Chapter 2: Prognosticating of Prostate Cancer via Multimodal Data Integration

Therapy-Agnostic Prognostication of Prostate Cancer via MR Imaging and Clinical Data Integration.
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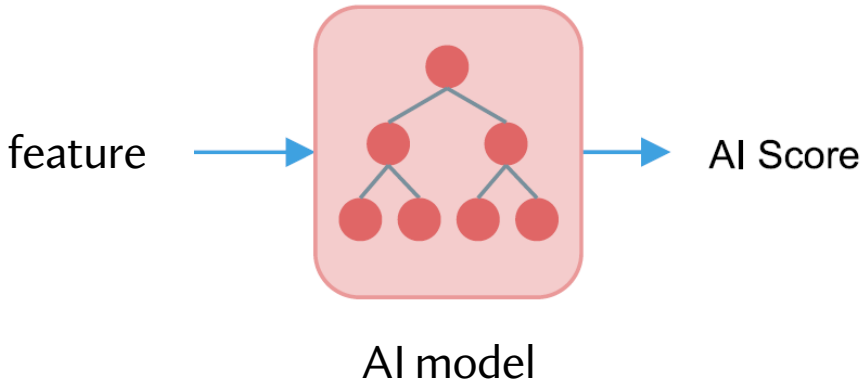
In submission.

What is cancer prognostication?

Prognostication refers to the process of **predicting the future outcome** of a medical condition.

Instead of determining whether a patient has cancer, prognostication focuses on patients who have already been diagnosed, predicting **how their disease will progress**, the risk of recurrence, or their survival prospects.

