to the general population [33], oftentimes secondary to concurrent PTSD [10, 12, 34] which can lead to difficulties with intimacy, aggression, and anxiety. However younger veterans who served in Iraq and Afghanistan and were exposed to combat blast or other physical injuries may have devastating long-term effects on the genitourinary system [35, 36], which can lead to significant quality of life issues in this younger veteran population. In patients with severe penile injuries, treatment options are limited; however, a penile transplant has been performed [37, 38] and this MRA technique may assist in visualization of vasculature to assist in surgical planning. In those veterans with less severe injuries which are nonetheless impeding their ability to resume sexual function, time-resolved MRA can evaluate the extent of their vascular injury and potentially provide urologists with information to consider alternative surgical options.

Limitations of our study include the retrospective design as well as small sample size. Our results are from a specific

patient population. We need to study more patients to improve the statistical validity with our current relatively low p value likely related to strong positive correlation with not enough data points to show a correlation with negative results. Long-term follow-up will be necessary of patients who have undergone surgery. Additional limitations include inherent limitations with all MRI examinations such as artifact from metallic hardware or patient motion leading to non-diagnostic time-resolved MRA. Additionally, MRA may suggest information that is discordant with PDUS and physical exam, leading to diagnostic confusion and possible delay of surgical management. However, unlike PDUS, MRA has little operator dependence. Additionally, there may be instances when the MRA does not add any additional information for surgical planning, although confirmation of initial diagnosis and reassurance of no additional vascular malformations requiring treatment or other disease processes may be reason enough for patients undergoing this examination in addition to PDUS.

In conclusion, dynamic MRA is a versatile non-invasive technique which allows for excellent temporal and spatial resolution with our customized protocol developed for evaluating penile vasculature and abnormal vascular processes contributing to patients ED symptoms. Radiology can greatly assist in optimal surgical planning with findings on MRA confirming and at times adding to abnormalities suspected on PDUS.

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