ORIGINAL RESEARCH ORİJİNAL ARAŞTIRMA

DOI: 10.5336/urology.2024-107842

Assessing the Diagnostic Value of PSA Derivatives and MpMRI in Prostate Cancer Detection: A Retrospective Study

Prostat Kanseri Tespitinde PSA Türevlerinin ve MpMRI'nin Tanısal Değerinin Değerlendirilmesi: Retrospektif Çalışma

Özcan SEVİM[a], Muharrem BATURU[b], Ömer BAYRAK[b], Faruk YAĞCI[b], Özlem BAŞGUT[b], Sakip ERTURHAN[b]

[a]Gaziantep City Hospital, Clinic of Urology, Gaziantep, Türkiye
[b]Gaziantep University Faculty of Medicine, Department of Urology, Gaziantep, Türkiye

ABSTRACT Objective: To examine the correlation between free prostate-specific antigen (fPSA)/total prostate-specific antigen (tPSA) ratios, multiparametric magnetic resonance imaging (Mp-MRI) findings, and pathological results in patients with PSA levels ranging from 4 to 10 ng/dl, which is considered the grey zone. **Material and Methods:** Mp-MRI was performed in 101 patients between 2020 and 2022. Transrectal ultrasonography-guided prostate biopsy was performed in patients with PSA values between 4-10 ng/dl. Patients were categorized into 2 groups based on their pathology results: malignant (group 1) and benign (group 2). The fPSA/tPSA ratios, Prostate Imaging Reporting and Data System (PI-RADS) scores, and International Society of Urological Pathology (ISUP) scores of patients in the malignant group were recorded. **Results:** Pathological analysis of 101 patients yielded following results: 31.7% (31 individuals) were diagnosed with cancer, 3% (3 cases) presented with atypical small acinar proliferation, and 66.3% (67 patients) were determined to have benign conditions. The mean fPSA/tPSA ratio of patients was lower in group 1 (group 1: 0.13±0.06, group 2: 0.22±0.08, p=0.001). The fPSA/tPSA ratio was significantly lower in PI-RADS-4 and 5 compared to PI-RADS-3. A significant correlation was found between PI-RADS scores and cancer detection rates (p=0.003). **Conclusion:** It is important to calculate fPSA/PSA ratio and decide to perform biopsy in patients with PSA values between 4-10 ng/dl. As PI-RADS scores increased and free/total PSA ratios decreased, the frequency of cancer detection increased. This study demonstrates the importance of PSA derivatives in diagnostic processes.

Keywords: Prostate neoplasm; prostate specific antigen; multiparametric magnetic resonance imaging

ÖZET Amaç: Gri son olarak kabul edilen 4-10 ng/dl arasında değişen prostat spesifik antijeni (PSA) düzeyleri olan hastalarda serbest [free (fPSA)]/total prostat spesifik antijen (tPSA) oranları, multiparametrik manyetik rezonans görüntüleme [magnetic resonance imaging (Mp-MRI)] bulguları ve patolojik sonuçlar arasındaki korelasyonu incelemek. **Gereç ve Yöntemler:** 2020-2022 yılları arasında 101 hastaya Mp-MRI uygulandı. PSA değerleri 4-10 ng/dl arasında olan hastalara transrektal ultrasonografi eşliğinde prostat biyopsisi yapıldı. Hastalar patoloji sonuçlarına göre 2 gruba ayrıldı: malign (grup 1) ve benign (grup 2). Malign gruptaki hastaların fPSA/tPSA oranları, Prostat Görüntüleme Raporlama ve Veri Sistemi [Prostate Imaging Reporting and Data System (PI-RADS)] skorları ve Uluslararası Ürolojik Patoloji Derneği [International Association of Urological Pathology (ISUP)] skorları kaydedildi. **Bulgular:** 101 hastanın patolojik analizi aşağıdaki sonuçları vermiştir: %31,7'sine (31 kişi) kanser tanısı konuldu, %3'ü (3 olgu) atipik küçük asiner proliferasyon (atypical small acinar proliferation) ile başvurdu ve %66,3'ünün (67 hasta) benign durumları olduğu belirlendi. Hastaların ortalama fPSA/tPSA oranı grup 1'de daha düşüktü (grup 1: 0,13±0,06, grup 2: 0,22±0,08, p=0,001). PI-RADS-4 ve 5'te fPSA/tPSA oranı PI-RADS-3'e kıyasla anlamlı derecede düşüktü. PI-RADS skorları ile kanser tespit oranları arasında anlamlı bir korelasyon bulundu (p=0,003). **Sonuç:** PSA değerleri 4-10 ng/dl arasında olan hastalarda fPSA/PSA oranının hesaplanması ve biyopsi yapılmasına karar verilmesi önemlidir. PI-RADS skorları arttıkça ve sPSA/tPSA oranları azaldıkça kanser tespit sıklığı artmaktadır. Bu çalışma, PSA türevlerinin tanısal süreçlerdeki önemini göstermektedir.