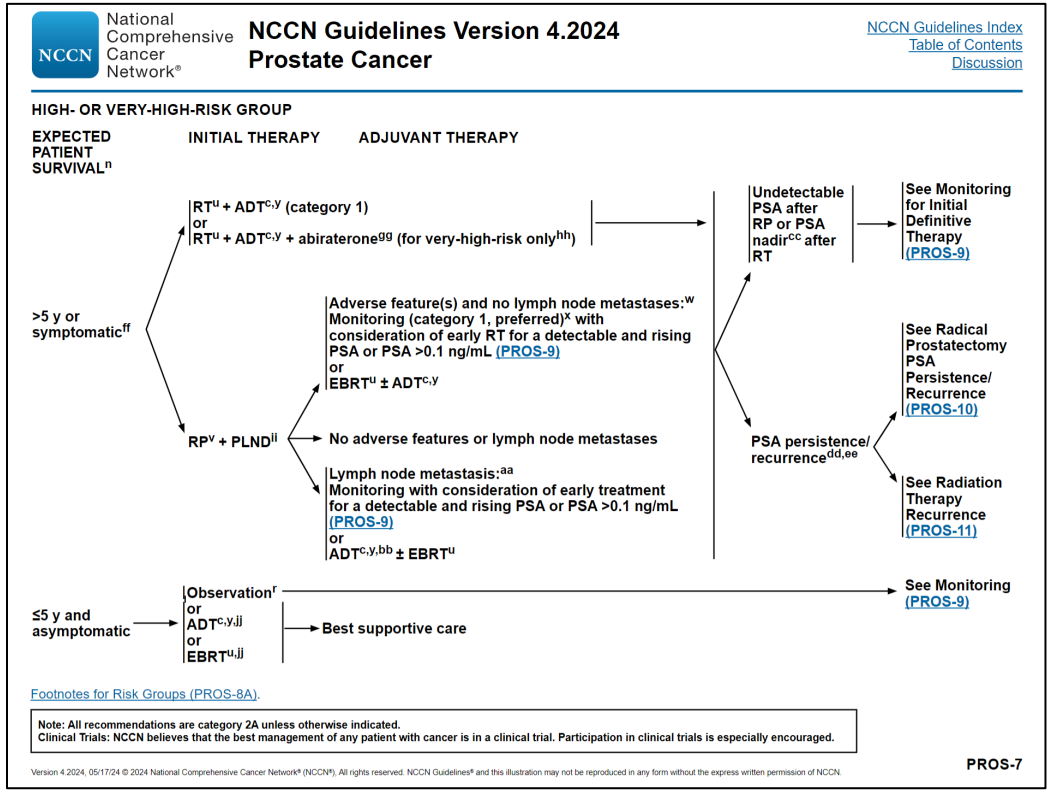


Personalize treatment

Categorize patients into risk groups

Treatment adjustments

Previous work



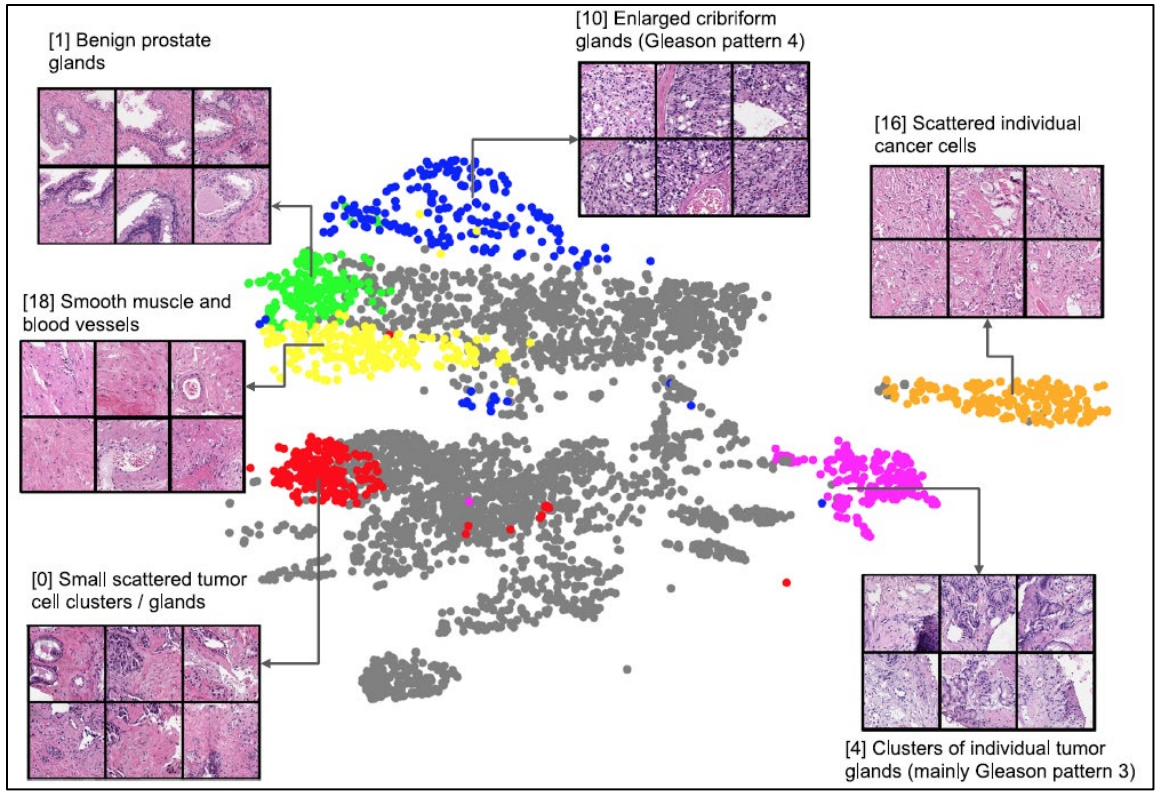
NCCN Guideline

NCCN is a traditional clinical practice, a structured, algorithmic decision-making pathway:

- Less accurate in predicting outcomes
- Discriminatory performance

Previous work

Clinical outcome	NCCN AUC estimates (95% CI)	MMAI AUC (95% CI)
Biochemical Failure (5-year)	0.61 (0.57–0.64)	0.69 (0.65–0.73)
Biochemical Failure (10-year)	0.62 (0.58–0.66)	0.68 (0.63–0.72)



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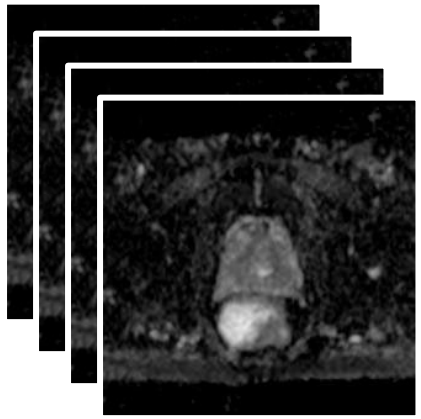
MMAI is a more recent histopathology-based method that uses histopathology and clinical score to make prognostication score, however :

- Struggle to reach better performance;
- Micro-level investigation

Workflow

Pure image model always shows a big generalization gap between the training and testing set.



