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ORIGINAL RESEARCH

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Metabolic syndrome as an independent determinant of prostate volume in elderly males over 60 years

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Abstract

Background: There is a high incidence of metabolic syndrome (MS) and prostate disease in elderly males over 60 years old. This study aimed to investigate the influence of MS on prostate-specific antigen (PSA) levels, prostate volume (PV) and PSA density (PSAD) in this population. **Methods**: We retrospectively analyzed 3918 males aged 60 and above who underwent physical examinations in our hospital from January 2022 to December 2024. The subjects were divided into MS group and non-MS group. PSA mass (PSA $\times$ plasma volume) was calculated to adjust plasma volume. PSA, PSA mass, PV and PSAD were compared between the 2 groups. To evaluate the impact of MS on the four parameters, linear regression analysis was used. **Results**: Compared with non-MS group, subjects of the MS group had significantly older age ($p = 0.017$), larger plasma volume ($p < 0.001$), larger PV ($p < 0.001$) and lower PSAD ($p = 0.013$). However, there was no statistical difference in PSA and PSA mass between the two groups ($p = 0.339$ and 0.919). In the multivariate linear regression, age, plasma volume and presence of MS were proved as independent factors for PV; age, Body Mass Index (BMI) and plasma volume were independent factors for PSAD. MS was proved as a significant factor for PSAD in univariate regression, but showed no statistical significance in multivariate regression analysis. Among the components of MS, central obesity was proved as independent influencing factor for both PV and PSAD. **Conclusions**: MS was independently associated with PV in elderly males over 60 years, but had no significant correlation with PSA. These results differed from previous research, as we selected an elder population in this study.

Keywords

Metabolic syndrome; Prostate specific antigen; Prostate cancer; Prostate volume; Density

1. Introduction

Metabolic Syndrome (MS) is a clinical syndrome centered around metabolic abnormalities, significantly increasing the risk of cardiovascular disease and type 2 diabetes [1–3]. Previous studies reported that MS was an independent influencing factor for serum prostate specific antigen (PSA) level in males, manifesting as lower PSA in the MS population compared to the non-MS one [4–6]. It was considered that men with MS have a larger plasma volume, which has a diluting effect on PSA, as the total PSA quantity (PSA $\times$ plasma volume) had no difference between MS group and non-MS group [7, 8]. However, there were also studies suggesting that serum PSA had no significant correlation with MS [9, 10]. The reason for these heterogeneous results might be that PSA can be influenced by many other factors, such as prostatic hyperplasia, inflammation, and age, *etc.* [10–12].

It should be noted that the age distribution range of participants in previous studies was extremely wide, with a large portion being young people, who do not need PSA screening and are unlikely to suffer with prostate disorders [8, 13]. Besides, previous studies did not exclude prostate cancer in subjects with abnormal PSA through prostate biopsy, causing prostate cancer to become a confounding factor. Alternatively, some researchers selected individuals with serum PSA <4 ng/mL as subjects [9]. These situations may lead to selection bias and inaccurate research results.

In this study, we exclusively included males aged 60 and above, who need to be vigilant about the incidence of prostate cancer and benign prostatic hyperplasia. Since aging itself influences prostate enlargement and metabolic dysfunction, we focused on elderly males ($\geq$60 years) to minimize confounding age-related effects. Moreover, prostate biopsy was performed to the subjects with abnormal PSA to eliminate the possibility of prostate cancer in the study. Due to the selection of elderly population as subjects, the correlation between MS and PSA may differ from previous studies.