Anahtar Kelimeler: Prostat neoplazmı; prostat spesifik antijeni; multiparametrik manyetik rezonans görüntüleme

TO CITE THIS ARTICLE:
Sevim Ö, Baturu M, Bayrak Ö, Yağcı F, Başgut Ö, Erturhan S. Assessing the diagnostic value of PSA derivatives and MpMRI in prostate cancer detection: A retrospective study. J Reconstr Urol. 2025;15(1):8-13.

Correspondence: Özlem BAŞGUT
Gaziantep University Faculty of Medicine, Department of Urology, Gaziantep, Türkiye
E-mail: drozlembasgut@gmail.com

Peer review under responsibility of Journal of Reconstructive Urology.

Received: 23 Dec 2024 ***Received in revised form:*** 13 Jan 2025 ***Accepted:*** 14 Jan 2025 ***Available online:*** 07 Mar 2025

According to the World Health Organization-Global Cancer Observatory 2024 data, prostate cancer is the second most common solid organ cancer after lung cancer (15.2%), with a prevalence of 14.2% and ranks 5th among the causes of death from cancer with 7.3%.[1] Prostate-specific antigen (PSA) elevation is used for prostate cancer screening, diagnosis, and follow-up of the treatment given, and can be affected by non-cancerous diseases of the prostate and prostate-directed interventions. Since PSA is an organ-specific molecule, not a cancer-specific molecule, its specificity and sensitivity in the diagnosis of prostate cancer are low.[2]

Multiparametric magnetic resonance imaging (MpMRI) has a strong importance in clinical use in patients considered to have prostate cancer.[3] Over time, data for MpMRI have been collected, interpretation and reporting recommendations have been developed and the most current version, Prostate Imaging Reporting and Data System (PI-RADS) v2.1, has emerged.[4] With the widespread use of MpMRI in recent years and the update of guideline information, MpMRI has gained popularity in the diagnosis of prostate cancer.[4] In the diagnosis of prostate cancer, MpMRI is used to detect lesions and determine their localization.[5]

In the present study, MpMRI was performed in patients with elevated PSA levels, and the free PSA (fPSA)/total PSA (tPSA) ratio was calculated. Subsequently, transrectal ultrasonography (TRUS)-guided prostate biopsy was performed. This study aimed to re-examine the role and importance of suspicious lesions on MpMRI and fPSA/tPSA ratios in the prediction of prostate cancer.

MATERIAL AND METHODS

PATIENT SELECTION

In the current study, with the permission of the Gaziantep University Faculty of Medicine Clinical Research and Ethics Committee (date: November 24, 2022; no: 2022/248), the data of 101 patients with a PSA value of 4-10ng/dl, who underwent MpMRI and TRUS-guided prostate biopsy in the Gaziantep University Faculty of Medicine Urology Clinic between 2020-2022 were retrospectively analyzed and included in the study. This study was conducted in accordance with the principles of the Declaration of Helsinki.

Participants who met any of the following criteria were excluded: PSA readings above 10ng/dl, previous lower urinary tract operations involving the prostate, prior prostate biopsies, history of diagnosed malignancies with subsequent medical or surgical interventions, treatment for acute prostatitis in either ambulatory or hospital settings, and Atypical small acinar proliferation (ASAP) findings in pathology reports.

