Prostatic Artery Embolization: Indications, Preparation, Techniques, Imaging Evaluation, Reporting, and Complications

Ubenicio Silveira Dias, Jr, MD[1]
Maurício Ruettimann Liberato de Moura, MD[1]
Publio Cesar Cavalcante Viana, MD
André Moreira de Assis, MD, PhD
Antônio Sérgio Zanfred Marcelino, MD, PhD
Airton Mota Moreira, MD, PhD
Claudia Costa Leite, MD, PhD
Giovanni Guido Cerri, MD, PhD
Francisco Cesar Carnevale, MD, PhD
Natally Horvat, MD, PhD

Benign prostatic hyperplasia (BPH) is a noncancerous growth of the transitional zone of the prostate, which surrounds the prostatic urethra. Consequently, it can cause lower urinary tract symptoms (LUTS) and bladder outlet obstruction symptoms that may substantially reduce a patient's quality of life. Several treatments are available for BPH, including medications such as α-blockers and 5α-reductase inhibitors and surgical options including transurethral resection of the prostate and prostatectomy. Recently, prostatic artery embolization (PAE) has emerged as a minimally invasive treatment option for selected men with BPH and moderate to severe LUTS. Adequate pre- and postprocedural evaluations with clinical examinations and questionnaires, laboratory tests, and urodynamic and imaging examinations (particularly US, MRI, and CT) are of key importance to achieve successful treatment. Considering that the use of PAE has been increasing in tertiary hospital facilities, radiologists and interventional radiologists should be aware of the main technical concepts of PAE and the key features to address in imaging reports in pre- and postprocedural settings.

An invited commentary by Lopera is available online.
Online supplemental material is available for this article.

Abbreviations: BPH = benign prostatic hyperplasia, CBCT = cone beam CT, DSA = digital subtraction angiography, IPP = intravesical protrusion of the prostate, IPSS = International Prostate Symptom Score, IVA = inferior vesical artery, LUTS = lower urinary tract symptoms, PAE = prostatic artery embolization, PERFECTED = proximal embolization first, then embolize distal, TURP = transurethral resection of the prostate

RadioGraphics 2021; 41:1509–1530

https://doi.org/10.1148/rg.2021200144

Content Codes: GU IR VA

From the Departments of Radiology (U.S.D., M.R.L.d.M., P.C.C.V., A.S.Z.M., C.C.L., G.G.C.) and Interventional Radiology (M.R.L.d.M., P.C.C.V., A.M.d.A., A.M.M., F.C.C.), Hospital Sírio-Libanês, Adma Jafet 91, Bela Vista, São Paulo, SP 01308-050, Brazil; Departments of Radiology (M.R.L.d.M., P.C.C.V., C.C.L., G.G.C.) and Interventional Radiology (M.R.L.d.M., P.C.C.V., A.M.d.A., A.M.M., F.C.C.), University of São Paulo, São Paulo, Brazil; and Department of Radiology, Memorial Sloan Kettering Cancer Center, New York, NY (N.H.). Presented as an education exhibit at the 2019 RSNA Annual Meeting. Received June 15, 2020; revision requested December 9 and received January 15, 2021; accepted January 20. For this journal-based SA-CME activity, the authors, editor, and reviewers have disclosed no relevant relationships. **Address correspondence to** U.S.D. (e-mail: *ubeniciojunior@gmail.com*).

[1]U.S.D. and M.R.L.d.M. contributed equally to this work.

SA-CME LEARNING OBJECTIVES

After completing this journal-based SA-CME activity, participants will be able to:

- Describe the normal anatomy of the prostate gland and changes in patients with BPH, the classification of prostatic artery vasculature, and the anatomic relationships of the prostate gland with adjacent organs.
- Discuss the importance of adequate evaluation before and after PAE, including imaging methods, protocols, and applications, with a proposal for systematic imaging reports.
- Identify the 10 steps of PAE and the indications, results, clinical and radiologic follow-up, and complications in comparison with conventional treatments and techniques to reduce radiation dose.

See rsna.org/learning-center-rg.

Introduction

Benign prostatic hyperplasia (BPH) is a noncancerous growth of the transitional zone of the prostate, which surrounds the prostatic urethra (Fig 1). Consequently, it can cause lower urinary tract symptoms (LUTS) and bladder outlet obstruction symptoms that may substantially reduce a patient's quality of life (1–3). LUTS can be divided into storage (irritative) and voiding (obstructive) symptoms (4).

TEACHING POINTS

- The indications for PAE include BPH with refractory LUTS or intolerance to medical treatment, long waiting time for TURP or open surgery, contraindications to or patient refusal of surgery, urinary retention and indwelling Foley catheter, and hematuria originating from the prostate gland.
- US elastography is a new tool for pre- and post-PAE evaluation and provides important anatomic and functional information about BPH. Prostatic elasticity is determined with shear wave velocity measurements, with strong correlation between the elastic modulus of the transitional zone and the severity of bladder outlet obstruction.
- The use of MR angiography before PAE by combining anatomic and dynamic contrast-enhanced angiographic sequences allows postprocessing maximum intensity projection and volume-rendered reconstructions.
- For a better understanding of the PAE technique, we divided the procedure into 10 steps and two main groups of steps: proximal embolization (steps 1–7) and distal embolization (steps 8–10).
- Imaging workflow optimization and routine use of CBCT for PAE planning, CBCT-fluoroscopic overlay for live three-dimensional augmented navigation guidance, and our cardiovascular interventional imaging system (Innova 4100, with Vessel ASSIST; GE Healthcare) showed promising radiation dose reduction. Additional features such as digital zoom and pulsed fluoroscopy are further opportunities to decrease dose levels.

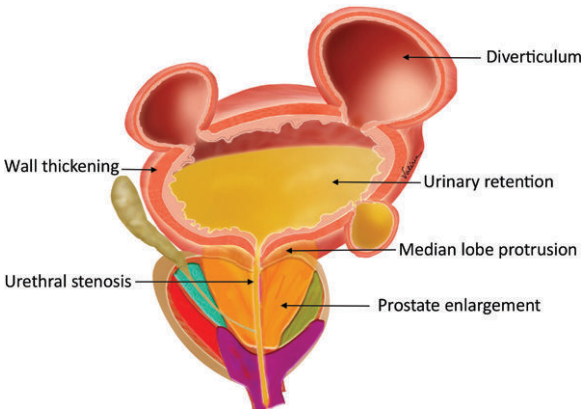


Figure 1. Illustration shows prostate enlargement due to benign prostatic hyperplasia (BPH), which is characterized by a nonneoplastic growth of the transitional zone, and its main consequences in the bladder and urethra.

The treatment options for LUTS are drug therapy and surgery. The first-line therapy is α-blocker medication (2–5), and the most common surgical options are transurethral resection of the prostate (TURP) and prostatectomy. Currently TURP is still considered the standard-of-care surgical treatment (1,2). However, several complications can occur, including transurethral resection syndrome, bleeding, and irritative urinary symptoms during the early postoperative period and long-term ejaculatory dysfunction (6–8).

Several minimally invasive techniques are now available, such as prostatic artery embolization (PAE), transurethral microwave thermotherapy, interstitial laser thermoablation, transurethral needle ablation, and water-induced thermotherapy (9–11). Recently, PAE has emerged as a promising minimally invasive treatment option for selected men with BPH and moderate to severe LUTS. PAE is a safe procedure that reduces prostate volume and improves clinical symptoms and quality of life, with low rates of complication (9,12,13).

A multidisciplinary approach with the involvement of urologists and interventional radiologists is essential to evaluate clinical outcomes, guide medical or surgical therapies, optimize treatment results, and avoid complications (14). The indications for PAE include BPH with refractory LUTS or intolerance to medical treatment, long waiting time for TURP or open surgery, contraindications to or patient refusal of surgery, urinary retention and indwelling Foley catheter, and hematuria originating from the prostate gland (3,15,16). In 2019, the Society of Interventional Radiology published a "Multisociety Consensus Position Statement on Prostatic Artery Embolization for Treatment of Lower Urinary Tract Symptoms Attributed to Benign Prostatic Hyperplasia" (17) (Table 1).

Anatomic Concepts

The prostate gland is the largest accessory sex gland, with a weight of 20 g in healthy adult men. It is divided into four histologic zones: the central zone, transitional zone, fibromuscular stroma, and peripheral zone. The transitional zone encircles the prostatic urethra and is where BPH develops (1,18) (Fig 2).

The prostate has an extraperitoneal location and is lined by a thin firm capsule that binds to the pubic symphysis through the puboprostatic ligament. It has several anatomic relationships that are important in the planning of PAE to avoid complications. The prostatic artery may have common origins and anastomoses with feeding arteries of important structures and organs of the male pelvis, making the risk of nontarget embolization a potential issue (19) (Fig 3).

Evaluation of the vascular prostate anatomy is critical to the planning and success of PAE (3,20–22). Table 2 summarizes the anatomic classification of the origin of the prostatic artery, which is also called the inferior vesical artery (IVA) (21) (Table 2) (Fig 4).

Pre-PAE Evaluation

The preprocedural evaluation should exclude conditions that cause bladder outflow obstruction and/or LUTS other than BPH, such as overac-

Table 1: Recommendations for PAE based on Society of Interventional Radiology Guidelines

Recommendation	Level of Evidence	Strength of Recommendation
1. Acceptable minimally invasive treatment option for appropriately selected men with BPH and moderate to severe LUTS	B	Strong
2. Treatment option in patients with BPH and moderate to severe LUTS who have a large prostate gland (>80 cm^3), without an upper limit of prostate size	C	Moderate
3. Treatment option in patients with BPH and acute or chronic urinary retention who wish to preserve bladder function as a method of achieving independence from catheter use	C	Moderate
4. Treatment option in patients with BPH and moderate to severe LUTS who wish to preserve erectile and/or ejaculatory function	C	Weak
5. Treatment option in patients with hematuria of prostatic origin as a method of achieving cessation of bleeding	D	Strong
6. Treatment option in patients with BPH and moderate to severe LUTS who are deemed not to be candidates for surgery for any of the following reasons: advanced age, multiple comorbidities, coagulopathy, or inability to stop anticoagulation or antiplatelet therapy	E	Moderate
7. PAE should be included in the individualized patient-centered discussion regarding treatment options for BPH with LUTS	E	Strong
8. Interventional radiologists, given their knowledge of arterial anatomy, advanced microcatheter techniques, and expertise in embolization procedures, are the specialists best suited for the performance of PAE	E	Strong

Source.—Reference 17.
Note.—LUTS = lower urinary tract symptoms, PAE = prostatic artery embolization.

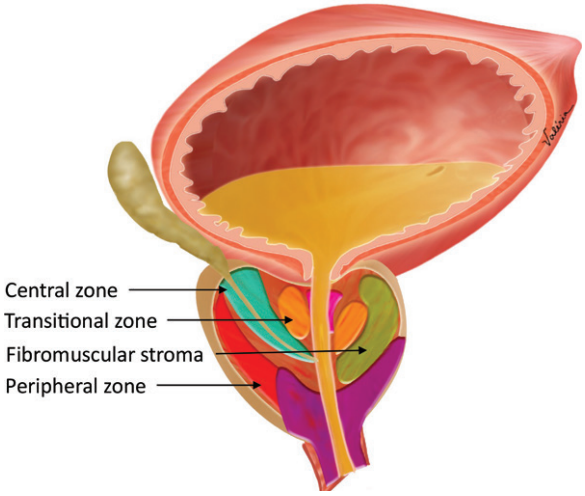


Figure 2. Illustration shows the prostate gland and its four histologic zones.

tive bladder syndrome, detrusor and urethral dysfunction, neurologic abnormalities, prostate cancer, prostatitis, bladder cancer, urethral stenosis, and urinary tract infection. In addition, it is important to evaluate the prostate gland and local vascular anatomy.

Physical examination; specific questionnaires; and laboratory, urodynamic, and imaging examinations should be performed (4,12,15). Figure 5 summarizes the pre-PAE evaluation. Imaging options include US, CT, and MRI of the prostate.

US and US Elastography of the Prostate

US provides important information about the prostate, kidneys, and bladder, such as size, volume, shape, and postvoid residual volume. US can be performed transabdominally or endorectally, with the latter being the most accurate form of assessment. When evaluating the shape of the prostate, the peripheral zone is homogeneous and hyperechoic when compared with the transitional zone. The central zone and transitional zone may not be easily distinguished from each other and are described together as the central gland. In older patients, the transitional zone may become more heterogeneous. The prostatic capsule is a thin line between the parenchyma and adjacent fat. When US is performed suprapubically, the prostate volume measurement is more accurate when the volume is greater than 50 mL (23). The use of postvoid residual volume to assess the degree of bladder outlet obstruction has interobserver variation, so other parameters are used to improve accuracy, such as the residual fraction, calculated as (postvoid residual volume × 100)/prevoid volume (24).

