Association of MyProstateScore (MPS) with Prostate Cancer Grade in the Radical Prostatectomy Specimen

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Running Title: MPS and Prostate Cancer Pathology

Manuscript Word Count: 2186
Abstract Word Count: 277
Tables: 3
Figures: 2

MeSH Keywords: Prostatic Neoplasms; Prostatectomy; Neoplasm Grading; Prostate-Specific Antigen; Biopsy; Biomarkers, Tumor

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ACKNOWLEDGEMENTS

JJT is supported by the National Institutes of Health/National Cancer Institute Advanced Training in Urologic Oncology Grant (T32/CA180984). His research is funded in part by a University of Michigan Precision Health Research Scholar Award and a SPORE Career Enhancement Program (CA186786).

AMC is a Howard Hughes Medical Institute Investigator and an American Cancer Society Research Professor.

This work was supported by the Prostate Cancer Foundation, Early Detection Research Network (UO1 CA214170), NCI Prostate SPORE (P50 CA186786), and an NCI Outstanding Investigator Award (R35CA231996).

TMM is supported by the A. Alfred Taubman Medical Research Institute.

Potential Conflicts of Interest:

JJT, YSN, and AMC are co-founders and have equity in Lynx Dx, which has licensed the urine biomarkers mentioned in this study from Hologic and the University of Michigan. JJT and YSN have leadership roles in Lynx Dx. The University of Michigan has been issued a patent on ETS gene fusions in prostate cancer on which AMC, RM and SAT are co-inventors. The diagnostic field of use has been licensed to Lynx Dx. SAT serves as CMO of Strata Oncology which was not involved in this study. Lynx Dx or Strata Oncology did not fund the conduct of this study.

ABSTRACT

Background: To evaluate the association between urinary MyProstateScore (MPS) and pathologic grade group (GG) at surgery in men diagnosed with GG1 prostate cancer (PCa) on biopsy.

Methods: Using an institutional biospecimen protocol, we identified men with GG1 PCa on biopsy and PSA ≤10 ng/ml who underwent radical prostatectomy (RP) at the University of Michigan. MPS was retrospectively calculated using prospectively collected, post-DRE urine samples. The primary outcome was upgrading on RP pathology, defined as GG≥2. The associations of MPS, PSA, and PSA density (PSAD) with upgrading were assessed on univariable logistic regression, and the predictive accuracy of each marker was estimated by the area under the receiver operating characteristic curve (AUC).

Results: There were 52 men with urinary specimens available that met study criteria, based on biopsy Gleason Grade and specimen collection. At RP, 17 men (33%) had GG1 cancer and 35 (67%) had GG≥2 cancer. Preoperative MPS was significantly higher in patients with GG≥2 cancer at surgery (median 37.8 [IQR, 22.2-52.4]) as compared to GG1 (19.3 [IQR, 9.2-29.4]; p=0.001). On univariable logistic regression, increasing MPS values were significantly associated with upgrading (odds ratio 1.07 per one-unit MPS increase, 95% CI 1.02-1.12, p=0.004), while PSA and PSAD were not significantly associated with upgrading. Similarly, the discriminative ability of the MPS model (AUC 0.78) for upgrading at RP was higher compared to models based on PSA (AUC 0.52) and PSAD (AUC 0.62).

Conclusions: In men diagnosed with GG1 PCa who underwent surgery, MPS was significantly associated with RP cancer grade. In this limited cohort of men, these findings suggest that MPS could help identify patients with undetected high-grade cancer. Additional studies are needed to better characterize this association.

INTRODUCTION

Although screening with serum prostate-specific antigen (PSA) has been shown to reduce prostate cancer (PCa) mortality (1–3), PSA is poorly specific for PCa diagnosis and clinically-significant PCa (Grade Group ≥2 [GG≥2]), such that a significant subset of biopsies performed prove to be unnecessary (i.e. negative or GG1) (4). As such, there is substantial need to better define the risk and detection of GG≥2 cancer in men traditionally referred for prostate biopsy, thereby sparing patients without cancer and those with low-grade disease from invasive, costly, and anxiety-provoking PCa evaluation (5).