TECHNIQUE AND MATERIAL

Before biopsy, MpMRI was performed using a 3T Ingenia (Philips, Netherlands) MRI device for the diagnosis and screening of prostate cancer. Lesions were evaluated using PI-RADS v2.1.

TRUS guided 10 quadrant prostate biopsy was performed. All patients received an enema (B.T. Enema, 135 ml, rectal, Yenisehir Laboratory, Ankara, Türkiye) before biopsy. Rectal cleansing with povidone-iodine was performed before the procedure. All patients were locally anesthetized with 2% lidocaine lubricant gel before rectal probe insertion for prostate biopsy. The procedure was performed in the right-lateral decubitus position. Patients were administered prophylactic antibiotics before biopsy. HITACHI 405 EUB (Tokyo, Japan) ultrasound device with 6.5 MHz biplane transrectal probe and an 18G 25 cm needle was used for systematic biopsy.

Participants were categorized into 2 groups based on biopsy outcomes. Group 1 included patients with malign results, while Group 2 included patients with benign findings. Age, PI-RADSv2.1 scores, PSA, fPSA values, and pathological results were recorded. The classification of pathological findings was conducted in accordance with the guidelines set forth by the International Society of Urological Pathology (ISUP). The results from both groups of patients with malignant and benign pathologies were compared.

The fPSA, PSA, PI-RADS v2.1, and pathological results of the patients in the prostate cancer group were evaluated as binary groupings. Significant values specific to cancer diagnosis were determined.

STATISTICAL METHOD

The suitability of the numerical variables for normal distribution was tested using the Shapiro-Wilk test. Student's t-test was used to compare normally distributed variables in the 2 groups, and the Mann-Whitney U test was used to compare non-normally distributed variables between the 2 groups. The relationships between categorical variables were tested using the chi-square test. ROC analysis was used to determine the cutoff point for the fPSA/PSA ratio. The SPSS 22.0 (IBM Corp., Armonk, NY, USA), Windows version package program was used in the analyses. $p<0.05$ was accepted as significant.

RESULTS

The mean age of the patients in group 1 was 65.94±7.40 years and the mean age of the patients in group 2 was 63.52±6.11 years (p=0.084). Pathological analysis of 101 patients yielded the following results: 31.7% (31 individuals) were diagnosed with cancer, 3% (3 cases) presented with ASAP, and 66.3% (67 patients) were determined to have benign conditions. The mean fPSA/tPSA ratio of patients was lower in group 1 (group 1: 0.13±0.06, group 2: 0.22±0.08, p=0.001) (Table 1).

The MpMRI results and ISUP grades of patients were summarized in Table 2. Analysis of the fPSA/tPSA ratios in relation to PI-RADS scores revealed significant differences. Patients with PI-RADS-3 on MpMRI had an average fPSA/tPSA ratio of 0.24±0.1. For those with PI-RADS-4, the ratio was 0.17±0.07, while patients scoring PI-RADS-5 showed a ratio of 0.16±0.08 (p=0.001). The fPSA/tPSA ratio was significantly lower in PI-RADS-4 and 5 compared to PI-RADS-3 (Table 2).

TABLE 1: Mean age, PSA, fPSA of patients with malignant and benign pathology

	Group 1 (n=34)	Group 2 (n=67)	p value
Age	65.94±7.40	63.52±6.11	0.084
tPSA (ng/dl)	8.38±2.20	7.23±2.27	0.017
fPSA (ng/dl)	1.08±0.71	1.59±0.74	0.001
fPSA/PSA	0.13±0.06	0.22±0.08	0.001

p<0,05; Group 1: Malignant pathology; Group 2: Benign pathology.
tPSA: Total prostate specific antigen; fPSA: Free prostate specific antigen; ng/ml: nanogram per deciliters

TABLE 2: Comparison of ISUP grade and fPSA/tPSA ratios according to PI-RADS scores