2. Patients and methods

2.1 Patients

This retrospective study was approved by the Ethics Committee of the First Affiliated Hospital of Soochow University. The research data were sourced from the database of the physical examination center of our hospital and accessed in 20 March 2025. The information that could identify individual participants during or after data collection was hidden and kept confidential. Males aged 60 years and above who underwent physical examinations in our hospital from 01 January 2022 to 31 December 2024 were included in this study. Exclusion criteria were age $<$60 years; medication of 5α reductase inhibitors for more than 6 months; indwelling folly catheter; incomplete clinical data for evaluating MS, PV and PSA; history of prostate cancer or other malignancy; newly diagnosed as prostate cancer by prostate biopsy; individuals with PSA levels greater than 10 ng/mL who did not perform prostate biopsy were also excluded due to the high incidence rate of prostate cancer. Finally, 3918 men were included in the research (Fig. 1).

2.2 Definition of MS

The definition of MS was based on the 2009 joint statement of the International Diabetes Federation Task Force on Epidemiology and Prevention, National Heart, Lung and Blood Institute, American Heart Association, World Heart Federation, International Atherosclerosis Society, and International Association for the Study of Obesity [14]. MS was diagnosed if any three of the following five components were present: waist circumference $\geq$90 cm, triglyceride level $\geq$150 mg/dL or drug treatment for elevated triglyceride, high-density lipoprotein (HDL) level $<$40 mg/dL or drug treatment for reduced high-density lipoprotein, elevated blood pressure (systolic pressure $\geq$130 mmHg, diastolic pressure $\geq$85 mmHg, or antihypertensive drug treatment for hypertension), and fasting blood glucose (FBG) level $\geq$100 mg/dL or drug treatment for elevated glucose.

2.3 Calculation formula for parameters

Serum PSA of all subjects were measured using an electrochemiluminescence immunoassay kit (SP10742, Yuande Bio-Medical Engineering Co. Ltd., Beijing, China), with a normal range of 0 to 4 ng/mL. Prostate volume (PV) is calculated based