Supplementing serum PSA with additional, cancer-specific biomarkers is one potential solution. The noncoding RNA Prostate Cancer Antigen 3 (PCA3) and the TMPRSS2:ERG (T2:ERG) gene fusion are two such cancer-specific markers, both of which are readily detectable in urine. Consequently, novel urinary assays quantifying these markers have demonstrated their association with GG≥2 PCa detection across initial and repeat biopsy settings (6–10). Furthermore, Sanda and colleagues demonstrated that combined testing with urinary PCA3 and T2:ERG could have prevented 42% of unnecessary biopsies, while failing to detect only 7% of GG≥2 cancers (11). Formerly named the Mi-Prostate Score (MiPS), the MyProstateScore (MPS) test combines these markers with serum PSA in a multivariable regression model. Initial validation in 1244 men showed that MPS provided superior predictive accuracy for GG≥2 cancer relative to PSA plus clinical variables (i.e. the Prostate

Cancer Prevention Trial high-grade [PCPThg] risk calculator). Additionally, the use of MPS was associated with a 35-47% reduction in prostate biopsy on decision curve analysis (DCA) while delaying diagnosis in only 1.0-2.3% of GG≥2 cases (12). More recently, the MPS threshold of 10 was shown to rule out GG≥2 cancer with 97% sensitivity and 98% negative predictive value (NPV) in two large validation populations.

While MPS appears to be highly accurate for detection of GG≥2 cancer, prostate biopsy is an imperfect reference standard for pathologic grading. Specifically, standard prostate biopsy misses an estimated 15-20% of cancers and underestimates cancer grade relative to final radical prostatectomy (RP) pathology (13–15). While the vast majority of patients with GG≥2 PCa undergo definitive treatment, under-grading on biopsy is most concerning in patients diagnosed with GG1 disease, as this population largely defers treatment in favor of active surveillance (16). Therefore, there is a need for methods of identifying GG1 patients harboring more aggressive, undetected disease on biopsy. Although previous studies have focused on using MPS to rule out clinically significant PCa in biopsy-naïve men, MPS may play a role in risk stratifying those with GG1 disease. As such, in a retrospective sample of patients with biopsy-detected GG1 cancer, we explored the association of pre-operative MPS with cancer grade in the radical prostatectomy based surgical pathology specimen – the gold standard for histologic diagnosis.

METHODS

Study cohort

Since 2008, first-catch, post-DRE urine specimens have been prospectively collected at our institution prior to prostate biopsy under an IRB-approved protocol. Specimens are mixed with RNA stabilization buffer and stored at -70°C prior to processing (11,12). For the current study, we identified patients with urine specimens available for MPS testing who had PSA≤10, GG1 PCa on biopsy, and proceeded to RP within one year of biopsy and urine collection. Of 56 eligible cases, MPS testing was informative in 52 (93%), yielding the study cohort.

Clinical Approach

Demographic and clinical data are recorded per protocol and were confirmed prior to analysis. All patients underwent standard 12-core transrectal ultrasound (TRUS) guided systematic biopsy. In patients that underwent multiparametric MRI (mpMRI), findings were reported in accordance with the prostate imaging reporting and data system (PI-RADS) v2 (17). Five out of six patients with PI-RADS ≥3 lesions underwent targeted biopsy. Biopsy and RP specimens were graded according to ISUP Grade Group per standard practice (18).

MPS testing

MPS was retrospectively calculated for all eligible cases as previously described (12). In brief, transcription-mediated amplification yielded PCA3, T2:ERG, and PSA mRNA (8).

PCA3 and T2:ERG scores were generated by normalization to PSA mRNA, and MPS was calculated using validated, locked models including serum PSA, PCA3 score, and T2:ERG score (12). The MPS assay provides a continuous score from 0 (very unlikely to detect GG≥2 PCa) to 100 (very likely to detect GG≥2 PCa).