MR Images
(Diffusion/ADC/T2)

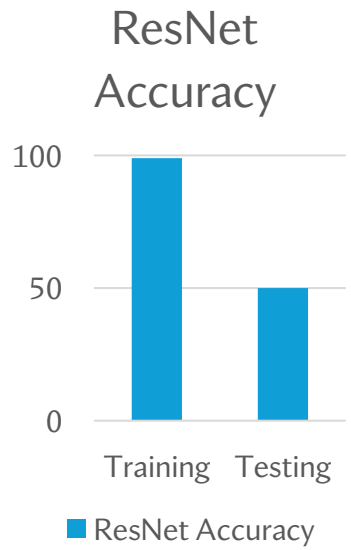
Overfitting!

Image Encoder
(ResNet/ViT)

Image Feature
v_{image}

Linear projection

✅ Not Fail
❌ Fail



Model	Accuracy
ResNet18	52.75%
ResNet34	54.13%
ResNet50	51.61%
ResNet101	50.80%

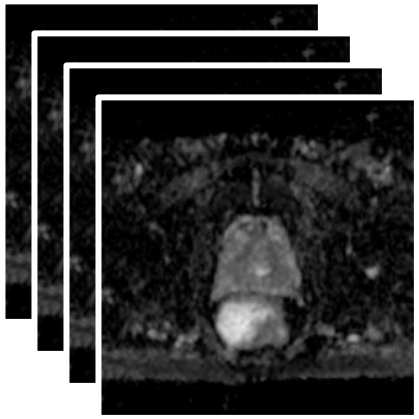
Model	Accuracy
ResNet	52.75%
ConvNeXt	53.03%
ViT	50.31%

Workflow

Image Branch

Clinical Feature Branch

Overfitting!



MR Images
(Diffusion/ADC/T2)

Image Encoder
(ResNet/ViT)

Image Feature
v_{image}

Clinical Feature	Value
CT stage	T1c
CN stage	N0
CM stage	M0
Primary Gleason Score	0
Secondary Gleason Score	3
...	...