	PI-RADS 3 n=33	PI-RADS 4 n=56	PI-RADS 5 n=12	p value
ISUP grade 1 (n, %)	3 (9.09)	6 (10.70)	3 (25.00)	
ISUP grade 2 (n, %)	0 (0)	8 (14.28)	0 (0)	
ISUP grade 3 (n, %)	0 (0)	1 (1.78)	2 (16.66)	0.003
ISUP grade 4 (n, %)	0 (0)	5 (8.92)	0 (0)	
ISUP grade 5 (n, %)	0 (0)	2 (3.57)	1 (8.33)	
fPSA/tPSA	0.24±0.1	0.17±0.07	0.16±0.08	0.001
Probability of detection of prostate cancer n (%)	3 (9.09)	22 (39.28)	6 (50)	0.004

p<0.05; PI-RADS: Prostate Imaging Reporting and Data System; n: Number; ISUP: International Society of Urological Pathology; fPSA: Free prostate specific antigen; tPSA: Total prostate specific antigen

A significant correlation was found between PI-RADS scores and cancer detection rates (p=0.003). No significant difference was found between PI-RADS 4 and PI-RADS 5 in terms of cancer detection rates, whereas significant differences were found between PI-RADS 3 and PI-RADS 4 and between PI-RADS 3 and PI-RADS 5 (PI-RADS 3 and PI-RADS 4 p=0.016; PI-RADS 4 and PI-RADS 5 p=0.066; PI-RADS 3 and PI-RADS 5 p=0.004). The reason for the significant difference was attributed to the low cancer detection rates in patients with PI-RADS 3 lesions. A significant difference was detected between PI-RADS scores in terms of probability of detection of prostate cancer (p=0.004). There was no significant difference between PI-RADS 4 and PI-RADS 5 in binary group comparison (p=0.494). The low rate of probability of detection of prostate cancer in PI-RADS 3 group is responsible for the significant difference between PI-RADS scores (Table 2).

In the examination of the predictive threshold for the average fPSA/tPSA ratio in individuals diagnosed with prostate cancer, the cutoff point for fPSA/tPSA was determined to be ≤0.15, with area under the curve (AUC) of 0.819 (95% confidence interval: 0.730-0.888, p<0.001). Based on this established cut-off value, the average fPSA/tPSA measurement demonstrated a sensitivity of 76% and a specificity of 85% (Figure 1).

DISCUSSION

The most frequently utilized PSA threshold for prostate cancer screening is ≥3.0 ng/dl, despite the

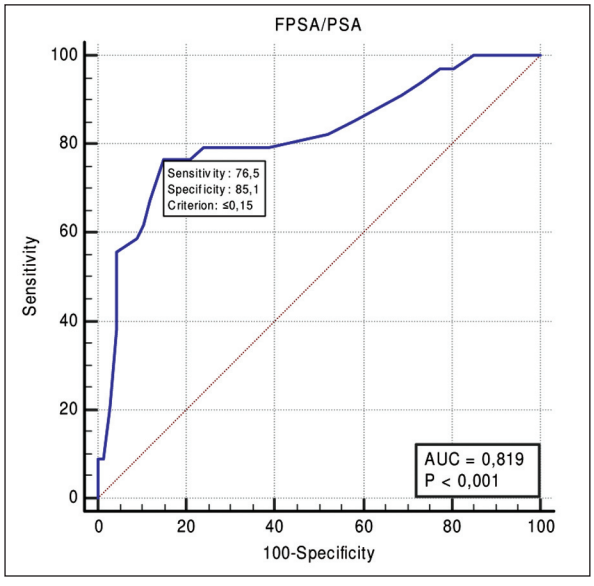

FIGURE 1: Receiver operating characteristics curve of the fPSA/tPSA ratio for the detection of prostate cancer
AUC: Area under curve; fPSA: Free prostate specific antigen; PSA: Prostate specific antigen

ability to detect the disease at lower PSA values. Employing this specific cutoff point results in a positive screening outcome for 16.5% of men screened.[6,7] However, no threshold value has been found for the diagnosis of absolute prostate cancer with PSA.[8]

In the Prostate Cancer Prevention Trial study, Feigl et al. found prostate cancer even at the lowest PSA values when biopsies performed at the end of the study in the placebo group were analyzed. In biopsies performed on subjects with PSA values below 4 ng/dl and normal finger rectal examination, the rate of detection of prostate cancer was 6.6% at PSA ≤0.5 and 0.8% for clinically significant cancer, whereas these rates were 26.9% and 6.7%, respectively, at PSA values between 3-4 ng/dl.[9]

