Segmentation-based Assessment of Tumor-Vessel Involvement for Surgical Resectability Prediction of Pancreatic Ductal Adenocarcinoma

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Motivation

Pancreatic ductal adenocarcinoma (**PDAC**) is one of the most aggressive malignancies with a dismal prognosis and an overall 5-year **survival rate of less than 10%.** PDAC often goes undetected until it has progressed into an advanced stage. As a result, **majority of patients have advanced or metastatic disease**, leading to limited treatment options and poor outcomes.

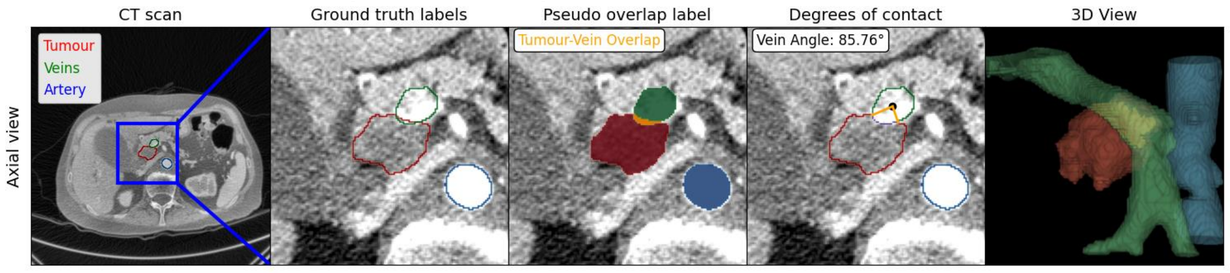

Figure 1: Slice from CT scan depicting the involvement.

Segmentation Networks

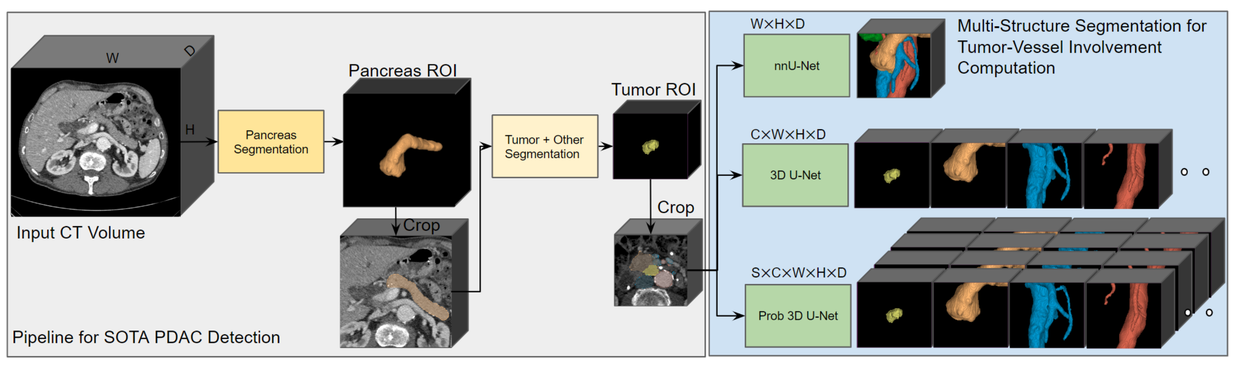

Figure 2: Workflow illustration for tumor segmentation from a CT scan.

This research introduces a **workflow** and **segmentation models** to automatically assess tumor-vessel involvement, a critical factor in determining **tumor resectability**. The **overlap loss (OLL)** improves segmentation accuracy in the important tumor-vessel overlapping region. $\hat{a} = T \odot A$, $\hat{v} = T \odot V$, $H_o = H(a, \hat{a}) + H(v, \hat{v})$, where H is the element-wise BCE. The complete loss can be writen as:

$$CLL = \alpha \times [\beta \times H(p, q) + (1 - \beta) \times Dice(p, q)] + (1 - \alpha) \times H_o(p, q).$$

