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ORIGINAL RESEARCH ARTICLE

Efficacy of embolic microspheres of different sizes for the treatment of benign prostatic hyperplasia: Correlation with serum prostate-specific antigen levels

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Abstract

Introduction: Benign prostatic hyperplasia (BPH) is a common condition in aging men that can significantly impact quality of life. Prostatic artery embolization (PAE) has emerged as a minimally invasive treatment option.

Objective: This study aimed to evaluate the clinical efficacy of super-selective PAE using microspheres of different sizes on BPH patients and investigate its correlation with serum prostate-specific antigen (PSA) expression.

Methods: A prospective, single-blind randomized study was performed on 80 eligible patients treated between January 2020 and October 2022. Patients were randomly assigned to Group A (100 – 300 μm microspheres) or Group B (300 – 500 μm microspheres), with 40 patients each. Follow-ups were conducted at 1, 3, and 6 months post-embolization using ultrasound and/or computed tomography/magnetic resonance imaging, alongside PSA testing. Data collection covered prostate volume (PV), maximum urinary flow rate (Q_{max}), post-void residual (PVR), international prostate symptom score (IPSS), quality of life (QoL), clinical symptoms, obstruction relief, and PSA levels.

Results: Significant improvements were observed in all parameters (IPSS, QoL, PV, PVR, and Q_{max}) at each follow-up point (all $p<0.05$). Group A showed superior outcomes at 6 months in both subjective (IPSS, QoL) and objective (PV, PVR, Q_{max}, PSA) parameters (all $p<0.05$). The PSA–PV correlation demonstrated a dose-response relationship. Minor complications occurred in Group A (20.0%) and Group B (12.5%), with no severe adverse events.

Conclusion: PAE using 100 – 300 μm microspheres demonstrated superior outcomes and PSA reductions compared to larger particles, supporting its safety and efficacy as a treatment option for BPH.

Keywords: Benign prostatic hyperplasia; Embolic agents; Polyvinyl alcohol microspheres; Prostate artery embolization; Prostate-specific antigen

1. Introduction

Benign prostatic hyperplasia (BPH) is a prevalent condition among middle-aged and elderly men, affecting >50% of men aged ≥50 years and nearly 90% of those aged ≥80 years.[1] As a leading cause of male voiding dysfunction, BPH-induced bladder outlet obstruction manifests as lower urinary tract symptoms (LUTS) and may progress to secondary bladder/renal complications, representing a predominant urological disorder in the aging male population. The contemporary management of symptomatic BPH involves three principal strategies: pharmacotherapy (α-blockers and 5α-reductase inhibitors [5-ARIs], surgical options (e.g., transurethral resection of the prostate [TURP]), and minimally invasive techniques, each carrying specific constraints. While pharmacotherapy remains the cornerstone of BPH treatment, its efficacy in relieving obstruction is often suboptimal. However, this approach is time-consuming and is commonly linked to medication side effects, particularly sexual dysfunction. Surgical management of BPH (primarily TURP and open prostatectomy) provides definitive symptom relief but carries risks of post-operative complications, including urinary tract infections, urethral strictures, and voiding/sexual dysfunction.[2] Minimally invasive treatments, including transurethral laser ablation, microwave therapy, radiofrequency ablation, and cryotherapy, are widely utilized. However, a comprehensive evaluation of efficacy, complications, morbidity, treatment costs, and safety has not yet identified any of these techniques as superior to transurethral prostatectomy.[3] Consequently, pursuing safer and more effective minimally invasive treatments for BPH remains a key research priority in medical research.