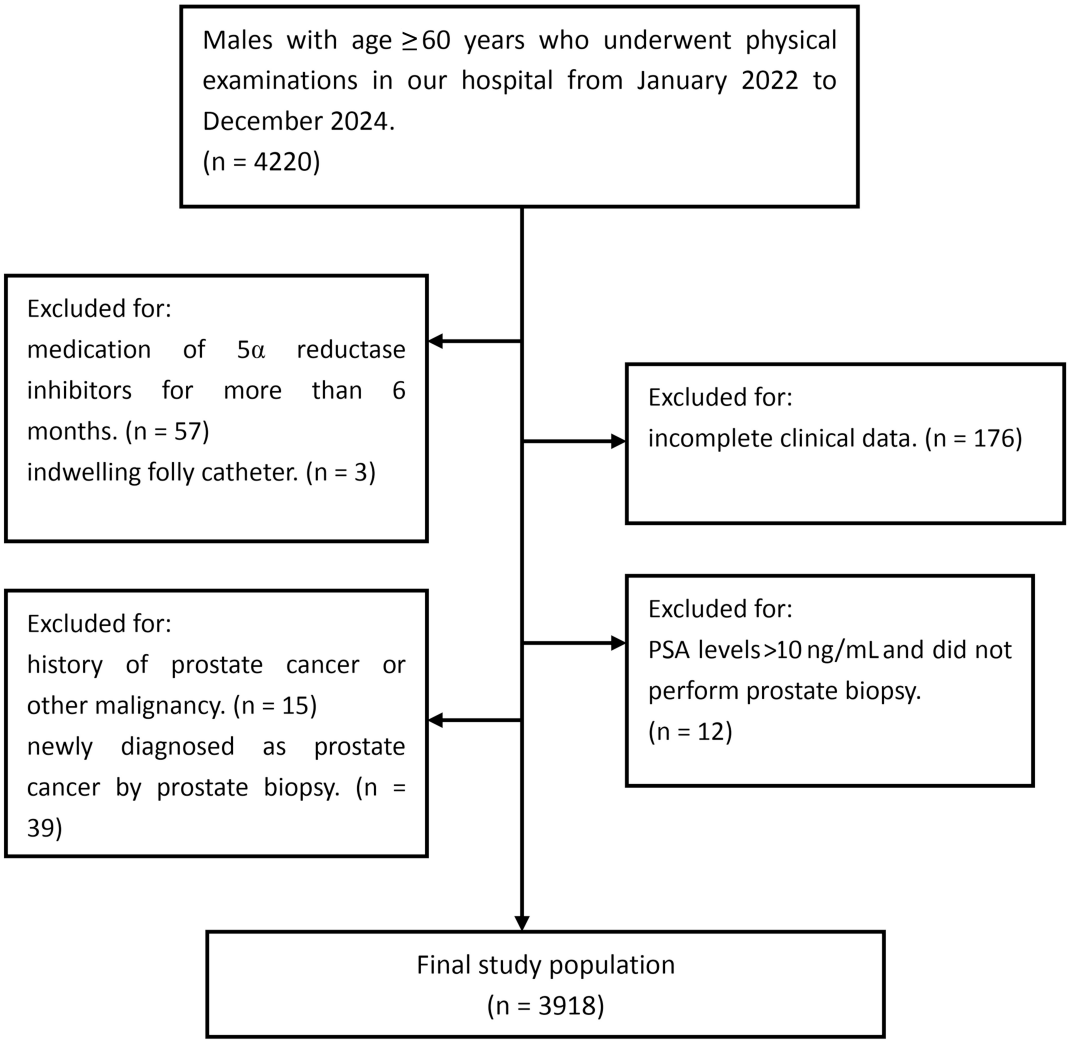

FIGURE 1. Flow chart of selection of the subjects in this study. PSA: Prostate specific antigen.

on the three diameters measured by Doppler ultrasound. To avoid the influence of plasma volume and prostate volume on PSA, PSA mass were calculated. The calculating formula for involved parameters were listed below:

Prostate volume (PV, mL) = anterior-posterior diameter (cm) × superior-inferior diameter (cm) × left-right diameter (cm) × 0.523

Body mass index (BMI) = body weight (kg)/height $(m)^2$

Body surface area (BSA) (m^2) = body weight $(kg)^{0.425}$ × height $(m)^{0.725}$ × 0.007184

Plasma volume (mL) = BSA (m^2) × 1670

PSA mass (ng) = PSA (ng/mL) × plasma volume (mL)

f/t PSA = free PSA (ng/mL)/total PSA (ng/mL)

PSA density (PSAD, ng/mL^2) = PSA (ng/mL)/PV (mL)

2.4 Statistical analyses

Data was evaluated using SPSS Version 17.0 software (IBM SPSS, Chicago, IL, USA). Data were presented as mean ± standard deviation. Student's *t*-test was used to assess differences between two groups. To evaluate influences of parameters on PSA, PSAD and PV, linear regression analysis was used. Significant factors in univariate analysis were further selected into the multivariate linear regression step. Differences were considered to be statistically significant if $p < 0.05$ (bilateral).

3. Results

3.1 Baseline characteristics

The subjects were divided into the MS group (1559 men) and the non-MS group (2359 men). 39.9% of men aged 60 and above possessed MS. Their clinical characteristics were presented in Table 1. The mean age and PSA of total subjects were 69.1 ± 7.3 years and 2.17 ± 2.75 ng/mL, respectively. The age, BMI, PV, and plasma volume of the MS group were greater than those of the non-MS group, with statistical significance. However, there were no statistical difference in PSA, f/t PSA, and PSA mass between the two groups. But the results showed that PSAD of the MS group was significantly lower than that of the non-MS group ($p = 0.013$). In the MS group, 55.5% of the males possessed three positive components of MS, and only 10.6% had five components.

3.2 Linear regression analysis

Variables with statistical significance aforementioned including age, BMI, plasma volume, and presence of MS were

TABLE 1. The baseline characteristics of the study population.