US elastography is a new tool for pre- and post-PAE evaluation and provides important anatomic and functional information about BPH. Prostatic elasticity is determined with shear wave velocity measurements, with strong correlation between the elastic modulus of the transitional zone and

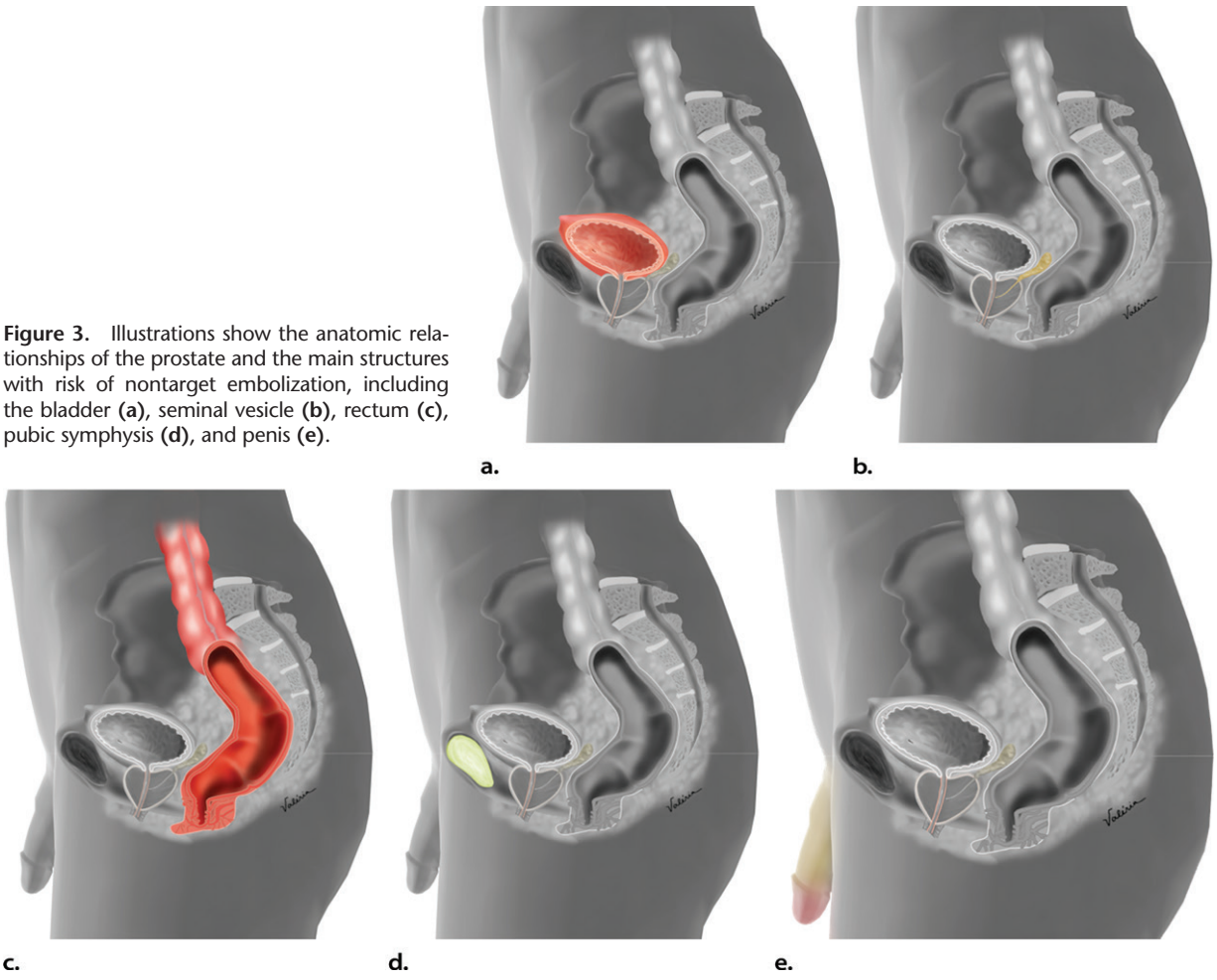


Figure 3. Illustrations show the anatomic relationships of the prostate and the main structures with risk of nontarget embolization, including the bladder **(a)**, seminal vesicle **(b)**, rectum **(c)**, pubic symphysis **(d)**, and penis **(e)**.

Table 2: Angiographic Anatomic Classification of the Origin of the IVA (Prostatic Artery)

Classification	Anatomic Description	Incidence (%)
Type I	IVA originating from anterior division of the IIA, in a common trunk with the SVA	28.7
Type II	IVA originating from the anterior division of the IIA, inferior to the SVA	14.7
Type III	IVA originating from the obturator artery	18.9
Type IV	IVA originating from the IPA	31.1
Type V (others)	Less common origins	5.6

Source.—Reference 21.
Note.— IIA = internal iliac artery, IPA = internal pudendal artery, IVA = inferior vesical artery, SVA = superior vesical artery.

the severity of bladder outlet obstruction (25). Mean shear wave velocity of the whole transitional zone at the middle one-third of the prostate is obtained. Sample shear wave velocity values are obtained with a 0.5-cm^2 region of interest at the right periurethral transitional zone and at the adjacent peripheral zone, and the ratio between them is calculated. Elastographic endpoints include shear wave velocity in meters per second and the elastic modulus in kilopascals (25) (Fig 6a).

CT and CT Angiography

MRI and US are the most common imaging modalities for evaluation before PAE, and CT is sometimes used. CT angiography may allow better procedural planning by allowing characterization of the origin of the IVA before the procedure. It is also useful in the evaluation of small prostate arteries, may help to identify troublesome anastomoses, and may allow detection of atherosclerosis before the procedure (Fig 7). Maclean et al (26)

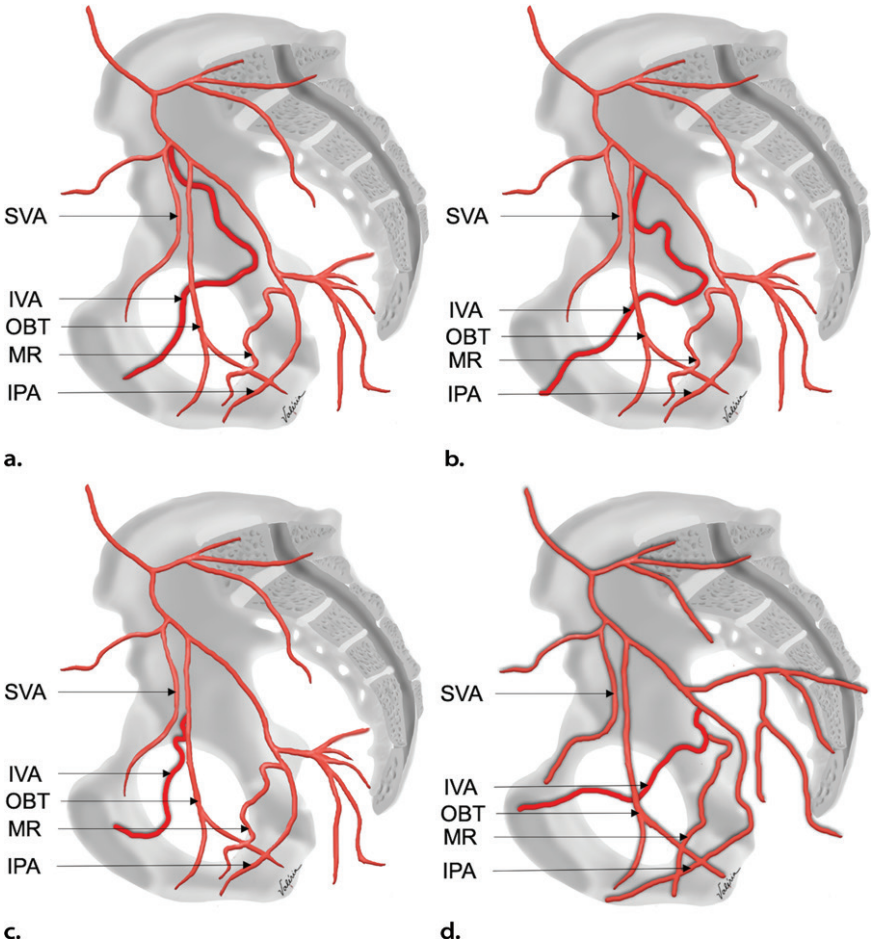


Figure 4. Illustrations show common anatomic variations of the IVA origins. *IPA* = internal pudendal artery, *MR* = middle rectal artery, *OBT* = obturator artery, *SVA* = superior vesical artery. **(a)** Type I is an IVA originating from the anterior division of the internal iliac artery, in a common trunk with the SVA. **(b)** Type II is an IVA originating from the anterior division of the internal iliac artery, inferior to the SVA. **(c)** Type III is an IVA originating from the obturator artery. **(d)** Type IV is an IVA originating from the internal pudendal artery.

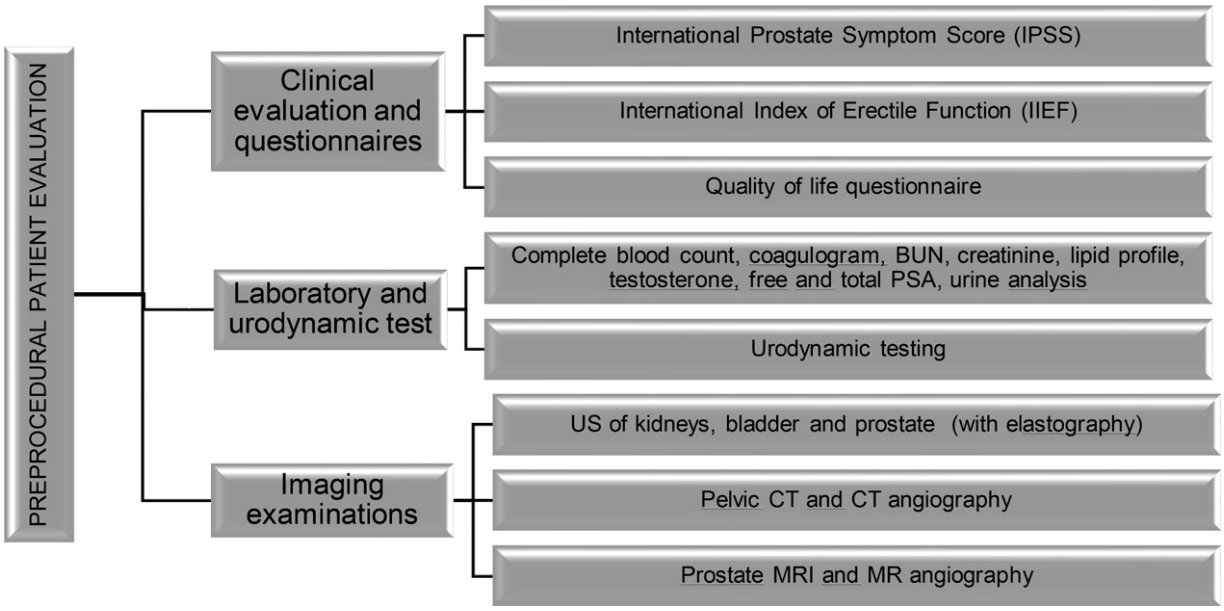


Figure 5. Flowchart summarizes pre-PAE evaluation. *Angio CT* = CT angiography, *BUN* = blood urea nitrogen, *MRA* = MR angiography, *PSA* = prostate-specific antigen.

analyzed 110 preprocedural CT angiographic examinations of patients who underwent PAE and identified the prostatic arterial supply in 214 of 220 pelvic sides with accuracy of 97.3%. This study also showed sensitivity of 59.0% and specificity of 94.2% for detection of anastomoses. However, CT angiography has disadvantages including limited evaluation of the prostate parenchyma,

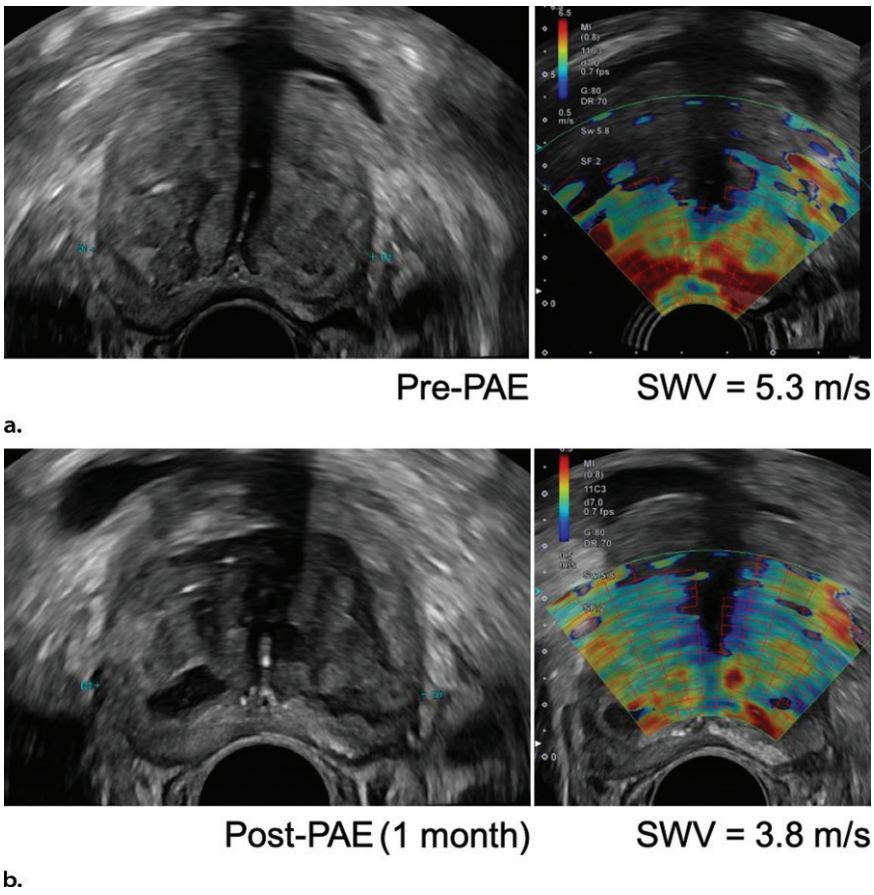


Figure 6. Axial endorectal US elastographic images in a 63-year-old man that were acquired before PAE **(a)** and at 1-month follow-up **(b)** show volumetric reduction of the gland and reduction of the prostatic elastic modulus. *SWV* = shear wave velocity.