Statistical Analysis

The primary outcome was detection of GG≥2 cancer on final radical prostatectomy based surgical pathology (i.e. upgrading). Demographic and clinical characteristics were compared by upgrading status using the Wilcoxon rank-sum test for continuous variables and Fisher's exact test for proportions. The association of patient-level factors with upgrading was assessed on univariable logistic regression analysis, yielding odds ratios (ORs) and 95% confidence intervals (CIs). The discriminative accuracy of PSA-, PSAD-, and MPS-based models for upgrading were quantified by the area under the receiver operating characteristic curve (AUC). To account for baseline demographic variables, we secondarily assessed multivariable models including the PCPThg-rc (i.e. PSA plus clinical factors). Tumor size (maximum tumor dimension in centimeters) was a secondary outcome, and the correlation of MPS with tumor size was evaluated using the Spearman correlation coefficient. Finally, we explored the association of MPS values with adverse pathologic features, including: GG≥3, pT stage ≥3 (seminal vesicle invasion [SVI] or extra prostatic extension [EPE]), pN1, or a positive surgical margin (19,20). Statistical analyses were conducted using Stata IC v16.1 and R version 3.6.1.

RESULTS

Study population

Of the 52 men with biopsy GG1 who underwent RP, 35 (67%) upgraded to GG≥2 cancer on final surgical pathology. **Table 1** presents demographic and clinical characteristics of the overall cohort. Age, race, family history, and history of negative prostate biopsy did not significantly differ by RP grade. Notably, preoperative PSA (median 4.3 vs. 4.7, p=0.8) and PSAD (median 0.09 vs. 0.11, p=0.17) did not significantly differ between patients with and without upgrading at RP, respectively. By contrast, median PCA3 (15.3 vs. 41.5, p<0.001), T2:ERG (26.0 vs. 58.1, p=0.03), and MPS (19.3 vs. 37.8, p=0.001) were significantly higher in cases of pathological upgrading. MPS values by pathological grade group are illustrated in **Figure 1**.

Logistic regression models for GG≥2 cancer at RP

Univariable logistic regression was performed on demographic and biochemical variables (**Table 2**). Demographic variables (i.e. age, abnormal DRE, previous negative biopsy, family history, PCPThg-rc, and number of positive cores), PSA, and PSAD were not associated with GG≥2 PCa. Meanwhile, MPS values were significantly associated with tumor upgrading (OR 1.07 per one-unit MPS increase, 95% CI 1.02-1.12, p=0.004). The discriminative accuracy of PSA (AUC 0.52) and PSAD (AUC 0.62) were poor, while MPS yielded an AUC of 0.78. Corresponding ROC curves for these biomarker-based models are illustrated in **Figure 2**. Similarly, relative to the PCPThg-rc (AUC 0.57) and

PCPThg-rc + prostate volume (AUC 0.70), the MPS-based PCPThg-rc model demonstrated superior predictive accuracy (AUC 0.80) (Supplementary Figure 1).

MPS and Secondary RP Outcomes

Among our cohort of 52 patients, 17 (33%) had GG1, 29 (56%) had GG2 without adverse pathology, and 6 (12%) had GG2 and/or GG3 with adverse pathology at RP. No patients with GG1 at RP were found to have adverse pathological features. Among the 35 men with GG≥2, three patients had positive surgical margins, two had GG3 disease, and one had EPE. Interestingly, MPS values increased from a median of 19.3 (IQR, 9.2 - 29.4) in GG1 men and 35.1 (IQR, 21.7 - 45.5) in GG2 men without adverse features to 62.0 (IQR, 52.0 - 67.1) in GG2 men with adverse pathology (**Table 3**). Additionally, MPS values were compared by dominant tumor size for all 52 men (median 1.25 cm [IQR, 0.85 - 1.65 cm]), and the Spearman rank-order correlation between MPS and RP tumor volume demonstrated statistical significance (r=0.347, p=0.012).