Since PSA is not disease specific, various PSA derivatives have been used to differentiate prostate cancer and benign prostatic hyperplasia. The most commonly used parameter is the ratio of fPSA level to the tPSA value.[10] The fPSA/tPSA ratio has been used for many years to decide on biopsy, especially in patients with PSA values in the grey zone.[11] The cutoff value is usually taken between 15-25%.[12] In previous studies, it was found that the sensitivity was 95% if the cut-off value of fPSA/tPSA ratio was accepted as 25% and 90% if it was accepted as 22% in cases in the grey zone.[13,14] Similarly, Pelzer et al. in their study with 1809 patients with prostate cancer, explained that when the cut-off value for the fPSA/t PSA ratio was accepted as 15%, there were significant differences between the groups with fPSA/tPSA ratio less than 15% and greater than 15% for the prediction of prostate cancer.[15] In the present study, fPSA/tPSA ratio ≤15% was found to be significant for prostate cancer with a sensitivity of 76% and specificity of 85% ($p<0.001$).

After the PSA screening programmes used to detect cancer at organ-confined stage and the lowering of PSA threshold values, the importance of systematic prostate biopsy has increased even more due to the fact that the lesions expected to be found are too small to be detected by transrectal ultrasound alone and approximately 40% of them are isoechoic on transrectal ultrasound.[16,17] TRUS-guided systematic prostate biopsies often yield false-negative outcomes due to the small size of lesions and the fact that 40% of them appear isoechoic. The rate of prostate cancer diagnosis has increased with cognitive and targeted biopsies performed by identifying lesions corresponding to significant prostate cancer using MpMRI, which has been widely used in recent years. While up to 4% of high-grade tumors are missed in systematic biopsies, it has been shown that 11-33% more cancers are detected with the combined use of targeted and systematic biopsy than when used alone.[18-21]

According to Fütterer et al. MpMRI demonstrated a range of effectiveness in identifying clinically significant cancer. This study found that the sensitivity of MpMRI ranged from 58% to 96%, whereas its specificity varied between 23% and 87%. Additionally, the positive predictive value ranged between 34% and 68%, and the negative predictive value ranged from 63% to 98%.[22] In a meta-analysis of 17 studies, Oerther et al. reported the detection rates of clinically significant cancers at the lesion level as 2% for PI-RADS1 lesions, 4% for PI-RADS 2, 20% for PI-RADS 3, 52% for PI-RADS 4, and 89% for PI-RADS 5. In patient-based analyses, clinically significant cancer detection rates were 6% for PI-RADS 1, 9% for PI-RADS 2, 16% for PI-RADS 3, 59% for PI-RADS 4, and 85% for PI-RADS 5.[23]

In the current study, fPSA/tPSA ratio was calculated separately for PI-RADS3, PI-RADS4 and PI-RADS5 scores. Results demonstrated a significant inverse relationship between the ratio and the score, with the ratio decreasing as the score increased ($p<0.001$). When multiple comparisons were made, it was calculated that the fPSA/tPSA ratio was significantly lower in PI-RADS-4 and 5 compared to PI-RADS-3. According to PI-RADS scores 3, 4 and 5 scores, 10%, 40% and 50% probability of cancer diagnosis was calculated respectively. The increase in PI-RADS score showed us an increase in the rate of cancer diagnosis ($p<0.05$).

In urological practice, patients with PI-RADS-4 and PI-RADS-5 results are strongly recommended for prostate biopsy, prioritising the diagnosis of prostate cancer (considered to be a high risk).[3] However, it should not be forgotten that prostate cancer can be diagnosed at lower PI-RADS scores and patients should be evaluated with fPSA/tPSA ratio.[23]

The present study had several limitations. Despite the availability of MpMRI results, the absence of cognitive or targeted biopsy procedures may have contributed to the lower biopsy positivity rates. Furthermore, the study's confinement to a single institution limits the generalizability of current results. Additional limitations included a small sample size, the retrospective nature of the investigation, the absence of long-term outcome data, and the lack of comparison with alternative tools such as PSA density.