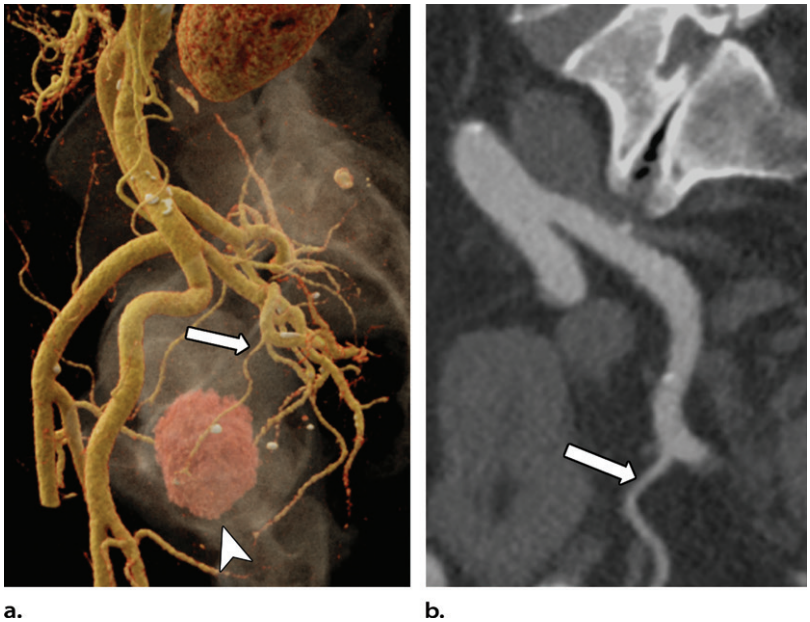
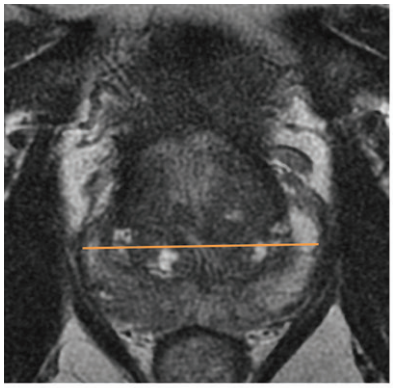


Figure 7. **(a)** Left lateral oblique three-dimensional (3D) cinematic rendering CT angiogram in a 60-year-old man shows the left IVA (arrow), which arises from the anterior division of the left internal iliac artery. Also note the enlarged prostate due to BPH (arrowhead). **(b)** Maximum intensity projection reconstruction CT image shows the origin of the left IVA (arrow).

the need for intravenous contrast material, and radiation exposure. Pre-PAE cone-beam CT (CBCT) is an option that allows identification of the IVA with a lower radiation dose compared with that for conventional CT angiography (and improved signal-to-noise and contrast-to-noise ratios) (27).

MRI and MR Angiography

MRI provides excellent anatomic assessment of the prostate gland because of its characterization of soft tissue. Preprocedural measurements such as central gland volume, whole gland volume, prostate zonal volumetry index (ie, central gland volume divided by whole prostate volume), and



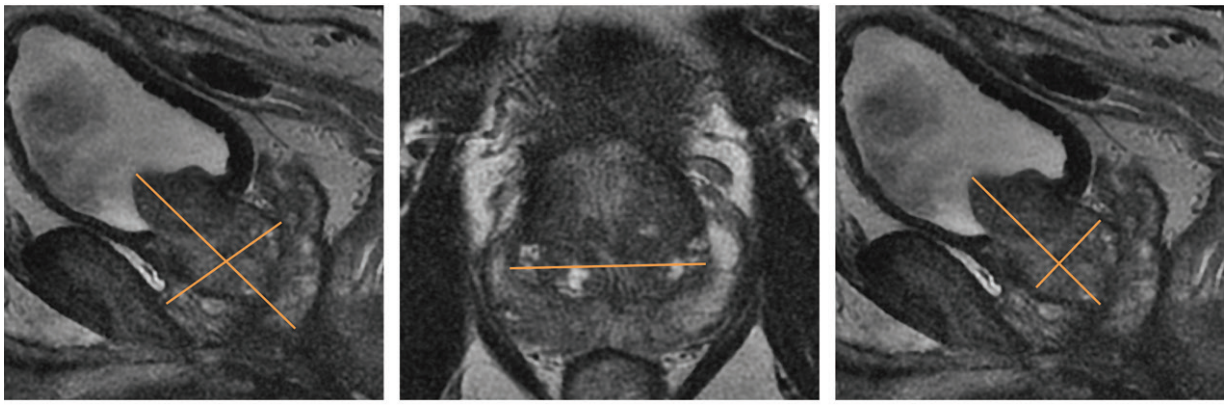


Figure 8. Axial **(a, c)** and sagittal **(b, d)** T2-weighted MR images in a 70-year-old man show calculation of the whole prostate volume and the central gland volume (central zone plus transitional zone). The prostate dimensions in this patient are 6.7 × 4.7 × 5.6 cm, with a whole prostate volume of 92 cm^3, central gland volume (central zone plus transitional zone) of 45 cm^3, and zonal volumetry index of 0.49.

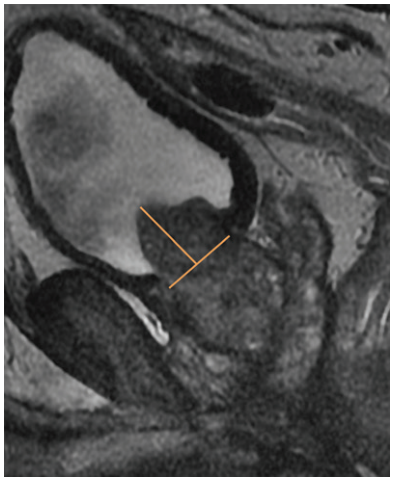


Figure 9. Sagittal T2-weighted MR image in a 70-year-old man shows calculation of the intravesical protrusion of the prostate *(IPP),* which is 2.2 cm.

intravesical protrusion of the prostate (IPP) are better evaluated with MRI (28).

Baseline central gland and whole prostate volumes and zonal volumetry index have a strong correlation with clinical outcomes in patients who undergo PAE. de Assis et al (28) compared baseline volumes to clinical outcomes and showed that higher pre-PAE whole prostate and central gland volumes had a positive correlation with the degree of clinical improvement after PAE. The zonal volumetry index also correlated with the degree of clinical improvement. A baseline zonal volume index of greater than 0.45 correlates with better clinical outcomes, with 85% sensitivity and 75% specificity. Therefore, these measurements are recommended to be included in pretreatment evaluation with all imaging modalities (Fig 8).

The IPP is a parameter obtained by measuring the prostate from the tip to the base of the gland and the circumference of the bladder in the sagittal plane (Fig 9). The IPP may correlate with the outcomes of several BPH treatment alternatives. Studies (29–31) have shown that men with bladder outlet obstruction and a higher IPP respond poorly to medical treatment. Current studies regarding PAE are still scarce, but some authors (32,33) suggest that a higher IPP is not a harmful factor for PAE results. A recent study (34) showed that IPP does not influence the efficacy of PAE.

MRI can also allow other causes of patient symptoms to be identified, particularly prostate cancer. The use of MR angiography before PAE by combining anatomic and dynamic contrast-enhanced angiographic sequences allows postprocessing maximum intensity projection and volume-rendered reconstructions. The best sequences for fusion are volumetric three-dimensional (3D) T2-weighted MRI with a large field of view

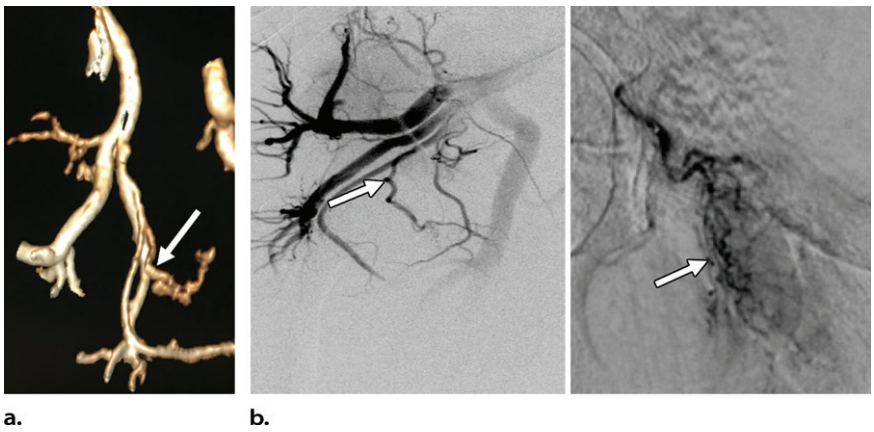


Figure 10. **(a)** Volume-rendered CT postprocessing reconstruction image in a 72-year-old man shows a type IV right IVA (arrow). **(b)** Proximal (left) and distal (right) digital subtraction angiograms (DSAs) in the same patient as in **a** show a type IV right IVA (arrow, left) and intraprostatic branches (arrow, right).

Table 3: Pre-PAE MRI Parameters Used at Our Institution

Imaging Parameter	T2-weighted MRI			DWI-EPI	LAVA Flex‡ 3D	LAVA Flex‡ Late 3D	DCE LAVA Flex‡ 3D
	FRFSE*	FRFSE*	Cube† 3D				
Plane	Axial	Sagittal	Coronal	Axial	Axial	. . .	. . .
Field of view (mm)	160	180	320	220	350	350	320
Section thickness (mm)	3	3	2.6	3	4	4	2.6
Matrix	256 × 256	256 × 192	288 × 288	130 × 80	320 × 224	320 × 224	192 × 160
Repetition time (msec)	2500–11000	2500–11000	2000	2000–17000	Min	Min	Min
Echo time (msec)	160	150	Min (100–140)	Min (40–80)	Min Full	Min Full	Min Full

Note.—DCE = dynamic contrast-enhanced, EPI = echo-planar imaging, ETL = echo train length; FRFSE = fast relaxation fast spin echo; LAVA Flex = liver acquisition with volume acceleration with a two-point Dixon method for water-fat separation, Min = minimum possible, 3D = three dimensional.
*Echo train length XL.
†Cube is a proprietary GE Healthcare three-dimensional fast spin-echo sequence.
‡LAVA Flex is a proprietary GE Healthcare sequence.

(anatomic sequence), with study of the aorto-iliac branches ("flow void") in the coronal plane, and high temporal and spatial resolution coronal dynamic contrast-enhanced angiographic sequences with the same field of view and angulation as T2-weighted MRI (Fig 10; Movie 1). This "road map" protocol allows accurate identification of IVA origins before PAE, potentially reducing the number of digital subtraction angiography (DSA) acquisitions and thus the time and radiation dose (35). Table 3 summarizes the MRI parameters used in pre-PAE evaluation. Table 4 contains a proposed MRI reporting template summarizing key imaging features to be addressed for PAE. Larger versions of the images in the table are shown in Figure 4.

The PERFECTED PAE Technique in 10 Steps

Use of the PERFECTED technique (proximal embolization first, then embolize distal) produces greater prostate ischemia and infarction and better clinical improvement of LUTS and lower recurrence rates than does use of previously described methods (3,36).

For a better understanding of the PAE technique, we divided the procedure into 10 steps and two main groups of steps: proximal embolization (steps 1–7) (Figs 11–14) and distal embolization (steps 8–10) (Figs 15–17).

Proximal Embolization

Step 1.—Initial pelvic angiography is performed to evaluate the iliac vessels and their branches (ie, the anterior trunk of the internal iliac artery) (Fig 11); this step may be skipped on the basis of preprocedural CT or MR angiographic findings.

Step 2.—With the guiding catheter placed at the common trunk of the internal iliac artery,

Table 4: Pre-PAE MRI and MR Angiography Report Template of Key Imaging Features

Patient identification:

Clinical information:

Prostate:

Dimensions: ___×___×__ cm

Whole prostate volume (WP): _____ cm^3

Central gland volume (CG) (central zone + transitional zone): _____ cm^3

Volume of the peripheral zone: _____ cm^3

Zonal volumetry index (ZVi) (CG/WP = ZVi): _____

Intravesical protrusion of the prostate (IPP): _____ mm

Other relevant findings:

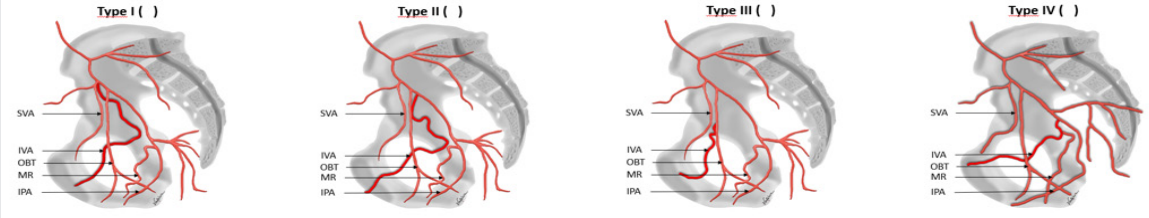
☐ No

☐ Yes, describe:_____

Vascular anatomy:

Atherosclerosis: ☐ yes ☐ no

RIGHT prostatic vascularization (single branch)



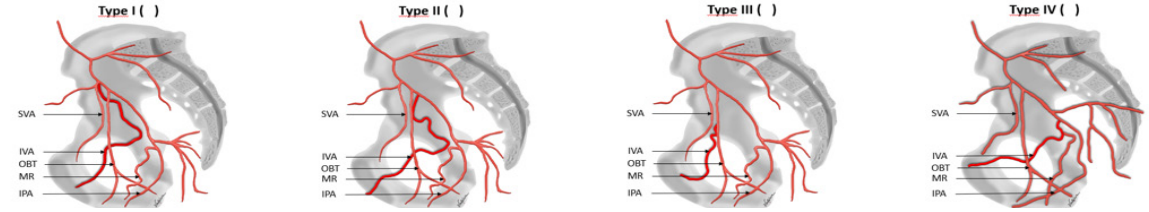
Others:_____

Are there branches with independent origins to the RIGHT (more than 1)?:

Anteromedial (transitional zone): ☐ type I, ☐ type II, ☐ type III, ☐ type IV

Posterolateral (peripheral zone/apex): ☐ type I, ☐ type II, ☐ type III, ☐ type IV

LEFT prostatic vascularization (single branch)



Others:_____

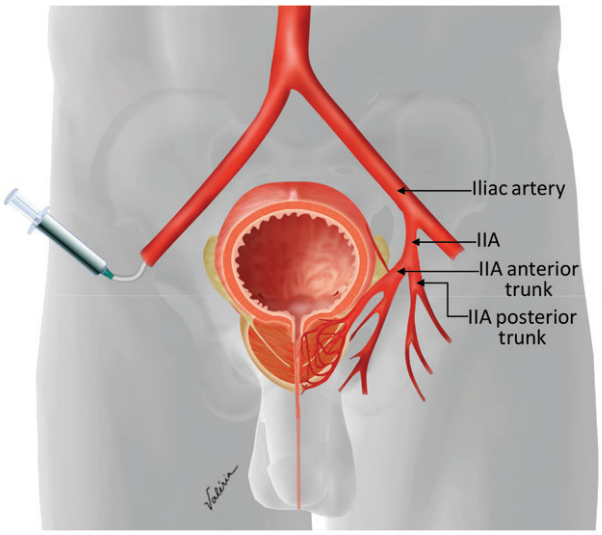
Are there branches with independent origins to the LEFT (more than 1)?:

Anteromedial (transitional zone): Type I ☐ Type II ☐ Type III ☐ Type IV ☐

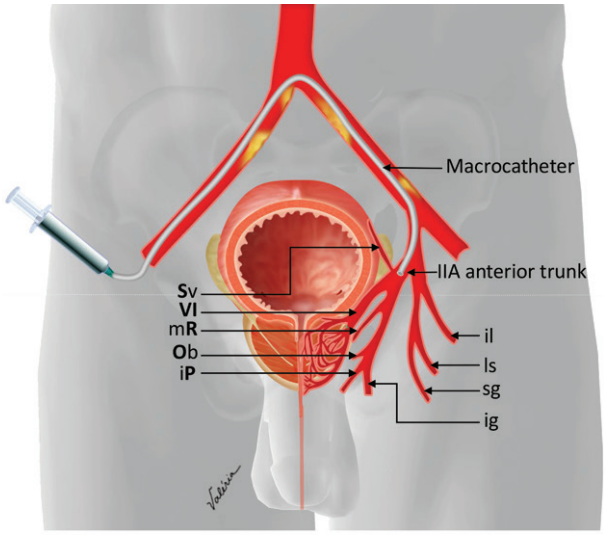
Posterolateral (peripheral zone/apex): Type I ☐ Type II ☐ Type III ☐ Type IV ☐

CBCT is performed to study its branches, which are described with the acronym PROVISO (ie, internal pudendal, middle rectal, obturator, and inferior and superior vesicals, under the ipsilateral oblique view), to assess the blood supply to the prostate, and to catheterize the IVA under optimal angulation indicated with CBCT fluoroscopic overlay, which is typically a 40°–55° ipsilateral-oblique view. DSA is the standard modality that is used at a 45° ipsilateral-oblique angle in this step, instead of or in additional to CBCT. However, DSA shows less anatomic information than does CBCT (37). Thus, we recommend CBCT as the standard imaging modality to support PAE planning and navigation into the prostatic arteries. Identification and embolization of all prostatic branches is important to reduce the risk of recurrence of LUTS (Fig 12).