	Total	Non-MS group	MS group	*p* value
N	3918	2359	1559	
Age	69.1 ± 7.3	68.9 ± 7.3	69.5 ± 7.2	0.017
BMI	24.8 ± 2.9	23.9 ± 2.7	26.3 ± 2.7	<0.001
SBP, mmHg	138.5 ± 18.9	134.3 ± 18.8	144.9 ± 17.2	<0.001
DBP, mmHg	79.2 ± 10.8	77.1 ± 10.7	82.2 ± 10.1	<0.001
Waist circumference, cm	87.7 ± 8.4	84.5 ± 7.7	92.5 ± 7.0	<0.001
Triglycerides, mg/dL	140.2 ± 101.5	107.5 ± 53.0	189.6 ± 132.8	<0.001
FBG, mg/dL	108.3 ± 26.9	101.5 ± 21.6	118.5 ± 30.7	<0.001
HDL, mg/dL	45.5 ± 11.3	49.6 ± 11.0	39.4 ± 8.6	<0.001
PSA	2.17 ± 2.75	2.20 ± 2.82	2.12 ± 2.65	0.339
f/t PSA	0.24 ± 0.15	0.24 ± 0.15	0.25 ± 0.15	0.252
PV, mL	36.6 ± 17.0	35.5 ± 15.9	38.3 ± 18.4	<0.001
PSAD	0.059 ± 0.075	0.062 ± 0.079	0.056 ± 0.068	0.013
Plasma volume, mL	2990.3 ± 223.2	2933.8 ± 214.4	3075.9 ± 208.7	<0.001
PSA mass, ng	6441.9 ± 801.5	6431.3 ± 812.9	6457.9 ± 784.2	0.919
No. of metabolic components, n (%)				
- 0		394 (10.0%)		
- 1		852 (21.7%)		
- 2		1113 (28.4%)		
- 3			866 (22.1%)	
- 4			527 (13.5%)	
- 5			166 (4.3%)	

MS: Metabolic Syndrome; PSA: Prostate specific antigen; HDL: High-density lipoprotein; FBG: Fasting blood glucose; PV: Prostate volume; BMI: Body mass index; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; PSAD: Prostate specific antigen density.

introduced into the linear regression to evaluate the influence on PV and PSAD. The multicollinearity of the parameters was analyzed, and all variance inflation factors (VIF) were less than 5. The results are shown in Tables 2 and 3. In univariate linear regression, age, BMI, plasma volume, and presence of MS were significant factors both for PV and PSAD. However, in the results of multivariate linear regression, only age, plasma volume and presence of MS were proved as independent factors that influenced PV, with a positive correlation. Besides, age, BMI and plasma volume were independent factors for PSAD. BMI and plasma volume were negatively correlated with PSAD, and the age had a positive correlation. However, presence of MS showed no independent significance to PSAD ($p = 0.399$).

We also explored the influence of components of MS on PV and PSAD (Tables 2 and 3). Hypertension, central obesity, and low HDL were independent factors for PV, showing a positive correlation to PV. While central obesity and high FBG were independent factors for PSDV, with negative correlations.

3.3 Trend analysis

The correlation between the number of positive MS components and PSA, PV, PSAD has also been researched. The results were shown in Fig. 2. PV linearly increased and PSAD decreased as each positive component of MS added, with statistical significance (p for trend were < 0.001 and 0.002, respectively). However, PSA did not show significant changes when components of MS were added (p for trend was 0.326).

4. Discussion

MS is common in Chinese population. It was reported that the incidence rate of MS in Chinese males over 21 years old is 29.88%, and it gradually increases with age [15, 16]. In our study, the incidence rate of MS in men over 60 years was 39.9%.

Previous studies have shown that the PSA of the MS group is lower than that of the non-MS group, and after calibrating plasma volume, there is no statistical difference between the

TABLE 2. The linear regression analysis of MS, the components of MS and other factors that affect PV.