CONCLUSION

In the present study, PSA derivatives and MpMRI data of patients in the grey zone according to PSA values were evaluated with biopsy results. It was concluded that as PI-RADS score increased, fPSA/tPSA values decreased significantly and prostate cancer detection rates increased. Our results support the literature it was re-emphasised that MpMRI and PSA derivatives should be used when deciding on prostate biopsy in patients in the grey zone.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Faruk Yağcı, Özcan Sevim;* ***Design:*** *Muharrem Baturu, Ömer Bayrak;* ***Control/Supervision:*** *Muharrem Baturu, Ömer Bayrak;* ***Data Collection and/or Processing:*** *Özcan Sevim, Özlem Başgut;* ***Analysis and/or Interpretation:*** *Sakıp Erturhan, Faruk Yağcı;* ***Literature Review:*** *Muharrem Baturu, Özlem Başgut;* ***Writing the Article:*** *Özcan Sevim, Muharrem Baturu;* ***Critical Review:*** *Sakıp Erturhan, Faruk Yağcı.*

REFERENCES

1. World Health Organization: Cancer Today [Internet]. Data visualization tools for exploring the global cancer burden in 2022. © IARC 1965-2025 [Cited: December 23, 2024] Available from: [Link]
2. Partin AW, Carter HB, Chan DW, Epstein JI, Oesterling JE, Rock RC, et al. Prostate specific antigen in the staging of localized prostate cancer: influence of tumor differentiation, tumor volume and benign hyperplasia. J Urol. 1990;143(4):747-52. [Crossref] [PubMed]
3. Westphalen AC, Rosenkrantz AB. Prostate imaging reporting and data system (PI-RADS): reflections on early experience with a standardized interpretation scheme for multiparametric prostate MRI. AJR Am J Roentgenol. 2014;202(1):121-3. [Crossref] [PubMed]
4. Turkbey B, Rosenkrantz AB, Haider MA, Padhani AR, Villeirs G, Macura KJ, et al Prostate imaging reporting and data system version 2.1: 2019 update of prostate imaging reporting and data system version 2. Eur Urol. 2019;76(3):340-51. [Crossref] [PubMed]
5. Demirel HC, Davis JW. Multiparametric magnetic resonance imaging: overview of the technique, clinical applications in prostate biopsy and future directions. Turk J Urol. 2018;44(2):93-102. [Crossref] [PubMed] [PMC]
6. Schröder FH, Hugosson J, Roobol MJ, Tammela TL, Ciatto S, Nelen V, et al; ERSPC Investigators. Prostate-cancer mortality at 11 years of follow-up. N Engl J Med. 2012;366(11):981-90. Erratum in: N Engl J Med. 2012;366(22):2137. [Crossref] [PubMed] [PMC]