Step 3.—After entering the IVA with the use of a 2.4-French or smaller microcatheter, a vasodilator (eg, nitroglycerine or isosorbide mononitrate) is injected to prevent vasospasm to facilitate microcatheter navigation and its distal positioning (Fig 13).



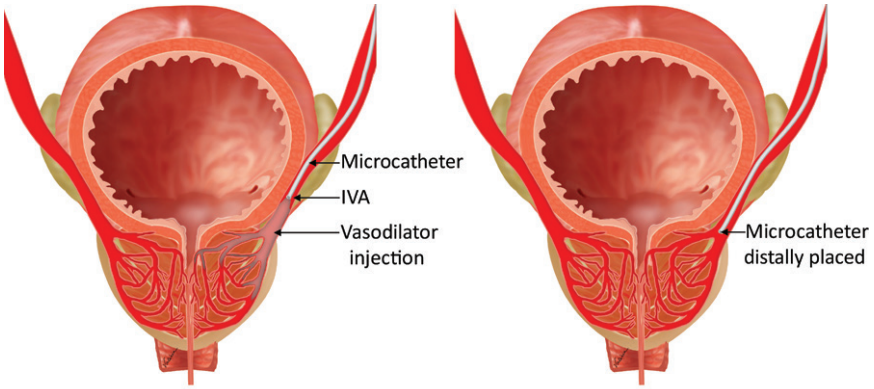
11.



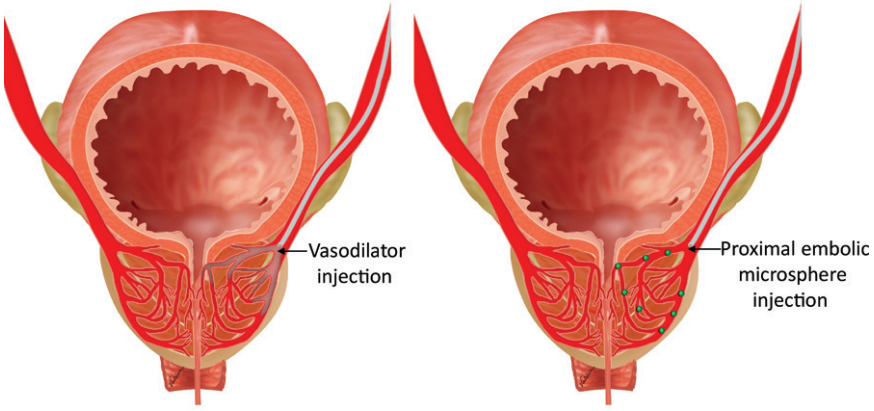
12.

Figures 11, 12. Illustrations show PAE steps 1 and 2. *IIA* = internal iliac artery. **(11)** Step 1 is to identify iliac vessels and their branches (anterior trunk of the internal iliac artery). **(12)** Step 2 is to perform cone-beam CT (CBCT) to study the branches of the iliac vessels, which are described with the acronym PROVISO (pudendal, rectal, obturator *[Ob]*, vesical inferior *[VI]* and superior *[Sv]*, under the ipsilateral oblique view). *ig* = inferior gluteal, *il* = iliolumbar, *iP* = internal pudendal, *ls* = lateral sacral, *mR* = middle rectal, *sg* = superior gluteal.

Figures 13, 14. Illustrations show PAE steps 3–6. **(13)** In step 3 (left), a vasodilator (nitroglycerine or isosorbide mononitrate) is injected to prevent vasospasm to facilitate microcatheter navigation and its distal positioning. In step 4 (right), a microcatheter is placed. **(14)** In step 5 (left), a vasodilator is injected, and in step 6 (right), embolic microspheres are injected.

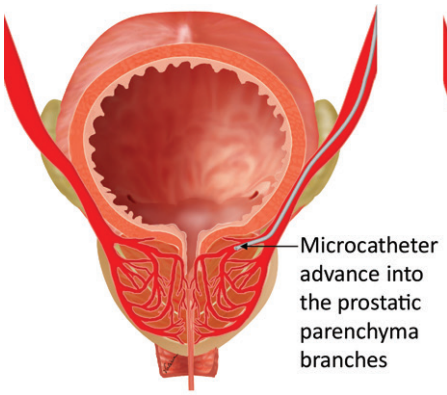


13.

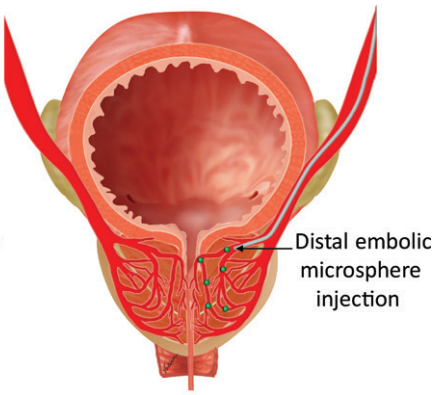


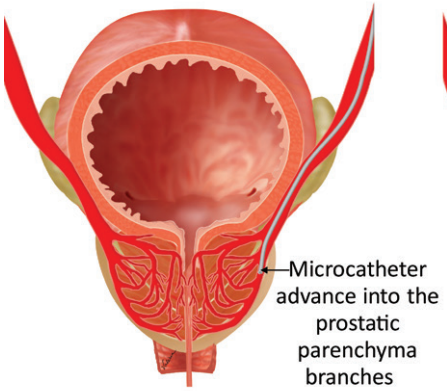
14.

Step 4.—The microcatheter should cross any collateral branch to the bladder, rectum, corpus cavernosum, gonads, or penis and be placed distally in the IVA before its division into the central gland branch (anteromedial) and peripheral zone branch (posterolateral) (Fig 13). CBCT can also be used at this time to confirm parenchymal perfusion in the prostate and identify branches with potential for nontarget embolization. As an alternative, protective embolization of nontarget arteries or creation of a high-flow anastomosis, usually with the use

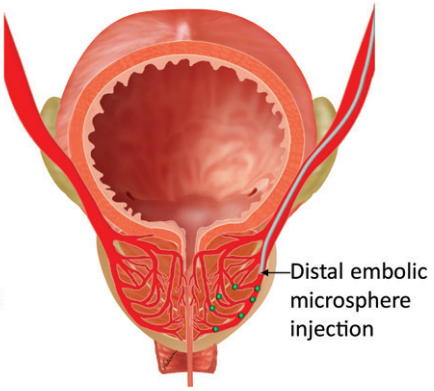


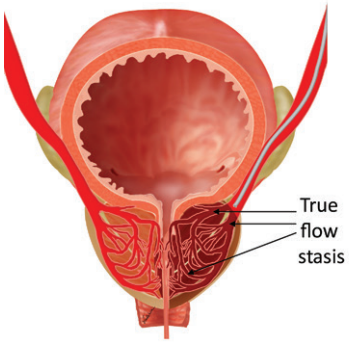
15.





16.





17.

Figures 15–17. Illustrations show distal intraprostatic embolization to achieve more embolic material delivery and greater tissue ischemia (central gland intraprostatic group of arteries). **(15)** In step 8 (left), the microcatheter is advanced distally over the microwire into the prostatic parenchyma. In step 9 (right), embolic material is delivered to the central gland. **(16)** Illustration also shows PAE steps 8 (left) and 9 (right), with embolic material delivered to the peripheral zone intraprostatic group of arteries. **(17)** PAE step 10 is achievement of flow stasis after embolization of both the central gland and peripheral zone branches.

of coils or a gelatin sponge, can be performed to redirect blood flow to the prostate and avoid complications.

Step 5.—At this point, an additional dose of vasodilator is injected to increase the intraprostatic vascularization so that a greater volume of embolic agent can be received (Fig 14, left).

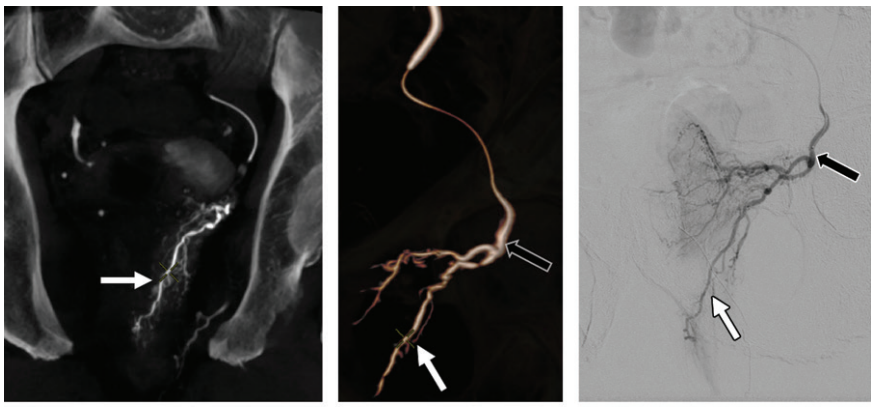
Step 6 (Embolic injection).—High dilution and slow injection of microparticles (preferably microspheres) with a 1-mL syringe is essential to avoid early occlusion and to obtain diffuse parenchymal ischemia in the prostate gland. Embolization should occur slowly and fluoroscopic exposure and collimation should be reduced as much as possible (Fig 14, right).

Step 7.—When near stasis is reached, contrast material is injected with a 1-mL syringe before proceeding to the second moment to observe any collateral shunts. Attention should be paid to avoid reflux of the embolic agent.

Distal Embolization

Step 8.—The microcatheter should be advanced distally over the microwire (ie, 0.014 or 0.016 inches) into the prostatic parenchymal branches for intraprostatic embolization. The anteromedial branch should be embolized first because BPH occurs mainly in this region. Anteromedial and posterolateral branches should be embolized separately. After moving forward into the intraprostatic branches, DSA is performed with a slow manual injection, and more embolic material can be delivered (Figs 15, 16).

Step 9 (Embolic Injection).—Embolization should be performed slowly and fluoroscopic exposure should be reduced as much as possible. Collimation of the target area is also very important to reduce staff and patient radiation exposure. The physician must be cautious during this step of injection because shunts can be opened and/or extravasation may occur when the microcatheter is wedged into the gland. With this technique, 30%–100% additional embolic



a. b. c.

Figure 18. Maximum intensity projection **(a)**, volume-rendered CBCT reconstruction **(b)**, and DSA **(c)** images in a 66-year-old man show a rectal branch (white arrow) originating from the prostatic posterolateral peripheral zone branch (black arrow in **b** and **c**).

material can be delivered into the prostate gland (36) (Figs 15, 16).

Step 10.—In this final step, true flow stasis must be seen. Then the microcatheter should be slowly retracted while additional embolic agent is injected to "pack-back" the entire IVA to its origin, and DSA with a manual injection of contrast material is performed for final control and to search for additional prostatic branches (Fig 17). This packing-back step is performed with the aim of avoiding earlier recanalization of the main IVA. All steps must be done on each pelvic side.

CBCT is useful for many reasons. First, it can help to identify the IVA origin, investigate accessory prostatic branches and collateral circulation, and avoid nontarget embolization, and it can show the percentage of the prostate that is filled by a specific IVA. Consequently, CBCT improves the safety and efficacy of the procedure (27,38) (Fig 18, Movies 2–7).

The size of the microspheres is important. Smaller particles have greater distal penetration, leading to greater ischemia of the gland; however, they have a greater risk of nontarget embolization (39). One study (40) showed that the combination of different sizes of embolic agents (ie, trisacryl gelatin microspheres, 100–300 μm and 300–500 μm) could achieve better outcomes when compared with 300–500-μm microspheres alone. Others compared different particle sizes but showed that there is no significant difference among them (41,42).