Parameters	Univariate regression			Multivariate regression		
	B	95% CI	p value	B	95% CI	p value
Age	2.849	2.450, 3.248	<0.001	2.890	2.490, 3.633	<0.001
Plasma volume	3.485	1.105, 5.865	0.004	7.618	4.737, 9.499	<0.001
BMI	1.707	0.642, 2.772	0.002	0.322	−0.925, 1.569	0.246
MS	2.755	1.672, 3.838	<0.001	1.804	0.676, 2.932	0.038
The components of MS						
- Hypertension	3.324	2.237, 4.412	<0.001	3.101	2.013, 4.189	<0.001
- Central obesity	3.158	2.083, 4.234	<0.001	2.720	1.631, 3.810	<0.001
- Hypertriglyceridemia	0.690	−0.474, 1.853	0.245			
- Low HDL	1.544	0.433, 2.655	0.006	1.141	0.024, 2.258	0.045
- High FBG	1.022	−0.042, 2.086	0.061			

MS: Metabolic Syndrome; HDL: High-density lipoprotein; FBG: Fasting blood glucose; BMI: Body mass index; CI: confidence interval.

TABLE 3. The linear regression analysis of MS, the components of MS and other factors that affect PSAD.

Parameters	Univariate regression			Multivariate regression		
	B	95% CI	p value	B	95% CI	p value
Age	0.004	0.003, 0.006	<0.001	0.003	0.001, 0.006	0.001
Plasma volume	−0.034	−0.044, −0.024	<0.001	−0.016	−0.029, −0.003	0.015
BMI	−0.015	−0.020, −0.011	<0.001	−0.011	−0.016, −0.005	<0.001
MS	−0.006	−0.011, −0.001	0.016	−0.001	−0.005, 0.004	0.399
The components of MS						
- Hypertension	0.004	0.001, 0.009	0.119			
- Central obesity	−0.010	−0.015, −0.006	<0.001	−0.010	−0.014, −0.005	<0.001
- Hypertriglyceridemia	−0.003	−0.008, 0.002	0.271			
- Low HDL	−0.004	−0.009, 0.001	0.137			
- High FBG	−0.007	−0.011, −0.002	0.005	−0.005	−0.010, 0.001	0.023

MS: Metabolic Syndrome; HDL: High-density lipoprotein; FBG: Fasting blood glucose; BMI: Body mass index; CI: confidence interval.