Results

Metric	3D nnU-Net	3D U-Net OLL	Prob. 3D U-Net OLL
Tumor Dice	0.65 ±0.01	0.63 ±0.01	0.49±0.08
Artery Dice	0.86 ±0.00	0.86 ±0.01	0.86±0.01
Vein Dice	0.90 ±0.00	0.87 ±0.00	0.88±0.01
Artery Overlap Dice	0.00 ±0.00	0.02 ±0.01	0.01±0.00
Vein Overlap Dice	0.08 ±0.01	0.14 ±0.03	0.12±0.02
Artery Sensitivity	0.23 ±0.05	0.53 ±0.17	0.05±0.08
Artery Specificity	0.94 ±0.02	0.91 ±0.04	0.83±0.08
Vein Sensitivity	0.85 ±0.06	0.81 ±0.09	0.73±0.08
Vein Specificity	0.77 ±0.06	0.75 ±0.18	0.60±0.11
Scan Sensitivity	0.81 ±0.00	0.83 ±0.08	0.77±0.07
Scan Specificity	0.74 ±0.07	0.74 ±0.13	0.67±0.09
Ensemble			
Tumor Dice	0.66	0.66	0.56
Artery Dice	0.86	0.86	0.87
Vein Dice	0.91	0.88	0.89
Artery Overlap Dice	0	0.01	0.01
Vein Overlap Dice	0.07	0.15	0.13
Artery Sensitivity	0.2	0.3	0.4
Artery Specificity	0.91	1	0.95
Vein Sensitivity	0.81	0.88	0.75
Vein Specificity	0.81	0.81	0.62
Scan Sensitivity	0.81	**0.88**	0.79
Scan Specificity	0.79	**0.86**	0.72
Critical Structures - Ensemble			
SMV or PV Sensitivity	0.92	0.92	0.77
SMV or PV Specificity	0.79	0.89	0.68
SMA or Truncus Sensitivity	0.5	0.5	0.5
SMA or Truncus Specificity	0.9	0.93	0.90
Scan Sensitivity	0.92	**0.92**	0.79
Scan Specificity	0.79	**0.89**	0.68

Table 1: Segmentation and overlapping scores obtained with the 3D nnU-Net, 3D U-Net and Probabilistic 3D U-Net across 3 validation folds. These three models applied to the test set and an ensemble of these predictions.

The models achieve **high accuracy** in segmenting **veins**, **arteries**, and the **tumor**, enabling automated detection of **tumor involvement** and computation of the degree of tumor-vessel contact. A closer look into the **critical vessels (SMV, PV, Truncus and SMA**) show further improvements in involvement prediction accuracies.

Metric	3D nnU-Net	3D U-Net	Prob. 3D U-Net
Artery R^2	-0.07 ± 0.26	-0.17 ± 0.09	-0.55 ± 0.56
Vein R^2	0.34 ± 0.39	0.16 ± 0.40	-1.95 ± 2.76
Artery R^2	-0.24 ± 0.01	0.12 ± 0.22	-0.24 ± 0.17
Vein R^2	0.37 ± 0.21	0.42 ± 0.13	-0.04 ± 0.44
Artery R^2	-0.27	-0.24	-0.06
Vein R^2	0.52	0.42	0.31
Artery R^2	-0.14	-0.01	-7.53
Vein R^2	0.54	0.44	0.60
0° = Involvement	(19/19), (27/30)	(19/19), (28/30)	(19/19), (27/30)
0° < Involvement ≤ 90°	(5/5), (1/1)	(5/5), (1/1)	(5/5), (1/1)
90° < Involvement ≤ 270°	(0/7), (0/1)	(2/7), (0/1)	(4/7), (0/1)
270° < Involvement	(1/1), (0/0)	(0/1), (0/0)	(1/1), (0/0)

Table 2: Correlation between ground-truth and predicted involvement. Following the DPCG criteria

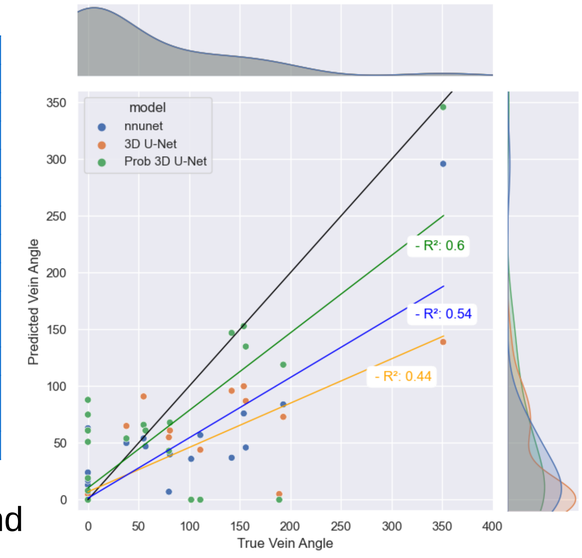

Figure 3: Maximum SMV or PV degrees of involvement.