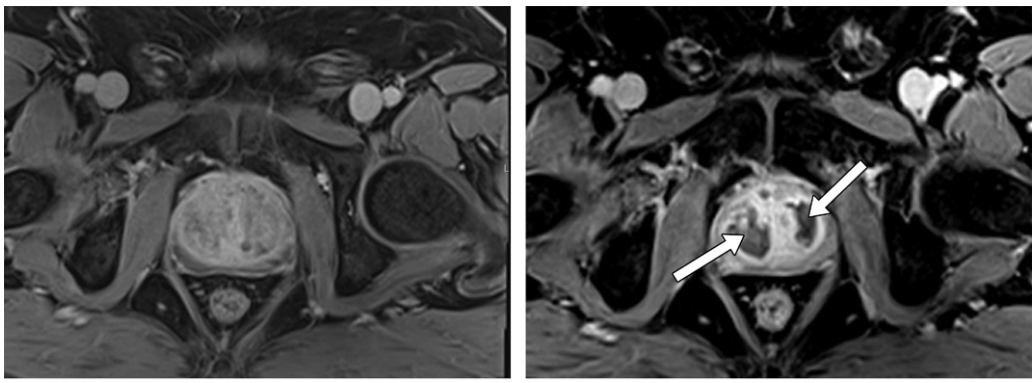
The conventional embolization technique, which is an alternative to the PERFECTED technique, consists of arterial access to the internal iliac artery to identify and embolize the anterior and posterior branches. The microcatheter is positioned in the main IVA before its bifurcation into the central gland and peripheral zone, and DSA is performed to localize the vasculature of the prostate and its collateral branches. Embolic material is injected slowly until complete stasis is achieved (3,9,43).

PAE can be performed with either femoral or radial artery access. The safety profile and technical results are similar with both approaches. However, some centers have shown that the radial access could result in a shorter procedure, and thus a lower radiation dose, a lower volume of contrast material injected, and a shorter recovery time (44,45).

Reduction of Radiation Dose

PAE technical complexity can result in long procedure times and high radiation doses for the patient and staff, especially for technicians with less experience. Dose-reduction measures are currently being investigated. Although Schott et al (38) showed that DSA was responsible for 43.3%, CBCT for 30.3%, and fluoroscopy for 26.4% of the dose-area product during PAE, Andrade et al (46,47) reported that DSA was responsible for 71.5% of the total dose-area product and that optimization of imaging settings could allow reduction in staff radiation exposure by up to 83%.

Although imaging settings and the staff's experience (48), with strict application of ALARA (as low as reasonably achievable) principles, are decisive in reducing radiation exposure, optimization and standardization of the imaging workflow, with advanced guidance, can also help in reduction of contrast material load and patient and staff radiation exposure, while making PAE more effective. At our institution, imaging workflow optimization (49) and routine use of CBCT for PAE planning, CBCT-fluoroscopic overlay for live three-dimensional augmented navigation guidance, and our cardiovascular interventional imaging system (Innova 4100, with Vessel ASSIST; GE



a. b.

Figure 19. **(a)** Pre-PAE MR image in a 73-year-old man shows heterogeneously intense enhancement of the central gland due to different components of BPH. **(b)** Post-PAE MR image in the same patient shows the evolution of the infarction areas (arrows), which are called "black holes."

Healthcare) showed promising radiation dose reduction. Additional features such as digital zoom and pulsed fluoroscopy are further opportunities to decrease dose levels.

Performing an MR angiographic "road map" protocol before embolization can also help to decrease radiation exposure time by providing vascular anatomic information before the PAE procedure (35).

Post-PAE Evaluation

Post-PAE imaging analysis is based on interpretation of the findings at US, US elastography, and MRI.

US Elastography after PAE

Two main components are responsible for the pathophysiologic characteristics of BPH: static and dynamic components. PAE shows results for both components. Ischemia caused by the occlusion of the microvasculature leads to coagulation necrosis of the nodules and reduction in the volume of the prostate gland and thus a reduction in the static component of BPH. The dynamic component, represented by the increase in stromal smooth muscle tone, which is responsible for the increase in stiffness, is also affected by the procedure. The prostatic elasticity is substantially changed, with a demonstrated reduction in the elastic modulus measured with US elastography with shear wave velocity (2,25,50).

This dynamic component is related to activation of α receptors inside the prostate gland and in the bladder neck, which leads to an increase in the overall stiffness of the gland, creating a functional obstacle in the prostatic urethra. PAE leads to ischemic necrosis of the tissue in the transitional zone, reducing the density of local receptors and the overall prostatic α activity (25,50,51).

US elastography is a tool for pre- and post-PAE evaluation. de Assis et al (25) conducted a prospective pilot study that showed a significant reduction in both transitional zone shear wave velocity and elastic modulus after PAE (−19.0%, $P < .001$ and −29.8%, $P = .02$, respectively) and a reduction of the transition zone–to–peripheral zone ratio (−45.35%, $P < .05$) (25) (Fig 6b).

MRI after PAE

MRI has a key role in identifying PAE success at follow-up. MRI should be used primarily to assess prostate volume after PAE, evaluate changes in signal intensity and apparent diffusion coefficients of infarction, and assess lesions due to nontarget embolization (28,52–54) (Figs 19, 20).

Ali et al (53) showed that after 6 months of follow-up, 100% of patients had a decrease in the size of the median lobe, 93% had a decrease in whole prostate volume, 100% had a decrease in central gland volume, 33% had imaging features of infarction, 79% had decreased signal intensity at T2-weighted MRI, and 51% had decreased enhancement. No patients (0%) had an infection or inflammation, edema, or changes in periprostatic fat.

Frenk et al (52) demonstrated central gland infarcts in 70.6% of cases after PAE with the use of the conventional technique. Features of infarcts include hyperintensity at T1-weighted MRI and predominant hypointensity at T2-weighted MRI that became smaller and isointense to the remaining central gland over time. Zhang et al (54) evaluated MR images at intervals of 10 days and 1, 3, 6, and 12 months after PAE and showed that diffusion-weighted MRI with a very high *b* value can show early infarction better than that with a lower *b* value.

The prostate gland should be systematically reviewed, with comparison with previous examinations, and whenever possible the imaging findings should be correlated with clinical findings. MRI must include dynamic contrast-enhanced

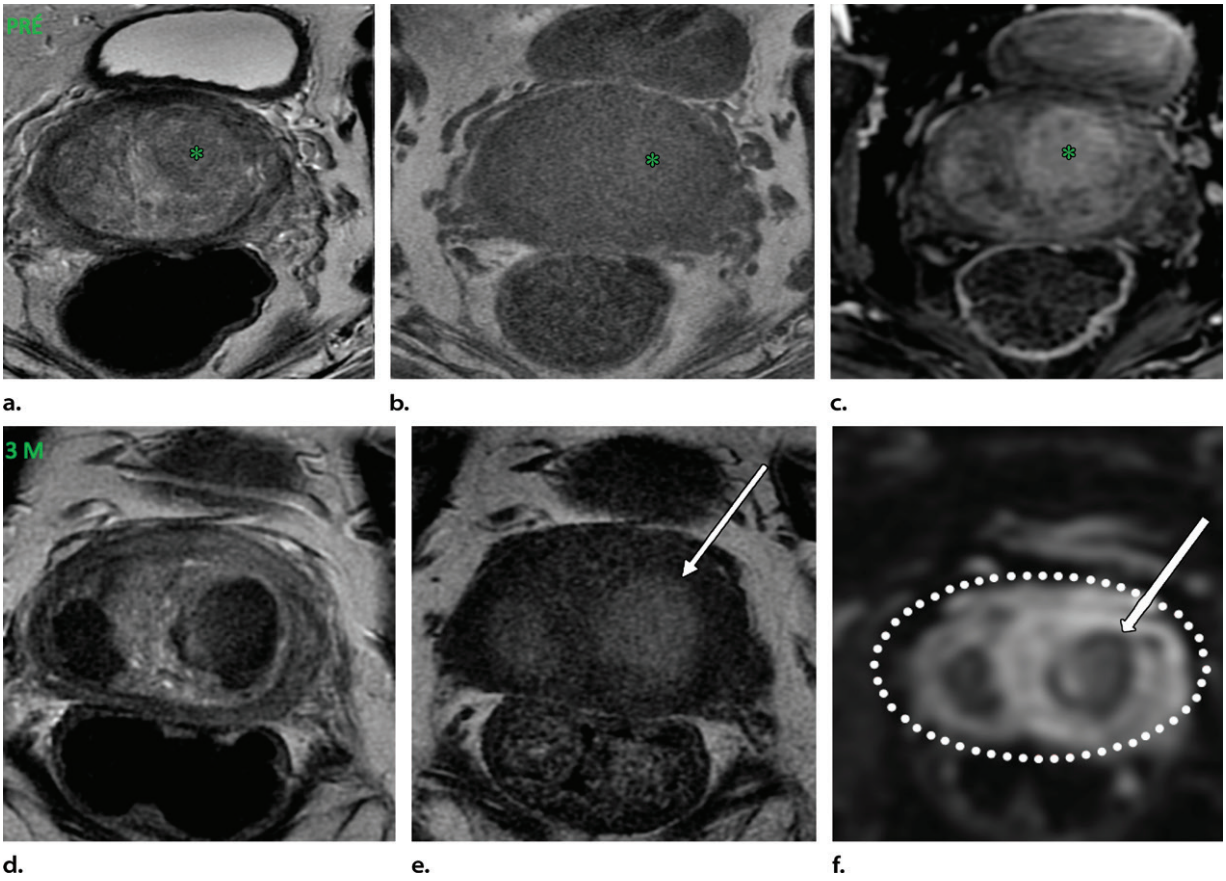


Figure 20. **(a–c)** Pre-PAE images in a 74-year-old man. Axial T2-weighted **(a)**, T1-weighted **(b)**, and dynamic contrast-enhanced **(c)** MR images show a BPH nodule with heterogeneous signal intensity (∗ in **a**), isointensity (∗ in **b**), and hyperintensity (∗ in **c**). **(d–f)** Axial T2-weighted **(d)**, T1-weighted **(e)**, and diffusion-weighted **(f)** MR images obtained 3 months after PAE show infarction areas in the central gland as predominant hypointensity in **d**, infarcts represented by new areas of hyperintensity in the central gland (arrow in **e**), and typical "black holes" (arrow in **f**). The dotted oval in **f** represents the whole prostate gland.

sequences and diffusion-weighted sequences or apparent diffusion coefficient maps. Table 5 is an example of an MRI reporting template that summarizes the key imaging features to be addressed after PAE.

PAE Outcomes

Embolization of at least one-half of the prostate varied from 90% to 98% in almost all published articles. However, the goal of PAE should always be to achieve bilateral embolization because it achieves better clinical results, higher primary treatment success rates, less recurrence of symptoms, and less need for re-embolization (55–57). The clinical success and failure criteria after PAE were established by the Cardiovascular and Interventional Radiological Society of Europe (CIRSE) in December 2019 (56). The criteria of symptomatic improvement are defined as an International Prostate Symptom Score (IPSS) of less than 18, with a decrease in score of at least 25%, a quality of life score less than or equal to 3, and at least a one-point decrease compared with the score at baseline. On the other hand, clinical failure of the procedure is defined as the persistence of severe symptoms (ie, a decrease in IPSS score of ≤25%, IPSS score ≥18, a quality of life score decrease of ≤1, and a quality of life score of ≥4) or a decrease in peak urinary flow.

PAE shows success rates of 78% at 6 months and 75% at 12 months after treatment (57). PAE also shows an average reduction of 24% in prostate-specific antigen A levels and a decrease in prostate volume of 20%–30%. However, there is no statistical association between reduction in prostate volume and clinical improvement (56).

In patients with an indwelling bladder catheter, PAE has been shown to be effective and safe, especially for patients at high surgical risk. Studies (58,59) show similar results after the procedure, with catheter removal occurring in up to 86.7% of patients (58). PAE is effective for the treatment of refractory hematuria, with good results achieved in up to 92% of patients at 18 months of follow-up (59).

Carnevale et al (40) showed only 1.9% early clinical failure and recurrence of LUTS in 23% of men at a median time after treatment of 72

Table 5: Post-PAE MRI Report Template for Key imaging Features

Patient Identification:
Clinical Information:
Time since PAE: ____ months
PAE: ☐ unilateral (☐ right ☐ left) or ☐ bilateral
Prostate:
Dimensions: ___×___×__ cm
Whole prostate volume (WP): _____ cm^3
Central gland volume (CG) (central zone + transitional zone): _____ cm^3
Volume of the peripheral zone: _____ cm^3
Zonal volumetry index (ZVi) (CG/WP = ZVi): _____
Intravesical protrusion of the prostate (IPP): _____ mm
Other relevant findings: ☐ no ☐ yes
If yes, describe:_____
Central prostate gland:
General appearance ☐ homogeneous ☐ heterogeneous
Infarcted areas? ☐ no ☐ yes, if yes, ☐ unilateral (☐ right ☐ left) ☐ bilateral
Peripheral prostate zone
general appearance ☐ homogeneous ☐ heterogeneous
Infarcted areas? ☐ no ☐ yes, if yes, ☐ unilateral (☐ right ☐ left) ☐ bilateral
Comparison with pre-PAE MRI: Was there a reduction in:
Prostate dimensions? ☐ yes ☐ no
Whole prostate volume? ☐ yes ☐ no
Central gland volume? ☐ yes ☐ no
Volume of the peripheral zone? ☐ yes ☐ no
ZVi? ☐ yes ☐no
IPP? ☐ yes ☐ no
Calculate percentage of central gland volume reduction (post-PAE CG volume/pre-PAE CG volume) × 100: _____%
Possible nontarget embolization? ☐ no ☐ yes
If yes, ☐ bladder ☐ rectum ☐ seminal vesicle ☐ bone ☐ penis ☐ others_____

months. Unilateral PAE was associated with a higher recurrence rate. The baseline prostate-specific antigen level was inversely related to recurrence. None of the patients presented with urinary incontinence or erectile dysfunction.

Pisco et al (55) also demonstrated good results of PAE in patients with BPH. The cumulative clinical success rate at medium-term follow-up (1–3 years) was 81.9%, and at long-term follow-up (>3–6.5 years) was 76.3%. No patient in the study had urinary incontinence or erectile dysfunction.

In a comparison of PAE with conventional treatment (TURP or prostatectomy), five important aspects can be considered (8,13,56,60–62): *(a)* Clinical failure rates between TURP and PAE do not differ significantly; *(b)* length of hospital stay is significantly lower after PAE; *(c)* adverse events occur less frequently after PAE; *(d)* reduction in IPSS in 3 months is similar; and *(e)* the changes in peak urinary flow, postvoid residual volume, prostate volume, and deobstruction effectiveness according to results of pressure flow studies in 3 months are smaller in PAE.

Another important study (UK-ROPE) (63) demonstrated the importance of PAE in patient care as a therapeutic alternative to treatment with drugs and surgery. The results indicated that PAE is safe, and patients showed significant clinical improvement and early return to activities owing to the shorter hospital stay when compared with TURP. However, regarding IPSS and quality of life improvements, the study did not prove the noninferiority of PAE when compared with TURP. Nonetheless, the results for PAE were inferior to what is usually seen in centers in which the practitioners have the most experience. The study also emphasizes the importance of highly qualified and experienced interventional radiologists performing PAE and the use of CBCT as an essential tool for better results.