DISCUSSION

Given the well-studied risks and limitations of prostate biopsy (4,21,22), the need for novel biomarkers to aid in diagnosis of GG≥2 PCa remains prominent. The urinary MPS test has previously been validated for improved detection of GG≥2 cancer on biopsy relative to PSA and clinical risk factors (PCPThg-rc) (12). However, standard prostate biopsy is estimated to miss cancer in 15-20% of men, and relative to RP pathology, fails to identify the highest-grade cancer in approximately one-third of cases (15). This is particularly concerning for men diagnosed with GG1 PCa, where active surveillance (AS) may be recommended based on the presumed absence of clinically significant disease. We therefore sought to explore the association of MPS with cancer grade on RP pathology – the gold standard for histologic diagnosis – in men diagnosed with GG1 PCa on biopsy. We found that preoperative MPS was significantly higher in men found to have GG≥2 cancer at RP compared to those who did not (median 37.8 vs. 19.3, p=0.001). Furthermore, MPS was associated with superior predictive accuracy for GG≥2 cancer at RP (AUC 0.78) as compared to PSA (AUC 0.52) and PSAD (AUC 0.62).

While urinary T2:ERG has been associated with biopsy findings in multiple studies, there are limited data exploring the association of T2:ERG with more definitive pathologic endpoints. By contrast, several groups have measured the association of PCA3 with surgical pathology. Although one initial study of 62 patients found no significant association of PCA3 with pathologic tumor grade or size (23), a larger body

of evidence supports the association of PCA3 with definitive pathologic outcomes. For example, in 305 men who underwent RP with biopsy-proven clinically localized PCa, Auprich et al. found that a PCA3 score cutoff of 24 was strongly associated with GG≥2 cancer (OR 3.3; p<0.001) and tumor volume <0.5 cm^3 (OR 0.18; p<0.001) on surgical pathology (24). Similarly, on multivariable analysis including PCA3 score, PSAD, biopsy criteria (tumor volume on biopsy), and MRI findings, Ploussard et al. found that a PCA3 score cutoff of 25 was strongly associated with significant PCa (OR 12.7; p=0.003) based on Epstein criteria and tumor volume ≥0.5 cm^3 (OR 5.4; p=0.01) (25). Building upon these data, we found that the MPS test – combining urinary PCA3 and T2:ERG with serum PSA – was significantly associated with tumor grade and volume on RP pathology. Given the association of the PCPThg-rc with cancer in previous studies (26,27), we confirmed our findings in a multivariable model adjusting for this clinical risk score. Indeed, the MPS-PCPThg-rc model (AUC 0.80) outperformed PCPThg-rc alone (AUC 0.57) and PCPThg-rc + prostate volume (AUC 0.70).

In addition to improving the diagnostic pathway, it is possible that emerging tools such as MPS could help guide management decisions after diagnosis, particularly in men with GG1 disease (28). For instance, a particularly high MPS score could suggest the presence of higher-grade cancer not detected on biopsy. Clinically, such findings could prompt earlier confirmatory biopsy or additional assessment with MRI prior to enrollment in active surveillance. Currently, no available diagnostic or prognostic tools provide sufficient evidence to consider forgoing early repeat biopsy in these patients (29,30). Consistent with prior studies highlighting the association of PCA3 and upgrading during

AS (31,32), our findings suggest that MPS could have a potential role as a non-invasive tool to reduce the morbidity of monitoring during AS. It is also conceivable that a test capable of predicting non-organ confined disease could have implications for initial management decisions. Such an application would require a high level of evidence in the appropriate clinical populations. Still, it is encouraging that MPS was highly elevated in the minority of patients with RP GG≥3 disease or other adverse pathological features (pT≥3, pN1, or positive surgical margin).