In recent years, interventional minimally invasive therapy has emerged as a novel treatment modality. This approach involves using interventional techniques to perform super-selective catheterization of the prostate artery supply, followed by targeted embolization of the microcirculation using specialized embolic agents. The goal is to induce controlled necrosis and subsequent atrophy of hyperplastic prostate tissue. Key advantages of this technique include the absence of general anesthesia, minimal tissue trauma, rapid post-operative recovery, and excellent patient tolerance, leading to growing acceptance among clinicians and patients.[4] Recently, prostate artery embolization (PAE) for symptomatic BPH has become a significant advancement and research focus in urology and interventional radiology.[5] The mechanism of PAE for BPH involves blocking the prostate artery supply, inducing prostate ischemia and atrophy, thereby reducing bladder outflow resistance and improving LUTS. Animal experiments and several clinical studies have preliminarily validated the feasibility, safety, and efficacy of PAE.[6-8] PAE was initially developed to control prostatic hemorrhage in benign or malignant prostatic conditions, utilizing temporary embolic agents like absorbable gelatin sponge for hemostasis.[9] Interestingly, post-embolization observations demonstrated incidental prostate volume (PV) reduction, which spurred systematic evaluation of PAE for BPH treatment. This paradigm shift transformed PAE from a hemostatic procedure to a dedicated BPH therapy. The introduction of permanent embolic agents—polyvinyl alcohol (PVA) particles and tris-acryl gelatin microspheres—represented a critical advancement, enabling durable prostatic ischemia while maintaining safety. Bilhim *et al.*[10] established that 100 μm PVA particles effectively reduce PV, whereas 200 μm particles yield superior clinical outcomes. These findings suggest that PAE induces prostate ischemia, glandular atrophy, and liquefactive necrosis, achieving the objective of PV reduction. Another study proposed that PAE might reduce adrenergic receptors in the prostate, potentially alleviating urinary obstruction symptoms.[11] Clinically used embolic microspheres possess smooth surfaces, enhanced vascular compliance, and deformability, enabling more effective distal vascular beds to reach optimal embolization.[12] Differences in microsphere size influence the embolization process. Smaller microspheres (100 – 300 μm) can reach capillary beds, inducing extensive and uniform ischemia but increasing the risk of post-operative pain and urinary retention. Larger microspheres (300 – 500 μm), on the other hand, less frequently reach terminal vessels, resulting in a more limited embolization range and higher safety, thereby reducing the likelihood of non-target embolization.

As patient priorities increasingly emphasize quality of life, BPH—a condition predominantly affecting older men—has become a key focus in urological care. Current treatment options face limitations: medical therapies often provide incomplete symptom relief with undesirable side effects, while surgical interventions may pose excessive risks for elderly populations. This clinical challenge has accelerated the development of minimally invasive alternatives that better balance efficacy and safety. PAE has emerged as a promising option due to its minimally invasive approach, favorable treatment outcomes, and broad applicability. The technique's evolving methodology continues to gain recognition in urological and interventional radiological practice. Yuan *et al.*[13] have established the safety and efficacy of super-selective PAE for BPH. Although prior investigations have reported promising results with interventional embolization, most were limited by small sample sizes and utilized varying embolic agents, primarily 300 – 500 μm microspheres. This investigation on size-specific treatment outcomes directly

compared 100 – 300 μm and 300 – 500 μm microspheres. In addition, this study examined temporal changes in prostate-specific antigen (PSA) levels post-surgery as a potential biomarker for treatment response and the extent of tissue necrosis.

2. Materials and methods

2.1. Study population

This prospective, single-blind randomized study analyzed data from 80 male patients treated at The Second Affiliated Hospital, Zhejiang Chinese Medical University, from January 2020 to October 2022. Participants were randomly assigned using block randomization (block size = 10) to ensure balanced allocation, with 40 patients each in Group A and B. Group A received PAE with 100 – 300 μm embolic microspheres, whereas Group B was treated with 300 – 500 μm embolic microspheres. Pre-operative prostate magnetic resonance imaging (MRI) (Figure 1) was obtained, demonstrating a gland volume of about 6.8 × 5.4 cm.^{2} Follow-up evaluations with ultrasound, computed tomography (CT), or MRI, along with serum PSA testing, were conducted at 1, 3, and 6 months post-embolization. A follow-up prostate MRI (Figure 2) was performed to assess changes in PV using volumetric analysis. This study used a single-blind design, in which only patients were blinded to their treatment allocation. However, operators and follow-up physicians were not blinded due to the visible difference in microsphere size. The primary outcome (serum PSA levels) was analyzed by an independent central laboratory using blinded assays to reduce measurement variability and bias. All patients completed the study per protocol, with no missing data observed. The statistical analysis plan included prespecified methods (e.g., multiple imputation) to address potential missing data and maintain statistical validity.

2.2. Inclusion criteria

The study enrolled patients who met all of the following inclusion criteria:

(i) Male patients aged ≥ 50 years
(ii) Diagnosis of BPH with moderate-to-severe LUTS;
(iii) Failure of pharmacological therapy (e.g., α-blockers, 5-ARIs) for at least 6 months, with IPSS > 18 and QoL score > 3;
(iv) Acute urinary retention in patients who declined drug therapy;
(v) Patients who refused surgery or were deemed physically frail and unable to tolerate surgical intervention.