PAE is already an important noninvasive option for the treatment of LUTS related to BPH, with increasingly accurate indications that were revised and reestablished in 2019 (Table 1) (17). Also, the United Kingdom institute that is responsible for indicating improvements in health care, the National

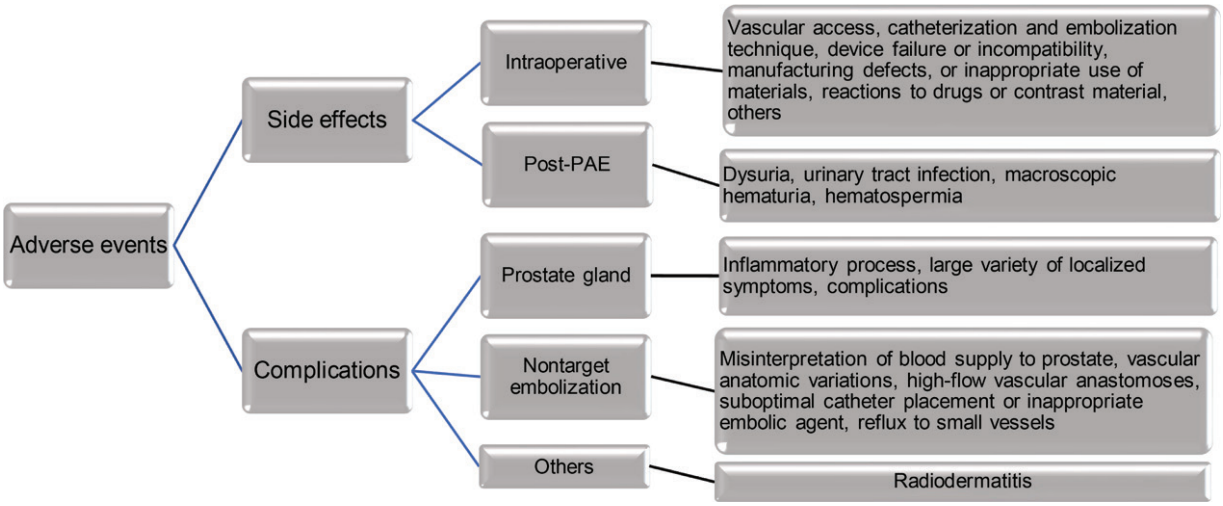


Figure 21. Flowchart summarizes PAE adverse events.

Table 6: Clavien-Dindo Classification of Surgical Complications Adapted to PAE

Grade	Definition
I	Any unexpected deviation from the normal postembolization course without the need for additional pharmacologic treatment or urologic, surgical, endoscopic, or radiologic procedures
II	The need for pharmacologic treatment other than drugs allowed for grade I as therapeutic use of antibiotics for infection, indwelling catheters for early acute urinary retention, additional noninvasive tests
III	The need for pharmacologic treatment with drugs used in grade II and surgical, endoscopic, or radiologic procedures, with or without general anesthesia
IV	Any deviation from the normal postembolization course with a life-threatening complication requiring intensive care unit treatment due to single or multiorgan dysfunction
V	Death
Suffix "d"	The suffix "d" (for disability) is added to the complication grade if the patient has a complication at the time of discharge, indicating the need for follow-up evaluation

Source—Reference 62.

Institute for Health and Care Excellence (NICE) (3), also advises PAE for properly selected patients for services performed by well-trained professionals.

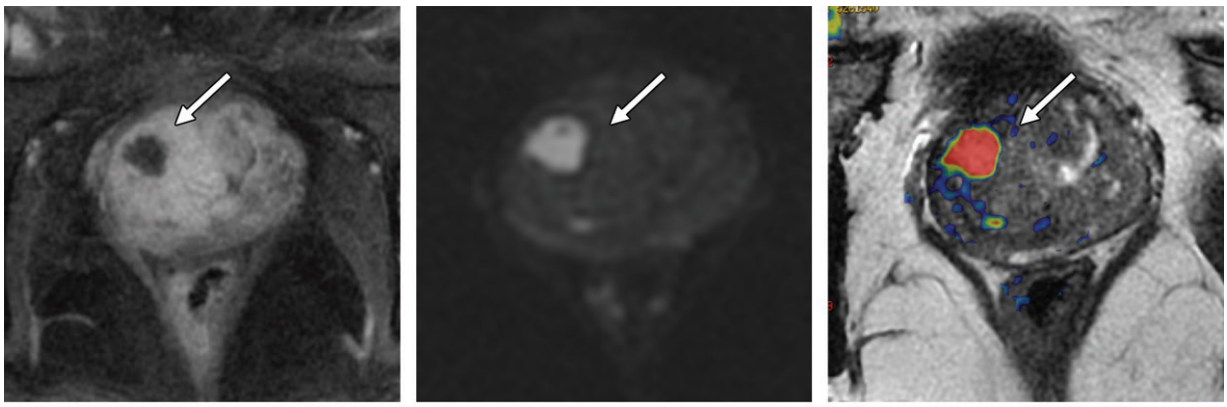
Overall, the scientific evidence about PAE is rapidly evolving, as described by the Society of Interventional Radiology (17) in the publication of the Multisociety Consensus Position Statement on PAE for Treatment of LUTS Attributed to BPH. In this article, the number of patients studied increased from 400 in 2014 to 2200 in September 2018, and the follow-up time increased from 3 years to 6.5 years.

Complications of PAE

Low rates of adverse events have been reported for PAE. We can divide them into two groups: side effects, which are any expected but untoward response, or complications, which are any unanticipated negative outcomes related to treatment (64). Figure 21 summarizes the adverse events after PAE.

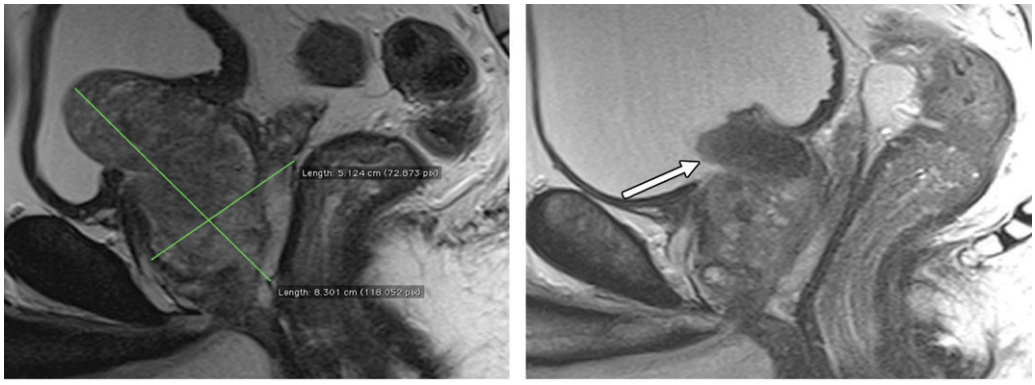
The systematization of post-PAE adverse events aims to facilitate the identification and management of these changes. The Clavien–Dindo grading system (I–IV) for classification of surgical complications can be used for this purpose (58,65,66). Moreira et al (64) suggested a modified Clavien classification system, which has been adapted to PAE (Table 6).

One of the concerns with the procedure is the risk of infection, so antibiotic prophylaxis is recommended as a form of prevention (67). Adverse events can also be divided into intraoperative and postoperative events. Intraoperative events may be drug or contrast material reactions, accidents during vascular access, device failure or incompatibility, unsuccessful catheterization and embolization technique, manufacturing defects, or inappropriate use of materials (64,68). Most postoperative events are transient, including dysuria (9%), hematuria (5.6%), rectal bleeding (2.5%), hematospermia (0.5%), urinary infec-



a. b. c.

Figure 22. Axial dynamic contrast-enhanced **(a)**, diffusion-weighted **(b)**, and fusion T2-weighted–diffusion-weighted **(c)** MR images acquired 1 year after PAE in a 69-year-old man show a small well-defined avascular area (arrow) in the right prostate central zone and diffusion restriction in the same area, which is consistent with a prostate focal abscess. (Figure 22 reprinted, with permission, from reference 64.)



a. b.

Figure 23. Sagittal T2-weighted MR images in a 70-year-old man show significant volume reduction after PAE, but a "ball-valve effect" of the middle lobe protrusion is causing a persistent infravesical obstruction (arrow in **b**) after infarction of the median lobe.

tion (7.6%), and acute urinary retention (2.5%). Most post-PAE adverse effects are classified as type I or II (minor), reaffirming PAE as a safe procedure (64). Routine adoption of CBCT may help to improve clinical outcomes and reduce postoperative events. Figures 22–29 demonstrate case examples of adverse events. Most were detected at MRI, which is the main imaging modality indicated for evaluation of post-PAE complications. Then, to deepen the discussion on post-PAE complications, this subtopic is divided into two main groups: prostate involvement and nontarget embolization.

Ischemia after PAE leads to an important inflammatory process in the prostate, which causes a series of signs and symptoms (eg, pelvic pain and discomfort, irritative voiding symptoms, local pain, fever, and nausea and vomiting, among other less common findings) that is described as *postembolization syndrome*, which is not a complication but is considered a combination of expected side effects (16,64,69). Some treated areas may develop a superinfection including prostatitis, abscess, or urosepsis. The treatment may be clinical, with antibiotic therapy, but percutaneous drainage and even surgery may be necessary (64,70,71).

The prostatic urethra, with its arterial branches, may be affected by embolic agents, and this may lead to ischemia and pelvic pain; however, the risk for strictures is low (64,72).

Nontarget embolization of the bladder can result in ischemic areas and even perforation. Small areas are treated with antibiotics and a Foley catheter. To our knowledge, there are no reports of patients with urinary incontinence in the follow-up of patients who have undergone PAE (40,55).

The rectum can be uncommonly affected by nontarget embolization,which results in ischemic rectitis. Patients may experience low abdominal pain, diarrhea with mucus that may include bloody discharge, and even fistulas and abscesses. In more severe cases, colonoscopy or proctoscopy

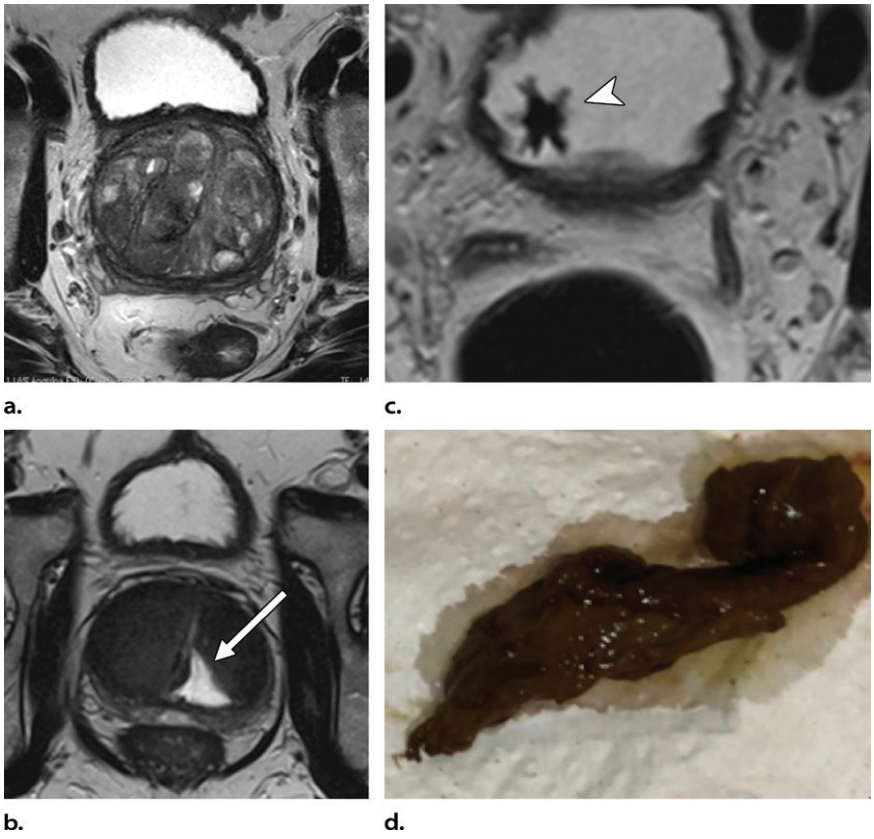


Figure 24. (a–c) Axial T2-weighted MR images of the prostate in a 74-year-old man before **(a)** and 12 weeks after **(b, c)** PAE show a prostatic cavity (arrow in **b**) in the left central gland and prostatic tissue detachment in the bladder (arrowhead in **c**). **(d)** Photograph shows spontaneous prostatic tissue elimination.

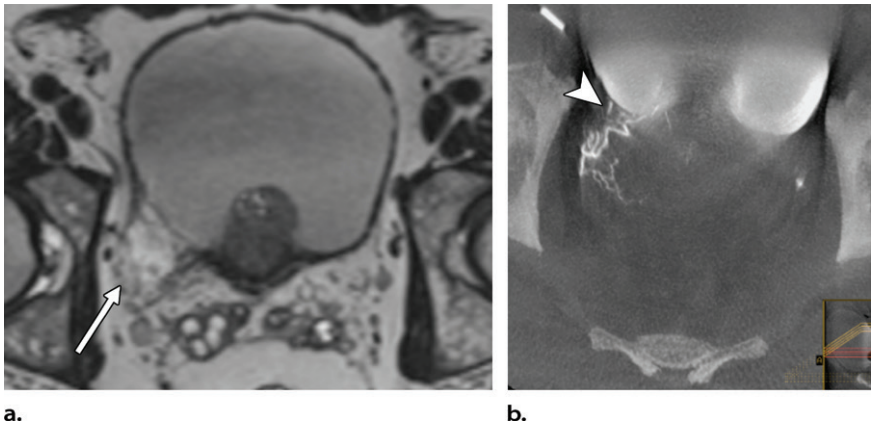


Figure 25. (a) Axial T2-weighted post-PAE MR image in a 71-year-old man shows a bladder diverticulum (arrow), which is caused by bladder wall ischemia due to nontarget embolization. **(b)** DSA image in the same patient shows (retrospective analysis) a small branch of the superior vesical artery (arrowhead) that caused the bladder ischemia.

may be necessary. To our knowledge, there are no reports of serious conditions that require a surgical approach to treatment (19,64,73).