The current study has notable limitations. First, limiting our cohort to men with PSA ≤10 ng/ml would be expected to reduce the predictive accuracy of all the studied markers. Given that PSA is a component of MPS testing as well, these data can be interpreted to reflect the incremental knowledge provided by MPS relative to PSA alone and PSAD in this clinical reference range. Moreover, this population was chosen to specifically assess the association of MPS with cancer grade in patients with similar, low-risk features at diagnosis (i.e. GG1 and PSA ≤10 ng/ml) eligible for AS. As MPS appears to reflect the underlying “true” cancer state, these data support additional study of RP pathology and longer-term clinical outcomes across PSA ranges. Additionally, our sample size was limited, which would have restricted the number of factors included in multivariable models. We were however able to account for baseline clinical factors using the single composite PCPThg-rc, and MPS outperformed PSA and PSAD in both the univariable and multivariable analyses. Still, the current analysis was not intended to drive clinical application, but rather to provide initial confirmation of the association of MPS with GG≥2 cancer in a more definitive histopathologic reference than biopsy – the

gold standard RP specimen. Additional data are needed to corroborate these findings and better characterize a potential clinical application.

CONCLUSIONS

In a cohort of men with biopsy confirmed GG1 cancer who underwent RP, we found that urinary MPS was significantly associated with cancer grade on final pathology. MPS provided substantially stronger discriminative ability for pathologic tumor grade in this population compared to PSA and PSAD. These data support a potential role for MPS in identifying the presence of occult, clinically significant PCa in the setting of low-risk cancer on biopsy. Additional studies are warranted to confirm these findings and better characterize the association of MPS with clinically-meaningful long-term outcomes.

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FIGURE LEGENDS

Table 1. Clinical and pathological characteristics of 52 men diagnosed with GG1 prostate cancer treated with RP.

Figure 1. Distributions of MPS scores in patients who did (GG≥2) or did not (GG1) upgrade on RP specimen pathology. MPS: MyProstateScore; GG: Grade Group.

Table 2. Univariable analyses of clinical variables and biomarkers in predicting the probability of GG≥2 cancer on surgical pathology.

Figure 2. Receiver operating characteristics curve for PSA-, PSAD-, and MPS-based univariable logistic regression models for the prediction of GG≥2 cancer on surgical pathology.

Table 3. MPS scores of patients based on RP tumor grade and the presence or absence of adverse pathological features.

Table 1. Clinical and pathological characteristics of 52 men diagnosed with GG1 prostate cancer treated with RP.

	Overall	Not upgraded	Upgraded	*p-value*
N	52 (100%)	17 (33%)	35 (67%)	
Clinical Characteristics				
Age	62.0 (54.5 - 66.9)	58.5 (54.0 - 66.9)	62.3 (55.9 - 66.8)	0.6
African American race	6 (12%)	2 (12%)	4 (11%)	> 0.9
Abnormal DRE	9 (17%)	2 (12%)	7 (20%)	0.7
Family history	14 (29%)	5 (31%)	9 (27%)	> 0.9
Prior negative biopsy	10 (19%)	3 (18%)	7 (20%)	> 0.9
PCPThg-rc (%)	9.6 (6.5 - 14.6)	8.3 (6.6 - 13.3)	10.2 (6.5 – 15.0)	0.5
Year of biopsy	2014 (2012 - 2016)	2012 (2011 - 2014)	2015 (2013 - 2017)	0.004
Biomarkers				
PSA (ng/mL)	4.6 (3.8 - 6.4)	4.3 (4.0 - 6.1)	4.7 (3.7 - 6.4)	0.8
PSA density (ng/mL/mL)	0.10 (0.07 - 0.15)	0.09 (0.06 - 0.13)	0.11 (0.08 - 0.18)	0.17
PCA3	33.0 (15.2 - 76.9)	15.3 (11.0 - 24.8)	41.5 (20.7 - 88.8)	< 0.001
T2:ERG	40.5 (13.8 - 103.7)	26.0 (11.0 - 47.4)	58.1 (15.9 - 173.7)	0.03
MPS	32.6 (18.7 - 48.3)	19.3 (9.2 - 29.4)	37.8 (22.2 - 52.4)	0.001
Imaging				
Underwent MRI	9 (17%)	1 (5.9%)	8 (23%)	0.2
PI-RADS ≤2	3 (33%)	1 (100%)	2 (25%)	
PI-RADS 3	0	0	0	
PI-RADS 4	5 (56%)	0	5 (63%)	
PI-RADS 5	1 (11%)	0	1 (13%)	
Biopsy Results				
Prostate volume on TRUS (mL)	44.0 (34.8 - 53.8)	46.7 (42.0 - 63.3)	41.0 (31.0 - 53.1)	0.04
Positive systematic cores (n)	2.5 (1.0 - 4.0)	2.0 (1.0 - 3.0)	3.0 (2.0 - 4.0)	0.047
Maximum core involvement (%)	25 (8.5 - 50)	15 (5.0 - 40)	30 (9.0 - 50)	0.18