2.3. Exclusion criteria

Patients meeting any of the following criteria were excluded from the study, which is critical for study design transparency:

(i) Presence of malignancy;
(ii) Large bladder diverticulum (maximum diameter >5 cm);
(iii) Large bladder stones (maximum diameter >2 cm);
(iv) Detrusor dysfunction;
(v) Neurogenic bladder;
(vi) Chronic renal failure (glomerular filtration rate <60 mL/min, serum creatinine > 133 μmol/L);
Active urinary tract infection;
(vii) Coagulation abnormalities;
(viii) Allergy to iodine-containing contrast agents;
(ix) Severe atherosclerosis and/or tortuosity of the iliac and/or prostatic arteries;

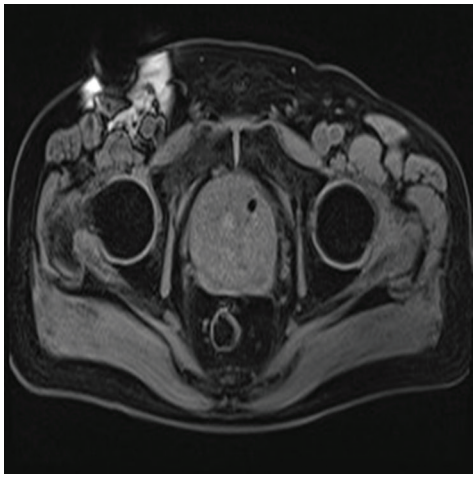

Figure 1. Prostate artery embolization pre-operative prostate magnetic resonance imaging. The image shows prostate hyperplasia; the prostate size is about 6.8 × 5.4 cm^2

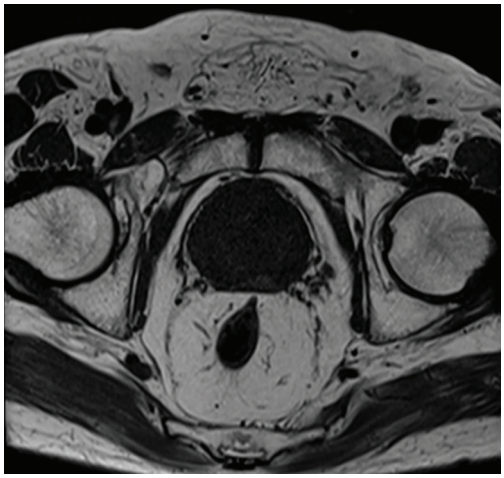

Figure 2. Magnetic resonance imaging at 3 months post-operation. The image showed that the prostate size (5.2 × 3.5 cm^2) was significantly smaller compared to pre-operation, indicating that the clinical symptoms improved

(x) Presence of iliac artery aneurysm or occlusion;
(xi) Inability to cooperate during the procedure due to involuntary limb movements;
(xii) History of bladder surgery or bilateral iliac artery embolization.

Patients with PSA ≥4.0 ng/mL and/or imaging findings suggestive of space-occupying lesions underwent transrectal biopsy to exclude prostate cancer. The study protocol was approved by the Ethics Committee of the Second Affiliated Hospital of Zhejiang Chinese Medical University.

2.4. PAE

In this study, a standardized femoral artery approach was employed. Following a successful unilateral femoral artery puncture, a 4F vascular sheath was inserted. Using SIM1, Cobra, or single-curve catheters with the loop technique, selective catheterization of the common iliac and internal iliac arteries was sequentially performed for angiography. The origin and course of the prostatic arteries were carefully identified on angiographic images. After confirming the origin, microcatheters were super-selectively advanced into the prostatic arteries, and subsequent angiography confirmed them as prostatic feeding arteries (Figures 3 and 4). Embolization was then performed using differently sized microspheres until complete arterial occlusion was achieved (Figures 5 and 6). Post-embolization prostatic artery angiography confirmed successful embolization before catheter removal.

Post-operative complications were closely monitored, and any complications were promptly treated and recorded. Given the frequent anatomical variations in prostatic artery origins, including multiple branches in some cases, each branch required separate super-selective catheterization and embolization. For cases with unclear origins, intra-procedural contrast-enhanced CT was performed; retained contrast in the prostate confirmed the prostatic artery. In cases where atherosclerotic stenosis or occlusion prevented super-selective catheterization, unilateral PAE was performed.