Penile ischemia can occur because of reflux or injection of embolic agents into the dorsal penile arteries through the pudendal artery. To our knowledge, there are no reports of irreversible injuries or post-PAE erectile dysfunction to date in the literature. It is important to note that erythematous areas on the glans may also be superinfected. Color Doppler US and culture are important in diagnosis and proper management, which includes the use of antibiotics (55,64).

The seminal vesicle can be affected in rare cases by nontarget embolization, but the true

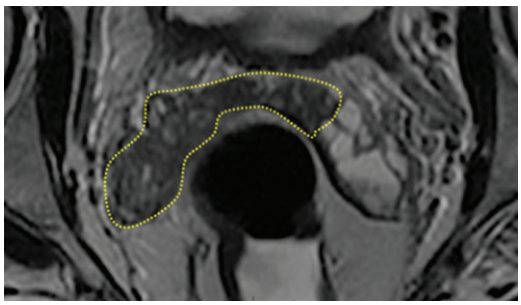


Figure 26. Axial T2-weighted MR image in a 74-year-old man shows abnormally low signal intensity in the right seminal vesicle and medial segment of the left seminal vesicle (dotted line), which is suggestive of infarction. (Reprinted, with permission, from reference 64.)

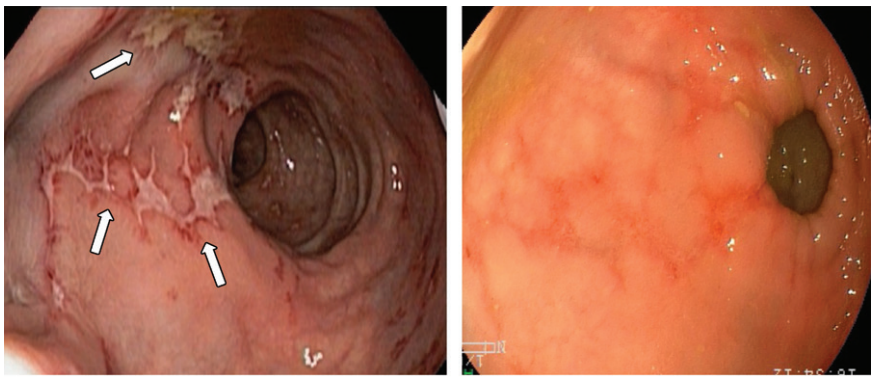


Figure 27. Transient ischemic proctitis caused by nontarget embolization of the middle rectal artery in a 68-year-old man. **(a)** Colonoscopic image shows small rectal ulcers due to ischemic proctitis (arrows). **(b)** Colonoscopic image obtained 10 days later shows a local healing process. (Figure 27 reprinted, with permission, from reference 19.)

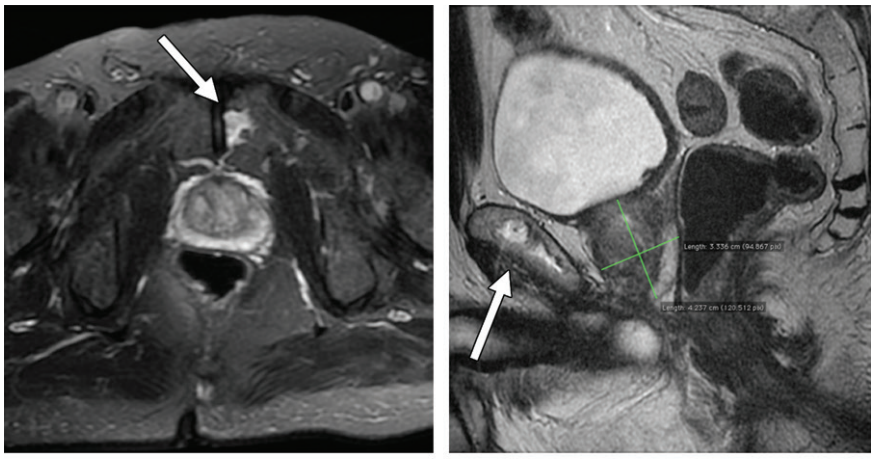


Figure 28. Axial dynamic contrast-enhanced MR images of the hip after PAE in a 76-year-old man show a small asymptomatic infarction zone in the left pubis (arrow).

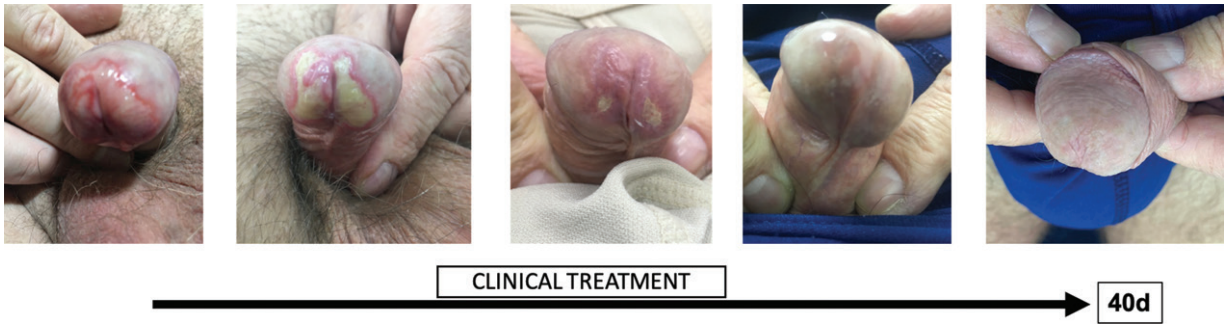


Figure 29. Photographs show ischemia of the penis glans due to inadvertent reflux of embolic agents (microspheres) or misembolization during PAE (which occurs because the dorsal penile arteries are terminal vessels) and its evolution and spontaneous resolution after 40 days. *d* = days.

incidence is not known. The patient may experience pain in the perineal region, hematospermia, reduced seminal volume, pain during ejaculation, and irritative or obstructive urinary symptoms (57,64). Bone structures, nerves, and skin can also be affected, but these are rare events (64). To prevent nontarget embolization, adequate training in the PAE technique, the proper study of vascular anatomy before and during the procedure, and the use of protection techniques for collateral branch embolization are essential for the safety and effectiveness of the procedure (26,64,74). Table 7 contains some important tips to avoid the pitfalls of PAE.

Follow-up

The follow-up proposal is based on clinical and imaging findings. Clinical follow-up appointments include the application of the following questionnaires: IPSS, International Index of Erectile Function, and quality of life. We suggest clinical and imaging assessment with US and MRI at 3 and 12 months after PAE and yearly thereafter (14,54,75).

Table 7: Tips to Avoid Pitfalls at PAE

Checklist	Instructions
I	Work as a multidisciplinary team; adequate patient selection is important for the PAE procedure
II	Investigate contraindications and treat urinary tract infections preprocedurally, if needed
III	Perform standard preprocedural preparation including prophylactic antibiotics
IV	Use time and resources (CT angiography, MR angiography, CBCT) to adequately study prostate vascular anatomy; knowing classification type and anatomic variations is mandatory for safe and effective PAE
V	Know all PAE steps and techniques; get training in technical skills and interventional radiology
VI	Avoid nontarget embolization; use protective embolization techniques or antireflux microcatheter devices, mainly to protect high-flow anastomoses or reflux to nontarget vessels; we strongly recommend using CBCT to differentiate prostatic from nontarget branches and to confirm that the whole prostatic lobe has been broadly embolized
VII	Search for alternatives to reduce radiation exposure: specific pre-PAE imaging protocols such as use of DSA, collimation, pulsed fluoroscopy, road map software, and CBCT
VIII	Actively manage urinary retention during immediate PAE follow-up with placement of a Foley urinary catheter; patients should be discharged 3–6 hours after PAE; hemostatic devices can be used to reduce hospital stay
IX	Be prepared for postprocedural care: clinical and imaging follow-up for an active search for complications in prostate gland or nontarget embolization
X	Manage postembolization syndrome for patient well-being and care; during the first 1–2 weeks, patients also receive proton-pump inhibitors, antiemetics, and nonopioid analgesics; nonsteroidal anti-inflammatory drugs, opioids, and steroidal anti-inflammatory drugs may also be used, whenever necessary; prophylactic antibiotics are mandatory for at least 7 days

Conclusion

BPH is a important health problem worldwide that has a major effect on quality of life for men. PAE has emerged as a minimally invasive outpatient procedure and a highly effective treatment option for selected men with BPH and moderate to severe LUTS. Adequate pre- and postprocedural evaluation and training and standardization of the PAE technique are of key importance to achieve a successful result. With the use of PAE increasing in many tertiary hospital facilities, radiologists and interventional radiologists should be aware of the main technical concepts of PAE to comprehend the key features to address on imaging reports.

In the near future, an increase in the availability of PAE in more interventional imaging centers and in other countries is expected. It is also expected that better selection criteria for PAE candidates will be defined, randomized trials to compare PAE with other procedures will be initiated, the outcome biomarkers for prediction of success or treatment failure will be validated and, consequently, PAE will have greater acceptability in the urological community.

Acknowledgments.—The authors would like to express their deepest gratitude to Giselli Moreira, photographer and illustrator; Julio Leite, art director; and Valéria Lira, master of law, for drawing the illustrations and graphic art.

References

1. McVary KT. BPH: epidemiology and comorbidities. Am J Manag Care 2006;12(5 Suppl):S122–S128.
2. Foster HE, Barry MJ, Dahm P, et al. Surgical Management of Lower Urinary Tract Symptoms Attributed to Benign Prostatic Hyperplasia: AUA Guideline. J Urol 2018;200(3):612–619.
3. Picel AC, Hsieh TC, Shapiro RM, Vezeridis AM, Isaacson AJ. Prostatic Artery Embolization for Benign Prostatic Hyperplasia: Patient Evaluation, Anatomy, and Technique for Successful Treatment. RadioGraphics 2019;39(5):1526–1548.
4. AUA Practice Guidelines Committee. AUA guideline on management of benign prostatic hyperplasia (2003). Chapter 1: Diagnosis and treatment recommendations. J Urol 2003;170(2 Pt 1):530–547.
5. Dahm P, Brasure M, MacDonald R, et al. Comparative Effectiveness of Newer Medications for Lower Urinary Tract Symptoms Attributed to Benign Prostatic Hyperplasia: A Systematic Review and Meta-analysis. Eur Urol 2017;71(4):570–581.
6. Ahyai SA, Gilling P, Kaplan SA, et al. Meta-analysis of functional outcomes and complications following transurethral procedures for lower urinary tract symptoms resulting from benign prostatic enlargement. Eur Urol 2010;58(3):384–397.
7. Reich O, Gratzke C, Bachmann A, et al. Morbidity, mortality and early outcome of transurethral resection of the prostate:

a prospective multicenter evaluation of 10,654 patients. J Urol 2008;180(1):246–249.
8. Gao YA, Huang Y, Zhang R, et al. Benign prostatic hyperplasia: prostatic arterial embolization versus transurethral resection of the prostate—a prospective, randomized, and controlled clinical trial. Radiology 2014;270(3):920–928.
9. Carnevale FC, Antunes AA, da Motta Leal Filho JM, et al. Prostatic artery embolization as a primary treatment for benign prostatic hyperplasia: preliminary results in two patients. Cardiovasc Intervent Radiol 2010;33(2):355–361.
10. Carnevale FC, Antunes AA. Prostatic artery embolization for enlarged prostates due to benign prostatic hyperplasia. How I do it. Cardiovasc Intervent Radiol 2013;36(6):1452–1463.
11. Reich O, Gratzke C, Stief CG. Techniques and long-term results of surgical procedures for BPH. Eur Urol 2006;49(6):970–978; discussion 978.
12. Carnevale FC, da Motta-Leal-Filho JM, Antunes AA, et al. Quality of life and clinical symptom improvement support prostatic artery embolization for patients with acute urinary retention caused by benign prostatic hyperplasia. J Vasc Interv Radiol 2013;24(4):535–542.
13. Carnevale FC, Iscaife A, Yoshinaga EM, Moreira AM, Antunes AA, Srougi M. Transurethral Resection of the Prostate (TURP) Versus Original and PErFecTED Prostate Artery Embolization (PAE) Due to Benign Prostatic Hyperplasia (BPH): Preliminary Results of a Single Center, Prospective, Urodynamic-Controlled Analysis. Cardiovasc Intervent Radiol 2016;39(1):44–52.
14. Cardarelli-Leite L, de Assis AM, Moreira AM, et al. Impact of 5-Alpha-Reductase Inhibitors Use at the Time of Prostatic Artery Embolization for Treatment of Benign Prostatic Obstruction. J Vasc Interv Radiol 2019;30(2):228–232.
15. Antunes AA, Carnevale FC, da Motta Leal Filho JM, et al. Clinical, laboratorial, and urodynamic findings of prostatic artery embolization for the treatment of urinary retention related to benign prostatic hyperplasia. A prospective single-center pilot study. Cardiovasc Intervent Radiol 2013;36(4):978–986.
16. Pisco J, Campos Pinheiro L, Bilhim T, et al. Prostatic arterial embolization for benign prostatic hyperplasia: short- and intermediate-term results. Radiology 2013;266(2):668–677.
17. McWilliams JP, Bilhim TA, Carnevale FC, et al. Society of Interventional Radiology Multisociety Consensus Position Statement on Prostatic Artery Embolization for Treatment of Lower Urinary Tract Symptoms Attributed to Benign Prostatic Hyperplasia: From the Society of Interventional Radiology, the Cardiovascular and Interventional Radiological Society of Europe, Société Française de Radiologie, and the British Society of Interventional Radiology: Endorsed by the Asia Pacific Society of Cardiovascular and Interventional Radiology, Canadian Association for Interventional Radiology, Chinese College of Interventionalists, Interventional Radiology Society of Australasia, Japanese Society of Interventional Radiology, and Korean Society of Interventional Radiology. J Vasc Interv Radiol 2019;30(5):627–637.e1.
18. McNeal JE. The zonal anatomy of the prostate. Prostate 1981;2(1):35–49.
19. Moreira AM, Marques CFS, Antunes AA, et al. Transient ischemic rectitis as a potential complication after prostatic artery embolization: case report and review of the literature. Cardiovasc Intervent Radiol 2013;36(6):1690–1694.
20. Carnevale FC, Soares GR, de Assis AM, Moreira AM, Harward SH, Cerri GG. Anatomical Variants in Prostate Artery Embolization: A Pictorial Essay. Cardiovasc Intervent Radiol 2017;40(9):1321–1337.
21. de Assis AM, Moreira AM, de Paula Rodrigues VC, et al. Pelvic Arterial Anatomy Relevant to Prostatic Artery Embolisation and Proposal for Angiographic Classification. Cardiovasc Intervent Radiol 2015;38(4):855–861.
22. de Assis AM, Moreira AM, Carnevale FC. Angiographic Findings during Repeat Prostatic Artery Embolization. J Vasc Interv Radiol 2019;30(5):645–651.
23. Feng KK, Chiang IN, Huang CY, Pu YS. Analysis of transrectal and suprapubic ultrasonography for prostate size evaluation. Urol Sci 2017;28(3):166–168.
24. Memon A, Ather MH. Use of residual fraction instead of residual volume in the evaluation of lower urinary tract symptoms. Tech Urol 2000;6(1):26–28.
25. de Assis AM, Moreira AM, Carnevale FC, et al. Effects of Prostatic Artery Embolization on the Dynamic Component of Benign Prostate Hyperplasia as Assessed by Ultrasound Elastography: A Pilot Series. Cardiovasc Intervent Radiol 2019;42(7):1001–1007.
26. Maclean D, Maher B, Harris M, et al. Planning Prostate Artery Embolisation: Is it Essential to Perform a Pre-procedural CTA? Cardiovasc Intervent Radiol 2018;41(4):628–632.
27. Desai H, Yu H, Ohana E, Gunnell ET, Kim J, Isaacson A. Comparative Analysis of Cone-Beam CT Angiogram and Conventional CT Angiogram for Prostatic Artery Identification Prior to Embolization. J Vasc Interv Radiol 2018;29(2):229–232.
28. de Assis AM, Maciel MS, Moreira AM, et al. Prostate Zonal Volumetry as a Predictor of Clinical Outcomes for Prostate Artery Embolization. Cardiovasc Intervent Radiol 2017;40(2):245–251.
29. Cumpanas AA, Botoca M, Minciu R, Bucuras V. Intravesical prostatic protrusion can be a predicting factor for the treatment outcome in patients with lower urinary tract symptoms due to benign prostatic obstruction treated with tamsulosin. Urology 2013;81(4):859–863.
30. Seo YM, Kim HJ. Impact of intravesical protrusion of the prostate in the treatment of lower urinary tract symptoms/benign prostatic hyperplasia of moderate size by alpha receptor antagonist. Int Neurourol J 2012;16(4):187–190.
31. Lee JW, Ryu JH, Yoo TK, Byun SS, Jeong YJ, Jung TY. Relationship between Intravesical Prostatic Protrusion and Postoperative Outcomes in Patients with Benign Prostatic Hyperplasia. Korean J Urol 2012;53(7):478–482.
32. Lin YT, Amouyal G, Thiounn N, et al. Intra-vesical Prostatic Protrusion (IPP) Can Be Reduced by Prostatic Artery Embolization. Cardiovasc Intervent Radiol 2016;39(5):690–695 [Published correction appears in Cardiovasc Intervent Radiol 2016;39(3):487.].
33. Maron SZ, Sher A, Kim J, Lookstein RA, Rastinehad AR, Fischman A. Effect of Median Lobe Enlargement on Early Prostatic Artery Embolization Outcomes. J Vasc Interv Radiol 2020;31(3):370–377.
34. Meira M, de Assis AM, Moreira AM, Antunes AA, Carnevale FC, Srougi M. Intravesical Prostatic Protrusion Does Not Influence the Efficacy of Prostatic Artery Embolization. J Vasc Interv Radiol 2021;32(1):106–112.
35. Kim AY, Field DH, DeMulder D, Spies J, Krishnan P. Utility of MR Angiography in the Identification of Prostatic Artery Origin Prior to Prostatic Artery Embolization. J Vasc Interv Radiol 2018;29(3):307–310.e1.
36. Carnevale FC, Moreira AM, Antunes AA. The "PErFecTED technique": proximal embolization first, then embolize distal for benign prostatic hyperplasia. Cardiovasc Intervent Radiol 2014;37(6):1602–1605.
37. Rocha A, Assis A, Moreira A, Carnevale F. Advantages of using cone-beam computed tomography over digital subtraction angiography to identify prostatic arteries in prostatic artery embolization. J Vasc Interv Radiol 2020;31(3 Suppl):S31.
38. Schott P, Katoh M, Fischer N, Freyhardt P. Radiation Dose in Prostatic Artery Embolization Using Cone-Beam CT and 3D Roadmap Software. J Vasc Interv Radiol 2019;30(9):1452–1458.
39. Bilhim T, Pisco J, Campos Pinheiro L, et al. Does polyvinyl alcohol particle size change the outcome of prostatic arterial embolization for benign prostatic hyperplasia? Results from a single-center randomized prospective study. J Vasc Interv Radiol 2013;24(11):1595–602.e1.
40. Carnevale FC, Moreira AM, de Assis AM, et al. Prostatic Artery Embolization for the Treatment of Lower Urinary Tract Symptoms Due to Benign Prostatic Hyperplasia: 10 Years' Experience. Radiology 2020;296(2):444–451.
41. Wang MQ, Zhang JL, Xin HN, et al. Comparison of clinical outcomes of prostatic artery embolization with 50-μm plus 100-μm polyvinyl alcohol (PVA) particles versus 100-μm PVA particles alone: a prospective randomized trial. J Vasc Interv Radiol 2018;29(12):1694–1702.

42. Torres D, Costa NV, Pisco J, Pinheiro LC, Oliveira AG, Bilhim T. Prostatic Artery Embolization for Benign Prostatic Hyperplasia: Prospective Randomized Trial of 100-300 μm versus 300-500 μm versus 100- to 300-μm + 300- to 500-μm Embospheres. J Vasc Interv Radiol 2019;30(5):638–644.
43. DeMeritt JS, Elmasri FF, Esposito MP, Rosenberg GS. Relief of benign prostatic hyperplasia-related bladder outlet obstruction after transarterial polyvinyl alcohol prostate embolization. J Vasc Interv Radiol 2000;11(6):767–770.
44. Bhatia S, Harward SH, Sinha VK, Narayanan G. Prostate artery embolization via transradial or transulnar versus transfemoral arterial access: technical results. J Vasc Interv Radiol 2017;28(6):898–905.
45. Isaacson AJ, Fischman AM, Burke CT. Technical feasibility of prostatic artery embolization from a transradial approach. AJR Am J Roentgenol 2016;206(2):442–444.
46. Andrade G, Khoury HJ, Garzón WJ, et al. Radiation Exposure of Patients and Interventional Radiologists during Prostatic Artery Embolization: A Prospective Single-Operator Study. J Vasc Interv Radiol 2017;28(4):517–521.
47. Andrade G, Garzón WJ, Khoury HJ, et al. Reduction of Staff Radiation Dose in Prostatic Artery Embolisation. Radiat Prot Dosimetry 2019;187(1):1–7.
48. Kriechenbauer BMT, Franiel T, Bürckenmeyer F, et al. Influence of Interventionists' Experience on Radiation Exposure of Patients Who Underwent Prostate Artery Embolization: 4-Year Results from a Retrospective, Single-Center Study. Cardiovasc Intervent Radiol 2020;43(8):1194–1201.
49. Carnevale FC, Moreira AM, de Assis AM, et al. Advanced image guidance for prostatic artery embolization – a multicenter technical note. Society of Interventional Radiology 2020 Virtual 2020. https://sir.multilearning.com/sir/2020/eposters/290056/francisco.carnevale.818.
50. Auffenberg GB, Helfand BT, McVary KT. Established medical therapy for benign prostatic hyperplasia. Urol Clin North Am 2009;36(4):443–459, v–vi.
51. Bosch JL, Bangma CH, Groeneveld FP, Bohnen AM. The long-term relationship between a real change in prostate volume and a significant change in lower urinary tract symptom severity in population-based men: the Krimpen study. Eur Urol 2008;53(4):819–825; discussion 825–827.
52. Frenk NE, Baroni RH, Carnevale FC, et al. MRI findings after prostatic artery embolization for treatment of benign hyperplasia. AJR Am J Roentgenol 2014;203(4):813–821.
53. Ali R, Gabr A, Mouli SK, et al. MR imaging findings of the prostate gland following prostate artery embolization: results from a prospective phase 2 study. Abdom Radiol (NY) 2019;44(2):713–722.
54. Zhang H, Shen Y, Pan J, et al. MRI features after prostatic artery embolization for the treatment of medium- and large-volume benign hyperplasia. Radiol Med (Torino) 2018;123(10):727–734.
55. Pisco JM, Bilhim T, Pinheiro LC, et al. Medium- and Long-Term Outcome of Prostate Artery Embolization for Patients with Benign Prostatic Hyperplasia: Results in 630 Patients. J Vasc Interv Radiol 2016;27(8):1115–1122.
56. Cornelis FH, Bilhim T, Hacking N, Sapoval M, Tapping CR, Carnevale FC. CIRSE Standards of Practice on Prostatic Artery Embolisation. Cardiovasc Intervent Radiol 2020;43(2):176–185.
57. Pisco JM, Rio Tinto H, Campos Pinheiro L, et al. Embolisation of prostatic arteries as treatment of moderate to severe lower urinary symptoms (LUTS) secondary to benign hyperplasia: results of short- and mid-term follow-up. Eur Radiol 2013;23(9):2561–2572.
58. Bhatia S, Sinha VK, Kava BR, et al. Efficacy of Prostatic Artery Embolization for Catheter-Dependent Patients with Large Prostate Sizes and High Comorbidity Scores. J Vasc Interv Radiol 2018;29(1):78–84.e1.
59. Tapping CR, Macdonald A, Hadi M, et al. Prostatic Artery Embolization (PAE) for Benign Prostatic Hyperplasia (BPH) with Haematuria in the Absence of an Upper Urinary Tract Pathology. Cardiovasc Intervent Radiol 2018;41(8):1160–1164.
60. Napal Lecumberri S, Insausti Gorbea I, Sáez de Ocáriz García A, et al. Prostatic artery embolization versus transurethral resection of the prostate in the treatment of benign prostatic hyperplasia: protocol for a non-inferiority clinical trial. Res Rep Urol 2018;10:17–22.
61. Bagla S, Smirniotopoulos J, Orlando J, Piechowiak R. Cost Analysis of Prostate Artery Embolization (PAE) and Transurethral Resection of the Prostate (TURP) in the Treatment of Benign Prostatic Hyperplasia. Cardiovasc Intervent Radiol 2017;40(11):1694–1697.
62. Abt D, Hechelhammer L, Müllhaupt G, et al. Comparison of prostatic artery embolisation (PAE) versus transurethral resection of the prostate (TURP) for benign prostatic hyperplasia: randomised, open label, non-inferiority trial. BMJ 2018;361:k2338.
63. Ray AF, Powell J, Speakman MJ, et al. Efficacy and safety of prostate artery embolization for benign prostatic hyperplasia: an observational study and propensity-matched comparison with transurethral resection of the prostate (the UK-ROPE study). BJU Int 2018;122(2):270–282.
64. Moreira AM, de Assis AM, Carnevale FC, Antunes AA, Srougi M, Cerri GG. A Review of Adverse Events Related to Prostatic Artery Embolization for Treatment of Bladder Outlet Obstruction Due to BPH. Cardiovasc Intervent Radiol 2017;40(10):1490–1500.
65. Angle JF, Siddiqi NH, Wallace MJ, et al. Quality improvement guidelines for percutaneous transcatheter embolization: Society of Interventional Radiology Standards of Practice Committee. J Vasc Interv Radiol 2010;21(10):1479–1486.
66. Clavien PA, Barkun J, de Oliveira ML, et al. The Clavien-Dindo classification of surgical complications: five-year experience. Ann Surg 2009;250(2):187–196.
67. Chehab MA, Thakor AS, Tulin-Silver S, et al. Adult and Pediatric Antibiotic Prophylaxis during Vascular and IR Procedures: A Society of Interventional Radiology Practice Parameter Update Endorsed by the Cardiovascular and Interventional Radiological Society of Europe and the Canadian Association for Interventional Radiology. J Vasc Interv Radiol 2018;29(11):1483–1501.e2.
68. Vatakencherry G, Gandhi R, Molloy C. Endovascular Access for Challenging Anatomies in Peripheral Vascular Interventions. Tech Vasc Interv Radiol 2016;19(2):113–122.
69. Sun F, Crisóstomo V, Báez-Díaz C, Sánchez FM. Prostatic artery embolization (PAE) for symptomatic benign prostatic hyperplasia (BPH): part 2, insights into the technical rationale. Cardiovasc Intervent Radiol 2016;39(2):161–169.
70. Ren J, Huang X, Wang H, et al. Prostatic abscess and seminal vesicle abscess: MRI findings and quantitative analysis of apparent diffusion coefficient values. Radiol Infect Dis 2015;2(1):27–32.
71. Abdelmoteleb H, Rashed F, Hawary A. Management of prostate abscess in the absence of guidelines. Int Braz J Urol 2017;43(5):835–840.
72. Wang MQ, Guo LP, Zhang GD, et al. Prostatic arterial embolization for the treatment of lower urinary tract symptoms due to large (>80 mL) benign prostatic hyperplasia: results of midterm follow-up from Chinese population. BMC Urol 2015;15(1):33.
73. Jones P, Rai BP, Nair R, Somani BK. Current status of prostate artery embolization for lower urinary tract symptoms: review of world literature. Urology 2015;86(4):676–681.
74. Bagla S, Rholl KS, Sterling KM, et al. Utility of cone-beam CT imaging in prostatic artery embolization. J Vasc Interv Radiol 2013;24(11):1603–1607.
75. Carnevale FC, Moreira AM, Harward SH, et al. Recurrence of Lower Urinary Tract Symptoms Following Prostate Artery Embolization for Benign Hyperplasia: Single Center Experience Comparing Two Techniques. Cardiovasc Intervent Radiol 2017;40(3):366–374.