Values displayed as median (IQR) or n (%). DRE: digital rectal examination; PCPThg-rc: Prostate Cancer Prevention Trial high grade risk calculator; PSA: prostate-specific antigen; PCA3: Prostate Cancer Antigen 3; T2:ERG: TMPRSS2:ERG gene fusion; MPS: MyProstateScore; PI-RADS: prostate imaging reporting and data system; TRUS: transrectal ultrasound.

Figure 1. Distributions of MPS scores in patients who did (GG≥2) or did not (GG1) upgrade on RP specimen pathology. MPS: MyProstateScore; GG: Grade Group.

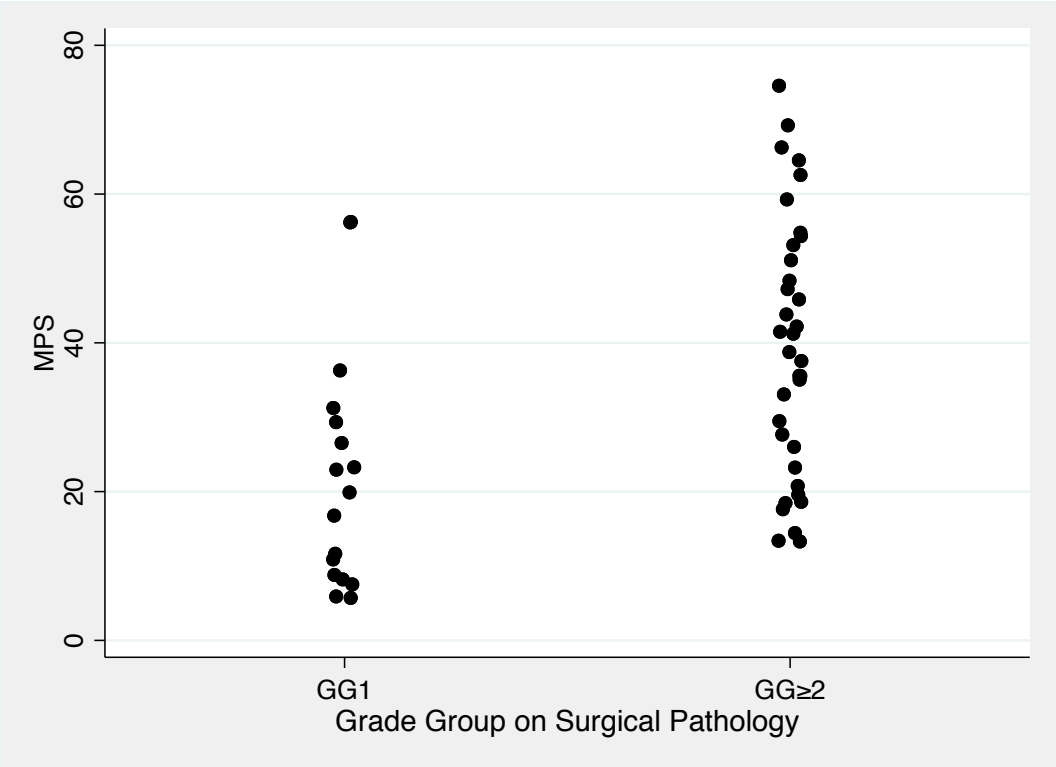

Table 2. Univariable analyses of clinical variables and biomarkers in predicting the probability of GG≥2 cancer on surgical pathology.