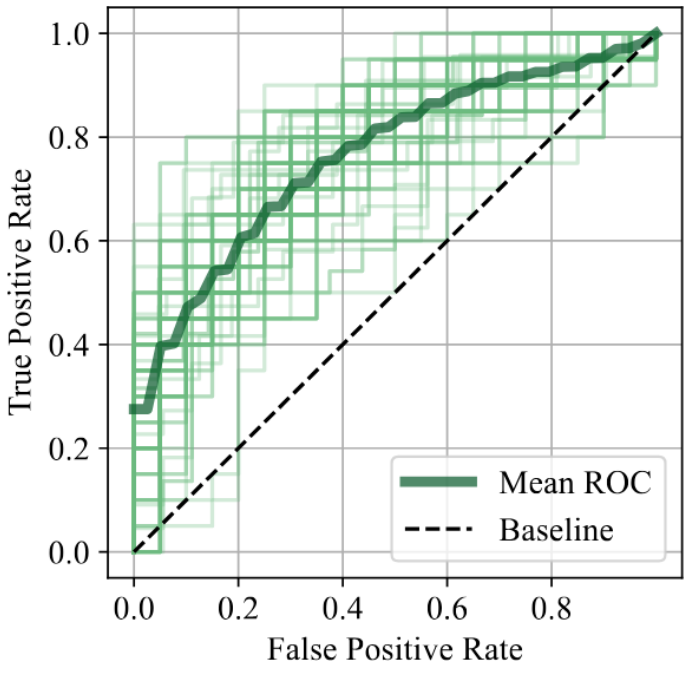
One-hot Feature
$v_{clinical}$

RF

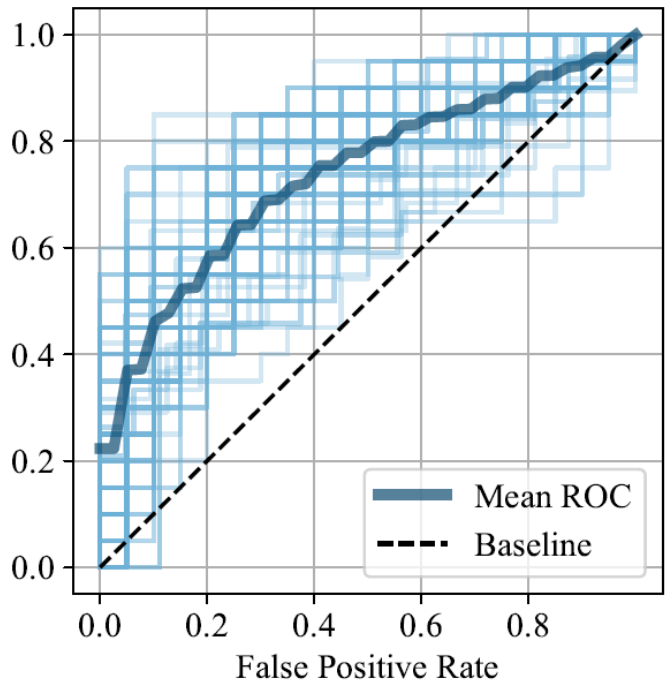
✅ Not Fail
❌ Fail

ROC curves under the different data splits

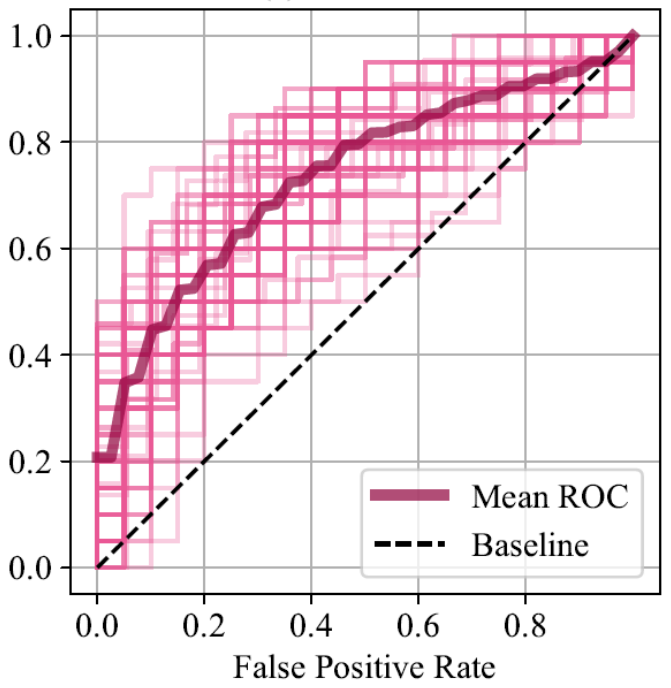
T2



ADC



Diffusion



We did 60 random splits on the dataset and calculate the ROC for each split.

Apparent Diffusion Coefficient (ADC) is a measure derived from diffusion-weighted MRI that quantifies the rate at which water molecules diffuse through tissue.
Diffusion reflects how freely water moves within tissue, and ADC provides a numerical value of this movement.