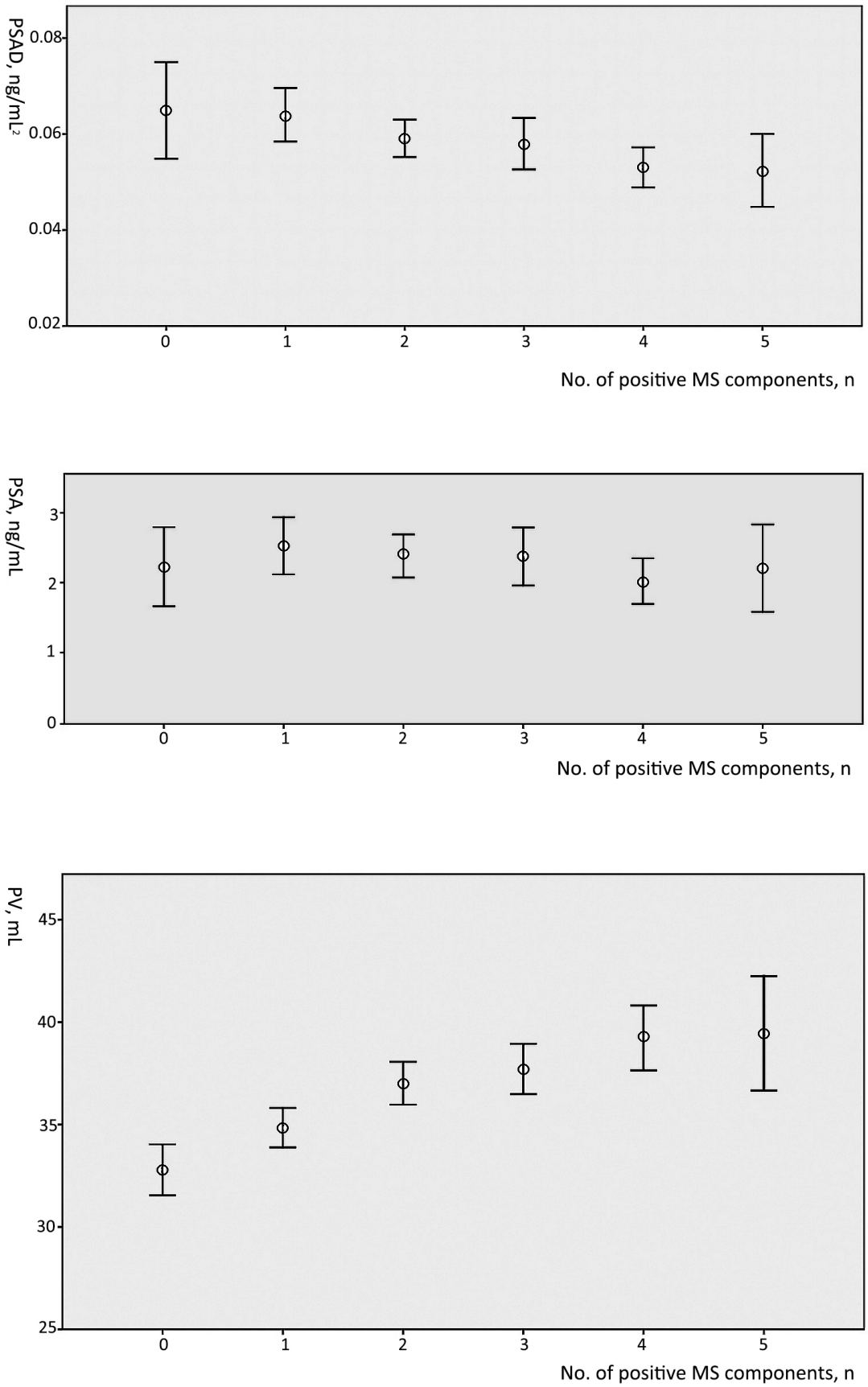

FIGURE 2. The correlation of PSAD, PSA, PV, and the sum of positive MS components. (*p*-trend were 0.002, 0.326 and < 0.001, respectively). MS: Metabolic Syndrome; PSA: Prostate specific antigen; PV: Prostate volume; PSAD: Prostate specific antigen density.

two groups [13, 17]. Therefore, it is believed that MS affects PSA by increasing plasma volume. In our study, the results showed that the serum volume of MS patients was greater than that of non-MS patients, and there was a significant correlation between MS and plasma volume ($R = 0.705$, $p < 0.001$). This is consistent with previous studies. But there was no statistical difference in PSA between the two groups. PSA mass also had no significant difference after adjusting the plasma volume. There was no correlation between PSA and the number of positive MS components. These results differed from previous studies. The possible reason is that the population selected for this study was individuals aged 60 and above, rather than the full age range used in other studies. For non-prostate cancer males with old age, the factors that affect PSA are mainly age, prostate volume, inflammation, sex hormone levels, *etc.*, while the impact of MS is negligible [10–12, 18].

Although there was no correlation between MS and PSA, MS was proven as an independent influencing factor of PV in the study. PV was also correlated with the number of positive MS components, with statistical significance. An animal experiment revealed the mechanism by which MS leads to an increase in prostate volume. Rabbits with MS showed change of prostate inflammation and fibrosis, by increasing the messenger RNA expression of several proinflammatory factors (such as Interleukin (IL)-6, IL-8, and Tumor necrosis factor (TNF)-α), which promote the proliferation of prostate cells [19]. One Clinical study also confirmed that the serum TNF-α level in the MS males is higher than those in the non-MS males [20]. Many researches have proved that chronic inflammation of the prostate has a promoting effect on volume enlargement [21–23]. Besides, Zou *et al.* [24] found that the growth rate of PV in patients with MS was higher than that in non-MS patients. As PV more than 40 mL is highly correlated with the progression of lower urinary tract symptoms (LUTS) and acute urinary retention [25], inhibiting prostate enlargement is essential for elderly men. Based on the above results, treatment of MS has significant clinical values in preventing prostate growth and alleviating LUTS.