Precise super-selective catheterization was essential to confirm the target as the prostatic artery and avoid non-target embolization. For prostatic arteries sharing a common trunk with other vessels (e.g., vesical or rectal arteries), where selective bypass was impossible, the following approach was used: super-selective catheterization into the common trunk, followed by

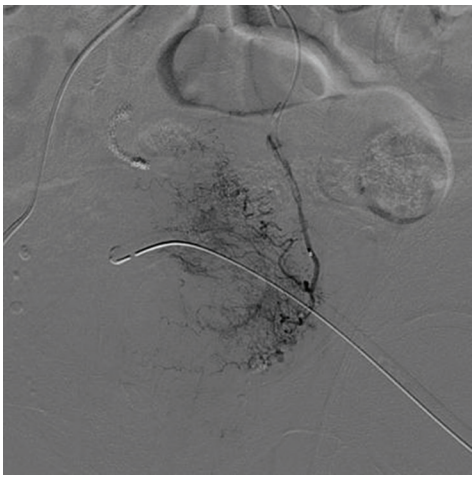

Figure 4. Prostatic artery angiography (left lobe). Increased blood flow in the prostate artery and semi-spherical staining of the prostate parenchymal blood vessels, consistent with the range of hypertrophic prostate on the left side

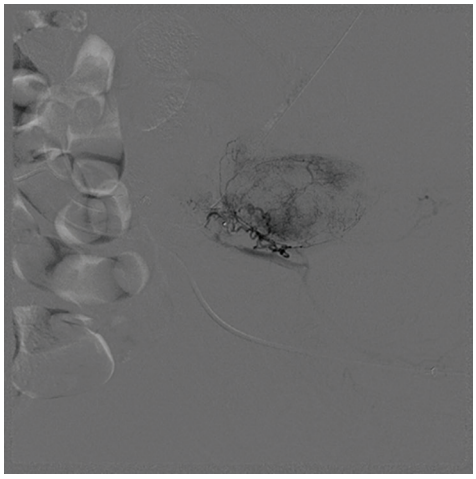

Figure 3. Prostatic artery angiography. Increased prostate artery, prostate vessels spherical staining, consistent with benign prostatic hyperplasia range

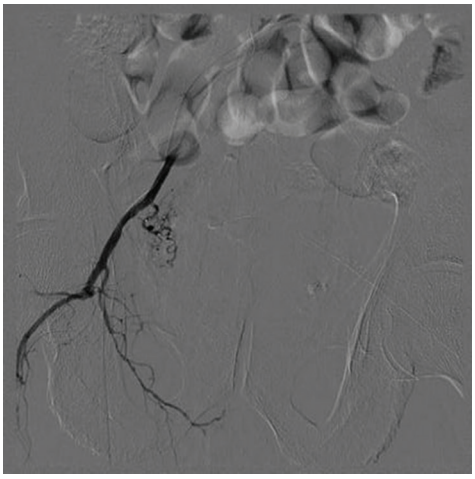

Figure 5. Post-embolization prostatic artery angiography. Microsphere embolization is complete, and the blood vessels in the prostate parenchyma are no longer visible

embolization of the trunk or its origin with a small amount of gelatin sponge before prostatic artery embolization (PAE). This ensured effective prostatic devascularization while preventing non-target embolization and damage to adjacent organs. All PAE procedures were performed by interventional radiologists with ≥5 years of experience, collaborating with interventional radiology and urology departments to manage complications such as acute urinary retention. Standard operating rooms were available for emergency surgical hemostasis if embolization failed, and pre-operative computed tomography angiography (CTA) evaluated collateral circulation to reduce mis-embolization risks.

2.5. Data collection

Data on PV, Q_{max}, post-void residual volume, IPSS, QoL assessment, clinical symptoms, improvement in lower urinary tract obstruction, and changes in serum PSA levels were recorded before and at 1, 3, and 6 months post-embolization. The number of patients in both groups who experienced complications such as dysuria, penile injury, urinary bleeding, bladder ischemia or perforation, perineal pain or skin bruising, and post-embolization fever was also recorded.

2.6. Statistical analysis

All data were processed using Statistical Package for the Social Sciences (SPSS 26.0, IBM, United States). Clinical and imaging data were expressed as mean ± standard deviation ($\bar{x}$ ± standard deviation). One-way analysis of variance, repeated measures, and custom between-group comparisons were used, with a $p<0.05$ considered statistically significant. Pearson correlation analysis was used to assess changes in pre- and post-operative serum PSA levels and analyze their correlation with PV reduction.

3. Results

3.1. Comparison of BPH intervention and microsphere embolization between Groups A and B before and after surgery

This study included 80 eligible patients treated at our hospital from January 2020 to October 2022. They were randomly divided into Group A (100 – 300 μm, n = 40) and Group B (300 – 500 μm, n = 40). Baseline data showed no significant differences between the groups (Table 1). At 1, 3, and 6 months postoperatively, IPSS and QoL scores significantly decreased compared to pre-operative values, indicating marked improvements in prostate symptoms and quality of life (Tables 2 and 3). At 6 months, differences in IPSS, QoL, PV, PVR, Q_{max}, and PSA levels between Group A and Group B were statistically significant ($p<0.05$).