7. Klotz L, Chin J, Black PC, Finelli A, Anidjar M, Bladou F, et al. Comparison of multiparametric magnetic resonance imaging-targeted biopsy with systematic transrectal ultrasonography biopsy for biopsy-naive men at risk for prostate cancer: a phase 3 randomized clinical trial. JAMA Oncol. 2021;7(4):534-42. Erratum in: JAMA Oncol. 2021;7(4):639. Erratum in: JAMA Oncol. 2021;7(7):1074. [Crossref] [PubMed] [PMC]
8. Albertsen PC. Screening for prostate cancer with prostate-specific antigen: the journey continues. Eur Urol. 2023;83(2):110-1. [Crossref] [PubMed]
9. Feigl P, Blumenstein B, Thompson I, Crowley J, Wolf M, Kramer BS, et al. Design of the Prostate Cancer Prevention Trial (PCPT). Control Clin Trials. 1995;16(3):150-63. [Crossref] [PubMed]
10. Van Cangh PJ, De Nayer P, De Vischer L, Sauvage P, Tombal B, Lorge F, et al. Free to total prostate-specific antigen (PSA) ratio improves the discrimination between prostate cancer and benign prostatic hyperplasia (BPH) in the diagnostic gray zone of 1.8 to 10 ng/mL total PSA. Urology. 1996;48(6A Suppl):67-70. [Crossref] [PubMed]
11. Christensson A, Björk T, Nilsson O, Dahlén U, Matikainen MT, Cockett AT, et al. Serum prostate specific antigen complexed to alpha 1-antichymotrypsin as an indicator of prostate cancer. J Urol. 1993;150(1):100-5. [Crossref] [PubMed]
12. Catalona WJ, Southwick PC, Slawin KM, Partin AW, Brawer MK, Flanigan RC, et al. Comparison of percent free PSA, PSA density, and age-specific PSA cutoffs for prostate cancer detection and staging. Urology. 2000;56(2):255-60. [Crossref] [PubMed]
13. Hofer C, Sauerstein P, Wolter C, Scholz M, Hartung R, Breul J. Value of free prostate-specific antigen (Hybritech Tandem-R) in symptomatic patients consulting the urologist. Urol Int. 2000;64(1):18-23. [Crossref] [PubMed]
14. Catalona WJ, Partin AW, Slawin KM, Brawer MK, Flanigan RC, Patel A, et al. Use of the percentage of free prostate-specific antigen to enhance differentiation of prostate cancer from benign prostatic disease: a prospective multicenter clinical trial. JAMA. 1998;279(19):1542-7. [Crossref] [PubMed]
15. Pelzer AE, Volgger H, Bektic J, Berger AP, Rehder P, Bartsch G, et al. The effect of percentage free prostate-specific antigen (PSA) level on the prostate cancer detection rate in a screening population with low PSA levels. BJU Int. 2005;96(7):995-8. [Crossref] [PubMed]
16. Stroumbakis N, Cookson MS, Reuter VE, Fair WR. Clinical significance of repeat sextant biopsies in prostate cancer patients. Urology. 1997;49(3A Suppl):113-8. [Crossref] [PubMed]
17. Roehrborn CG, Pickens GJ, Sanders JS. Diagnostic yield of repeated transrectal ultrasound-guided biopsies stratified by specific histopathologic diagnoses and prostate specific antigen levels. Urology. 1996;47(3):347-52. [Crossref] [PubMed]
18. Ahdoot M, Wilbur AR, Reese SE, Lebastchi AH, Mehralivand S, Gomella PT, et al. MRI-Targeted, Systematic, and Combined Biopsy for Prostate Cancer Diagnosis. N Engl J Med. 2020;382(10):917-28. [Crossref] [PubMed] [PMC]
19. Osses DF, van Asten JJ, Tijsterman JD. Cognitive-targeted versus magnetic resonance imaging-guided prostate biopsy in prostate cancer detection. Curr Urol. 2018;11(4):182-8. [Crossref] [PubMed] [PMC]
20. Elwenspoek MMC, Sheppard AL, McInnes MDF, Merriel SWD, Rowe EWJ, Bryant RJ, et al. Comparison of multiparametric magnetic resonance imaging and targeted biopsy with systematic biopsy alone for the diagnosis of prostate cancer: a systematic review and meta-analysis. JAMA Netw Open. 2019;2(8):e198427. [Crossref] [PubMed] [PMC]
21. Elkhoury FF, Felker ER, Kwan L, Sisk AE, Delfin M, Natarajan S, et al. Comparison of targeted vs systematic prostate biopsy in men who are biopsy naive: the prospective assessment of image registration in the diagnosis of prostate cancer (PAIREDCAP) study. JAMA Surg. 2019;154(9):811-8. [Crossref] [PubMed] [PMC]
22. Fütterer JJ, Briganti A, De Visschere P, Emberton M, Giannarini G, Kirkham A, et al. Can clinically significant prostate cancer be detected with multiparametric magnetic resonance imaging? A systematic review of the literature. Eur Urol. 2015;68(6):1045-53. [Crossref] [PubMed]
23. Oerther B, Engel H, Bamberg F, Sigle A, Gratzke C, Benndorf M. Cancer detection rates of the PI-RADSv2.1 assessment categories: systematic review and meta-analysis on lesion level and patient level. Prostate Cancer Prostatic Dis. 2022;25(2):256-63. [Crossref] [PubMed] [PMC]