Ablation study

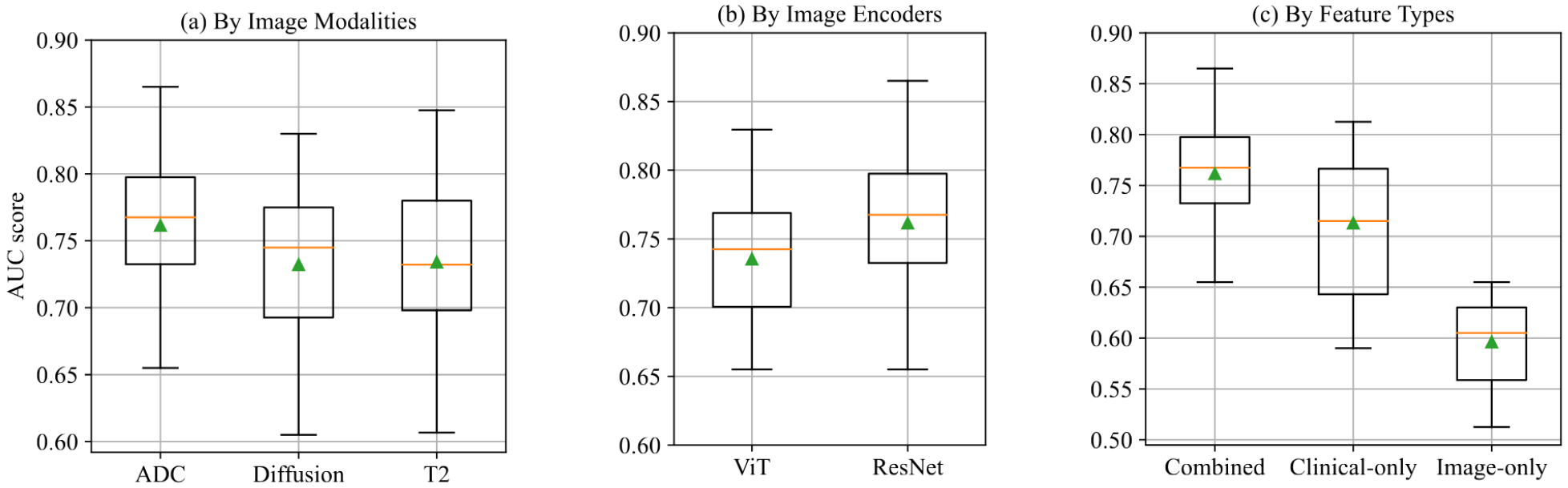
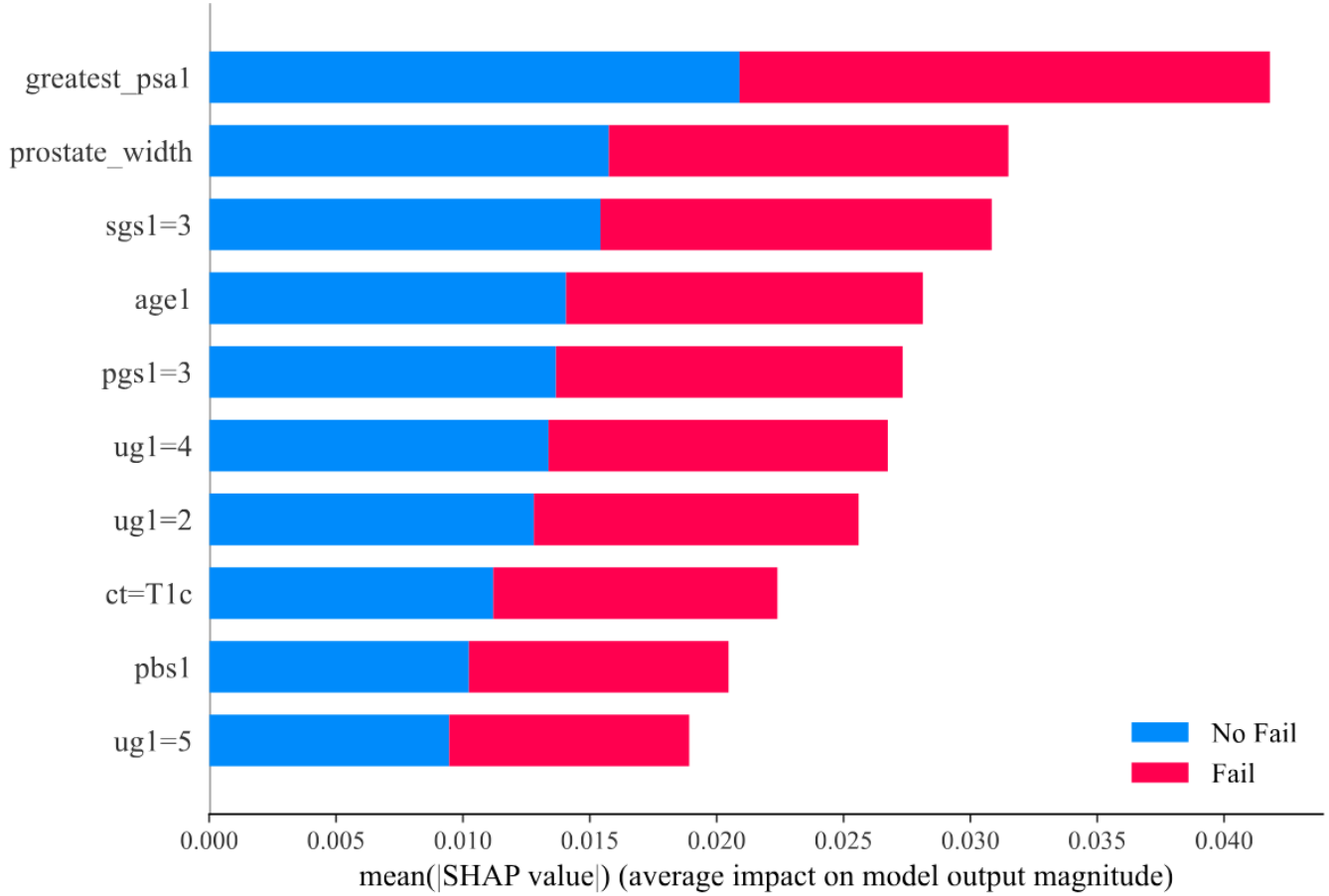