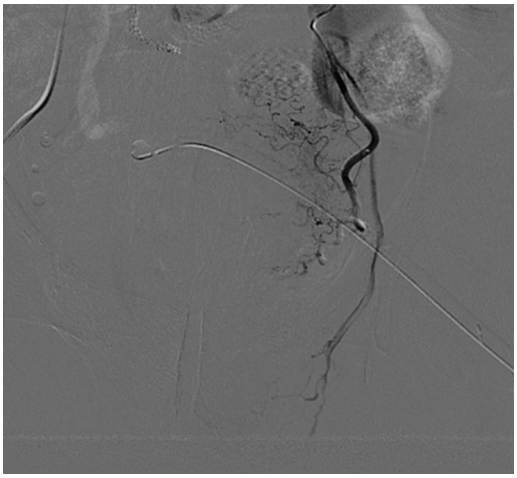

Figure 6. Post-embolization prostatic artery angiography. Complete embolization with microspheres and vascularization in the prostate parenchyma is no longer observed

Table 1. Baseline information of the patients included in the study

Evaluation indicators	Group A	Group B	*p*-value
IPSS (score)	23.00±5.41	23.45±3.79	0.720
QoL (score)	4.16±1.24	4.10±1.05	0.804
PV (cm^3)	94.58±41.41	90.78±34.70	0.470
PVR (mL)	121.53±24.38	118.79±19.78	0.668
Q_{max} (mL/min)	8.08±2.50	7.67±2.80	0.269
PSA (ng/mL)	4.08±2.56	4.56±2.79	0.875

Abbreviations: IPSS: International prostate symptom score; QoL: Quality of life; PV: Prostate volume; PVR: Post-void residual; Q_{max}: Maximum urinary flow rate; PSA: Prostate-specific antigen.

Group A demonstrated greater improvements in subjective clinical symptoms (IPSS, QoL) and objective parameters (PV, PVR, Q_{max}, PSA) than Group B at 6 months (Table 4).

3.2. Comprehensive analysis of serum PSA changes and their correlation with PV reduction before and after BPH embolization

Serum PSA levels were significantly different between Groups A and B at baseline and 6 months post-embolization (Group A: −2.43 ± 6.57 ng/mL vs. Group B: −1.05 ± 7.12 ng/mL, $p<0.05$), indicating a greater reduction in PSA in Group A. Similarly, the decrease in PV was more pronounced in Group A (−29.23 ± 20.15 mL) than in Group B (−21.33 ± 31.56 mL). The intergroup difference in PSA reduction was positively correlated with the change in PV, suggesting that a larger PV reduction was associated with a more significant PSA decline (Table 5).

Table 2. Comparison of efficacy evaluation indicators pre- and post-prostatic artery embolization in group A patients with benign prostatic hyperplasia

Time	IPSS (score)	QoL (score)	PV (cm^3)	PVR (mL)	Q_{max} (mL/min)
Pre-operation	23.45±3.79	4.10±1.05	90.78±34.70	118.79±19.78	7.67±2.80
1-month post-operation	15.43±5.23	2.79±1.23	70.34±41.32	70.32±39.42	12.23±3.17
3-month post-operation	11.38±4.65	2.07±1.46	63.49±37.42	52.38±41.34	13.44±3.14
6-month post-operation	8.62±3.98	1.81±0.78	46.38±30.46	45.21±39.21	13.79±3.81
p-value	<0.05	<0.05	<0.05	<0.05	<0.05

Abbreviations: IPSS: International prostate symptom score; QoL: Quality of life; PV: Prostate volume; PVR: Post-void residual; Q_{max}: Maximum urinary flow rate.

Table 3. Comparison of efficacy evaluation indicators pre- and post-prostatic artery embolization in group B patients with benign prostatic hyperplasia

Time	IPSS (score)	QoL (score)	PV (cm^3)	PVR (mL)	Q_{max} (mL/min)
Pre-operation	23.00±5.41	4.16±1.24	94.58±41.41	121.53±24.38	8.08±2.50
1-month post-operation	17.43±4.19	3.09±1.41	73.34±34.29	72.32±43.12	11.12±2.67
3-month post-operation	13.98±3.65	2.47±1.06	65.49±35.12	54.38±39.44	12.23±2.34
6-month post-operation	10.12±3.23	2.11±0.98	59.33±24.32	48.11±36.82	12.97±3.41
p-value	<0.05	<0.05	<0.05	<0.05	<0.05

Abbreviations: IPSS: International prostate symptom score; PSA: Prostate-specific antigen; PV: Prostate volume; Q_{max}: Maximum urinary flow rate; QoL: Quality of life; PVR: Post-void residual.