	Univariable Analysis	
Predictors	OR (95% CI)	*p-value*
Age	1.02 (0.95 – 1.10)	0.6
Abnormal DRE	1.88 (0.35 – 10.18)	0.5
Prior Negative Biopsy	1.17 (0.26 – 5.21)	0.8
Family History	0.83 (0.22-3.04)	0.8
PCPThg-rc	1.03 (0.93-1.13)	0.6
Number of positive cores	1.36 (0.94-1.97)	0.11
PSA	0.99 (0.75 – 1.30)	0.9
PSAD	1.07 (0.97 – 1.18)	0.15
PCA3	1.03 (1.01 – 1.06)	0.02
T2:ERG	1.00 (1.00 – 1.01)	0.2
MPS	1.07 (1.02 – 1.12)	0.004

OR: odds ratio; 95% CI: 95% confidence interval; DRE: digital rectal examination; PCPThg-rc: Prostate Cancer Prevention Trial high grade risk calculator; PSA: prostate-specific antigen; PSAD: PSA density; PCA3: Prostate Cancer Antigen 3; T2:ERG: TMPRSS2:ERG gene fusion; MPS: MyProstateScore.

Figure 2. Receiver operating characteristics curve for PSA-, PSAD-, and MPS-based univariable logistic regression models for the prediction of GG≥2 cancer on surgical pathology.

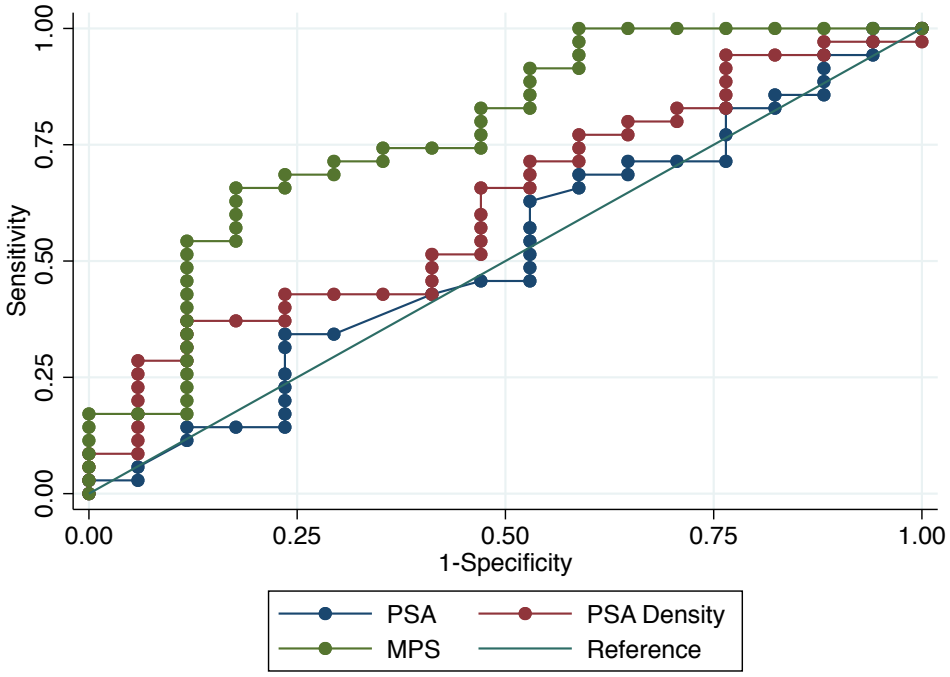

Table 3. MPS scores of patients based on RP tumor grade and the presence or absence of adverse pathological features.

RP Outcome	N (%)	MPS (median, IQR)
GG1	17 (33%)	19.3 (9.2 – 29.4)
GG2 without adverse pathology	29 (56%)	35.1 (21.7 – 45.5)
GG≥2 with adverse pathology	6 (12%)	62.0 (52.0 – 67.1)

Adverse Pathology = GG≥3, pT stage ≥3, pN1, or positive surgical margin; MPS: MyProstateScore; GG: Grade Group.

Supplementary Figure 1. Receiver operating characteristics curve for PCPThg-rc-based multivariable logistic regression models for the prediction of GG≥2 cancer on surgical pathology.