PSAD was proved lower in MS group compared with non-MS group, which is the same result as previous research [13, 17]. In this study, univariate regression analysis suggested that MS is an influencing factor of PSAD, while in multivariate regression analysis it was not the case. PV in MS group was significantly larger than non-MS group, indicating that the difference of PSAD was majorly caused by PV. This result indicated that we should consider the impact of MS when using PSAD to screen for prostate cancer in clinical work.

It was the first study to research the correlation between MS and f/t PSA, which has important diagnostic value in prostate cancer screening when PSA is 4 to 10 ng/mL [26]. The results showed no statistical difference in f/t PSA between the two groups, and there was no association between MS and f/t PSA ($p = 0.252$), indicating that this parameter could be not affected by patients' metabolic condition.

Among the five components of MS, central obesity is an independent influencing factor for both PV and PSAD. Previous studies have confirmed that obese individuals have larger prostate volumes and more severe LUTS [27, 28]. The possible reason is that obesity lowers serum testosterone and serum globulinbinding protein levels but increases estrogen levels in males [29]. The abnormal ratio of estrogen to androgen and enhanced sympathetic nervous activity are proved to promote Benign Prostatic Hyperplasia (BPH) development and LUTS severity [30, 31]. Besides, it was demonstrated that men with elevated FBG or insulin resistance had a significantly enlarged prostate [32, 33]. In our study, there is no correlation between FBG and PV, but FBG independently influenced on PSAD.

There were some limitations in this study. First, the study was conducted in a single institution, which cannot be representative of the entire Chinese population and may exist selection bias. Secondly, during the process of recruiting subjects, individuals with PSA levels greater than 10 ng/mL who did not perform prostate biopsy were excluded, and some of them may not have prostate cancer. Excluding these potential subjects will have an impact on the accuracy of the results. Thirdly, some parameters like serum sex hormone levels and serum inflammatory factor levels which can affect PSA and PV are not available in this study. Therefore, the conclusions drawn might not be comprehensive and further research is needed.

5. Conclusions

In conclusion, MS is independently associated with PV in elderly males over 60 years, but has no significant correlation with PSA. Besides, among the components of MS, central obesity is the independent influencing factor on both PV and PSAD.

ABBREVIATIONS

MS, Metabolic Syndrome; PSA, Prostate specific antigen; HDL, High-density lipoprotein; FBG, Fasting blood glucose; SBP, Systolic blood pressure; DBP, Diastolic blood pressure; PV, Prostate volume; BMI, Body mass index; BSA, Body surface area; PSAD, Prostate specific antigen density; LUTS, Lower urinary tract symptoms; VIF, variance inflation factors; IL, Interleukin; TNF-α, Tumor necrosis factor; BPH, Benign Prostatic Hyperplasia.

AVAILABILITY OF DATA AND MATERIALS

The authors declare that all data supporting the findings of this study are available within the paper and any raw data can be obtained from the corresponding author upon request.

AUTHOR CONTRIBUTIONS

YC, GSX—designed the study and carried them out; prepared the manuscript for publication and reviewed the draft of the manuscript. YL—collected the data. YC, GSX, YL—supervised the data collection; analyzed the data; interpreted the data. All authors have read and approved the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the First Affiliated Hospital of Soochow University. (Protocol Number: 111251145). Written informed consent was obtained from a legally authorized representatives for anonymized patient information to be published in this article.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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