Table 4. Comparison of the last observed efficacy evaluation indicators post-prostatic artery embolization in patients with benign prostatic hyperplasia between Groups A and B

Time (6-month post-operation)	IPSS (score)	QoL (score)	PV (cm^3)	PVR (mL)	Q_{max} (mL/min)
Group A	8.62±3.98	1.81±0.78	46.38±30.46	45.21±39.21	13.79±3.81
Group B	10.12±3.23	2.11±0.98	59.33±24.32	48.11±36.82	12.97±3.41
p-value	0.012	0.037	0.001	0.067	0.132

Abbreviations: IPSS: International prostate symptom score; PSA: Prostate-specific antigen; PV: Prostate volume; Q_{max}: Maximum urinary flow rate; QoL: Quality of life PVR: Post-void residual.

Table 5. Correlation between the change in PSA and the change in PV pre- and post-prostatic artery embolization in groups A and B

Evaluation index	Group A	Group B	*p*-value
PSA	−2.43±6.57	−1.05±7.12	0.026
PV	−29.23±20.15	−21.33±31.56	0.014
r	0.756	0.654	

Abbreviations: PSA: Prostate-specific antigen; PV: Prostate volume; r: Pearson correlation coefficient.

3.3. Post-operative complications

In Group A, there was one case of urinary bleeding, four cases of perineal pain or skin bruising, and three cases of fever, with a total of eight complications resulting in a postoperative complication rate of 20.0% (8/40). In Group B, there was one case of urinary bleeding, three cases of perineal pain or skin bruising, and one case of fever, leading to a total of five complications and a complication rate of 12.5% (5/40) (Table 6). All complications in both groups were mild or self-limiting, with no statistically significant difference between the groups.

4. Discussion

BPH is a prevalent condition in clinical practice, traditionally managed through surgical interventions such as transurethral resection.[14-17] While effective, these surgical procedures carry significant risks of complications,[18,19] including urinary tract infections, post-operative urethral strictures, pain, urinary incontinence, urinary retention, and sexual dysfunction, such as retrograde ejaculation. Consequently, there is an urgent need to explore novel treatments that are less invasive, relatively effective, and associated with fewer complications. PAE has emerged as

Table 6. Major complications after prostatic artery embolization

Complications	Group A	Group B	χ^2	*p*-value
Difficulty in urination	0	0		
Penile injury	0	0		
Urinary bleeding	1	1		
Bladder ischemia or perforation	0	0		
Perineal pain or skin bruising	4	3		
Fever	3	1		
Total number of cases	8(20.0%)	5(12.5%)	0.83	0.24

a promising minimally invasive approach in recent years. Its mechanism involves inducing ischemia in the prostatic blood supply, leading to aseptic necrosis and subsequent absorption, thereby reducing PV and alleviating urethral compression symptoms.[20,21] As demonstrated by Marzano *et al.*,[22] PAE significantly alleviates LUTS while preserving sexual function, representing a valuable alternative for patients with contraindications to urethral surgery or those seeking to maintain ejaculatory function. The key advantages of minimally invasive interventional therapy comprise minimal tissue trauma, avoidance of general anesthesia, rapid post-operative recovery, and lower incidence of treatment-related complications. The favorable patient tolerance profile highlights its promising clinical applicability.

Our study evaluated the clinical efficacy of super-selective PAE using different-sized spherical microspheres for BPH, demonstrating its therapeutic effects and systematically analyzing its safety. The primary hypothesis posited that PAE with smaller microspheres (100 – 300 μm) would demonstrate superior clinical efficacy compared to larger microspheres (300 – 500 μm). The hypothesis was based on the rationale that smaller embolic agents penetrate deeper into the prostatic microcirculation, inducing more extensive glandular ischemia and greater PV reduction, thereby resulting in improved clinical outcomes.

Our results indicated that smaller microspheres (100 – 300 μm) achieved significantly better outcomes in both symptom scores (IPSS) and urodynamic parameters (Q_{max}, PVR) compared to larger particles, which is in agreement with previous studies.[23,24] Specifically, PAE with 100 – 300 μm microspheres resulted in significantly greater reductions in both serum PSA levels (−2.43 ± 6.57; p=0.026) and PV (−29.23 ± 20.15; p=0.014), with statistically significant intergroup differences (p<0.05) as showed in Table 5. PSA changes positively correlate with PV reductions, reinforcing the relationship between PV reduction and symptom relief. Furthermore, both clinically meaningful and statistically significant improvements were observed in Q_{max} (6-month post-operation; 13.79 ± 3.81, p<0.05) and PVR volume (6-month post-operation; 45.21 ± 39.21 mL, p<0.05) (Table 2; all p<0.05). Given that PV reduction directly impacts bladder outlet obstruction and LUTS severity, the groups with greater PV and PSA decreases demonstrated more substantial symptom relief. These findings collectively indicate that PAE using smaller microspheres (100 – 300 μm) is an effective treatment option for BPH.