Image modalities	ADC > T2 > Diffusion
Image encoder	ResNet-10 > ViT (tiny)
Data integration	Combined > Clinical-only >> Image-only

Top 10 mean SHAP values

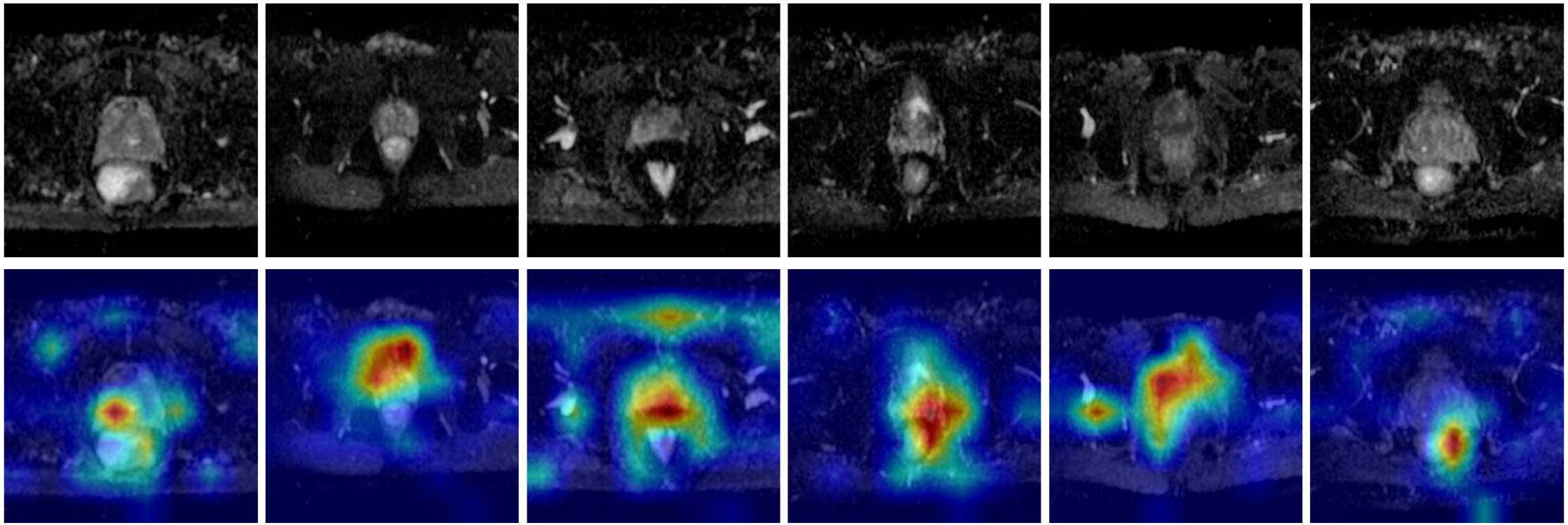
$$\phi_i = \sum_{S \subseteq F \setminus \{i\}} \frac{|S|!(|F| - |S| - 1)!}{|F|!} \left[f_{S \cup \{i\}}(x_S \right.$$

F is the full feature set,
S is the feature subset,
x is the input feature,
f is the model to be evaluated.



Grad-CAM Visualization

We show the Grad-CAM activation maps corresponding to the most significant image features identified by SHAP values.



**Grad-CAM highlights the regions in the image that are most influential or sensitive in determining the model's prediction.*

Conclusions

- Integrating MR images with clinical variables results in prognostication performance that matches or exceeds traditional risk classifiers and genomic classifiers for prostate cancer.

- The highest PSA level before treatment and the secondary Gleason score significantly enhance the prognostication model when combined with imaging analysis.

- MR image features alone are insufficient for accurate prediction; reliable prognostication requires combining both imaging features and clinical data.