4.1. Limitations

This study has several limitations. First, the scope of this study was limited to comparing the outcomes of PAE for BPH using relatively smaller (100 – 300 μm) and larger (300 – 500 μm) microspheres. The study design did not include smaller embolic microspheres (e.g., 50 – 100 μm) or an experimental protocol to evaluate their efficacy. Consequently, we cannot draw definitive conclusions regarding the theoretical advantages of smaller-diameter microspheres, particularly their ability to occlude distal branch vessels. Theoretically, 50 – 100 μm microspheres could more thoroughly embolize terminal capillary beds, inducing more extensive prostate tissue ischemia and necrosis, potentially leading to greater reductions in PV and more significant declines in serum PSA. The exclusion of such microspheres may have underestimated the potential maximum efficacy of PAE, and the conclusion that "100 – 300 μm is superior to 300 – 500 μm" may represent an intermediate rather than an optimal outcome. In addition, smaller microspheres (e.g., 50 – 100 μm) might increase the risk of non-target embolization (e.g., bladder or rectal ischemia). However, this hypothesis could not be validated due to the limited size range. These aspects require dedicated comparative studies for proper validation, constituting a key limitation of our current study and highlighting the need for future research. Future experimental designs should directly compare 50 – 100 μm, 100 – 300 μm, and 300 – 500 μm microspheres across three groups or introduce mixed-size groups (e.g., combining 100 – 300 μm and 300 – 500 μm microspheres) to explore synergistic effects, aiming to optimize embolic agent selection for PAE.

Second, PAE is increasingly recognized as a standard treatment for BPH, with bilateral PAE being the preferred approach. The primary distinction lies in treatment completeness: bilateral PAE achieves more extensive prostate ischemia by addressing dual blood supply, whereas unilateral PAE only partially reduces arterial inflow on the treated side. As a result, bilateral embolization demonstrates superior and more durable symptom relief, with significantly better improvements in objective parameters (Q_{max}, PV, PSA, PVR). Anatomically, bilateral

embolization induces more uniform glandular atrophy across the entire prostate, unlike unilateral PAE, which only achieves localized effects. While bilateral PAE poses greater technical challenges in cases of complex vascular anatomy, it remains the preferred method when vascular access permits. Unilateral PAE is still viable when anatomical constraints or patient-related factors prevent bilateral embolization. Notably, atherosclerotic changes in prostatic arteries (common in elderly patients) often cause severe stenosis or complete occlusion, particularly at the ostium of target branches, making super-selective catheterization difficult or impossible. In our study, three patients underwent unilateral embolization due to significant atherosclerotic narrowing or occlusion of one prostatic artery, which may have affected treatment outcomes. Future experimental designs are strongly recommended to incorporate stricter vascular assessment protocols, including pre-operative CTA or magnetic resonance angiography (MRA), to evaluate vascular patency and minimize the impact of unilateral embolization.

Third, prostatic artery anatomical variants pose major PAE technical difficulties. Although 90% arise from four standard origins (superior vesical, internal pudendal, gluteal-pudendal trunk, and obturator), rare variants (10%) occur more frequently in atherosclerotic (18 – 22%) and repeat PAE patients (15 – 20%).[25] These variations complicate super-selective catheterization, demanding higher operator skill and experience. Aberrant origins may render super-selective catheterization and embolization particularly challenging. Pre-operative CTA for patients with suspected aberrant origins can clarify prostatic artery anatomy, offering clear advantages in identifying complex variants. Future studies could further explore whether variant origins disadvantage certain microsphere sizes (e.g., 100 – 300 μm), potentially affecting treatment efficacy or safety.

Fourth, the limited sample size (n = 80) and follow-up duration (6 months) preclude definitive conclusions regarding long-term efficacy. Short-term (<2 years) assessments may overestimate PV reduction and IPSS/QoL improvement due to delayed fibrotic changes, whereas limited follow-up could obscure late complications or reintervention rates. These constraints prevent robust evaluation of treatment durability, necessitating larger multicenter studies with prolonged follow-up to validate our findings. Notably, fewer than five studies have reported ≥ 3-year outcomes, all with small cohorts (n < 100),[26] underscoring the evidence gap in long-term efficacy and safety comparisons between microsphere sizes.[27] A recent Chinese long-term single-center cohort study involving 125 patients from February 2014 to February 2020 reported that IPSS/QoL and PV improvements remained statistically significant at 5 years.[26] However, reintervention rates increased, with cumulative recurrence and reintervention rates at 1, 2, and 5 years being 6.8%, 12.7%, and 60.4%, and 5.9%, 10.2%, and 50.8%, respectively. Future experimental designs should consider incorporating reintervention rates as a key outcome measure.[28] Nevertheless, the recurrence of the condition can be effectively managed through pharmacological therapy or repeat PAE.

Despite its limitations, our study supports PAE as an effective, minimally invasive therapy for BPH. However, several critical questions remain unresolved and warrant investigation. For example, we could explore innovations in embolic materials and techniques. The embolic microspheres used in our study represent permanent agents; future research might investigate biodegradable alternatives (e.g., gelatin microspheres) or drug-eluting microspheres (e.g., loaded with 5-ARIs) to validate the long-term efficacy of PAE. Further optimization of microsphere diameter, such as evaluating smaller particles (e.g., 50 – 100 μm in diameter), could clarify their impact on embolic efficacy, complication rates, and recurrence. In addition, improved endpoint assessment methods, such as intraoperative near-infrared fluorescence imaging,[29] could enhance vascular visualization and help avoid over- or under-embolization.

To address frequent anatomical variations in prostatic artery origins, integrating artificial intelligence-assisted vascular identification—such as deep learning-based CTA or MRA segmentation algorithms—could help interventional radiologists identify prostatic arteries and variant branches more quickly and accurately. During procedures, cone-beam CT is typically used for real-time image guidance to improve super-selective catheterization precision. Exploring strategies to optimize its clinical utility remains a valuable research area.

Procedural techniques and post-operative complication management can be refined and optimized to improve study rigor and enhance patient outcomes through optimized perioperative care. For postoperative pain control, multimodal analgesia strategies—such as regional nerve block combined with nonsteroidal anti-inflammatory drugs—could provide effective pain relief.[30] For isolated PAE cases with poor treatment outcomes that require reintervention, further research is needed to evaluate whether combining PAE with 5-ARIs or α-blockers can delay disease progression by targeting complementary pathological mechanisms. As clinicians, we must offer patients optimal therapeutic options and carefully consider cost-effectiveness. Comprehensive comparisons between PAE and traditional surgical methods (e.g., TURP)

should encompass multiple economic factors: procedural and material costs, post-operative care requirements, hospital stay duration, and reintervention rates. Such analyses facilitate truly personalized care tailored to each patient's needs. This economic perspective promotes truly personalized medicine—one that aligns clinical outcomes with individual socioeconomic factors while ensuring economic sustainability. The ideal treatment strategy achieves a balance between therapeutic benefits and efficient resource utilization.

5. Conclusion

Our study demonstrated the efficacy of PAE using 100 – 300 μm or 300 – 500 μm microspheres. Compared with 300 – 500 μm microspheres, PAE with 100 – 300 μm microspheres resulted in greater reductions in serum PSA levels and PV, more pronounced improvements in clinical symptoms, and superior overall outcomes.

During PAE, angiography revealed that some prostatic arteries communicated with vessels supplying organs at risk of non-target embolization, such as the rectum and bladder. Based on our clinical observations, precise identification of angiographic anatomical structures enables accurate localization and super-selective embolization of prostatic arteries, thereby avoiding embolization of communicating vessels and non-target organs. For inevitable collateral vessels, we propose the following strategies based on our procedural experience:

(i) Intraprocedural cone-beam CT may delineate vascular anatomy and exclude non-prostatic supply, facilitating precise prostatic artery selection;
(ii) Temporary embolization with an absorbable gelatin sponge (350 – 500 μm) before microsphere deployment can safely occlude collaterals. In our cohort, this approach achieved technical success without major complications (e.g., non-target embolization).

If collateral persistence risks end-organ injury, aborting the procedure remains the safest option. No major complications or adverse events occurred during the study, and patients generally recovered well. Our results demonstrate that interventional embolization offers a novel, minimally invasive, safe, and effective treatment modality for BPH in clinical practice.

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Conflict of interest

The authors declare that there are no competing interests.

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Ethics approval and consent to participate

This study was reviewed and approved by The Second Affiliated Hospital of Zhejiang Chinese Medical University Ethics Committee (Approval ID. 2019-KL-131-01). Informed consent was obtained from all individual participants included in the study.

Consent for publication

All participants provided informed consent for the publication of the findings derived from this study. Where applicable, participants gave explicit permission for the publication of any data, images, or information that could potentially reveal their identity. The authors affirm that all relevant consent forms have been obtained and are available upon request.

Availability of data

Data are available upon reasonable request to the corresponding authors.

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