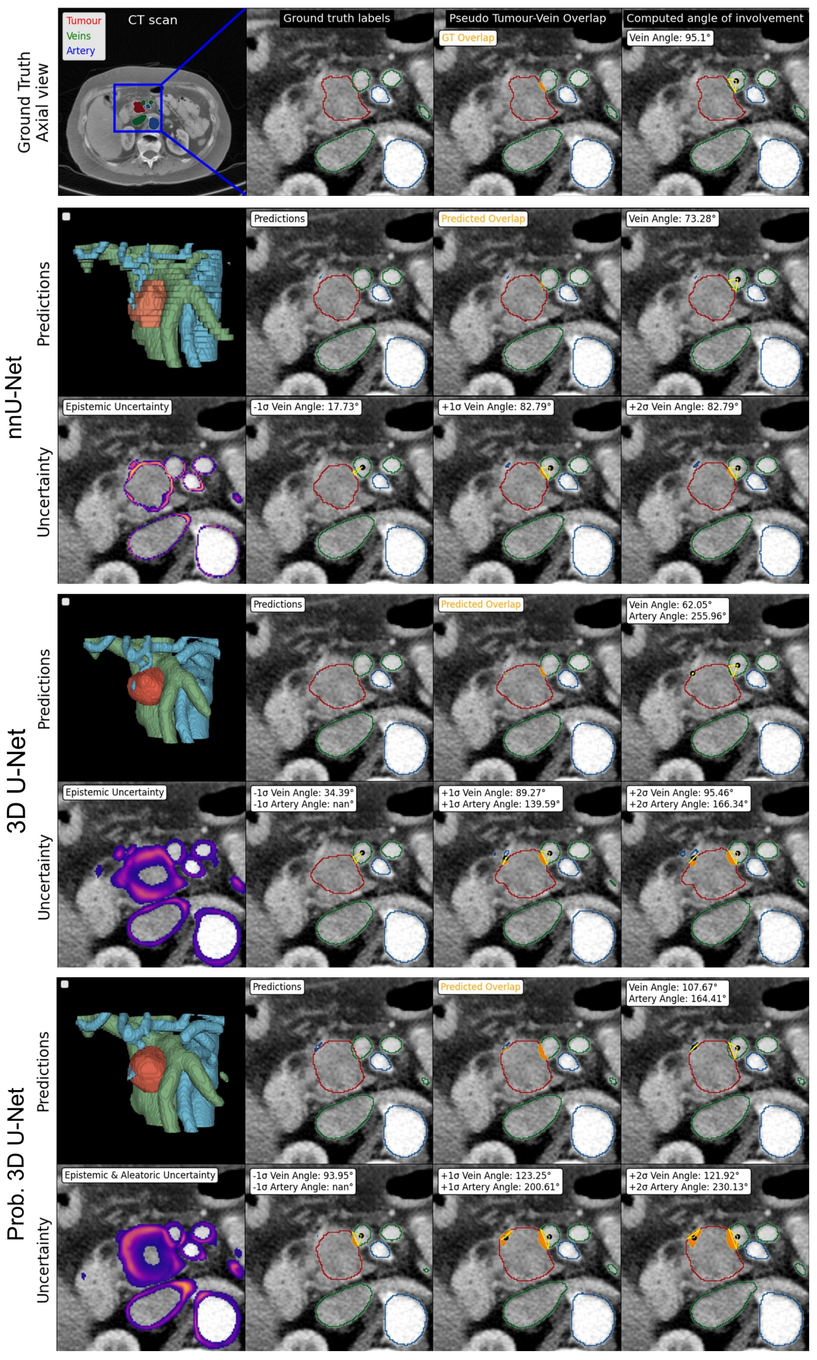

Figure 4: Ground truth (top) and predictions of the three models from a test set case.

Considering uncertainty in segmentation predictions aids evaluating tumor-vessel involvement. In our case, the nnU-Net **underestimates** the involvement, indicating resectable tumor, while the 3D U-Net, accounting for uncertainty, correctly suggests a borderline resectabile tumor, demonstrating the **value of uncertainty assessment** in treatment decisions. This approach, **informed by expert radiologists' practices**, provides clinicians with a clear indication of tumor-vessel involvement, enhancing the potential for more informed decision-making regarding surgical interventions.

Conclusion

A novel workflow is developed for acquiring focused regions of interest in PDAC CT scans to **predict tumor-vessel involvement and resectability**. Three deep learning-based segmentation models **enable automated detection of involvement, computation of involvement degrees and uncertainty estimation**. Utilizing the computed degrees of involvement with the critical structures to classify resectability shows compelling results. The presence of tumor involvement is determined with **high sensitivity (0.88) and specificity (0.86).** These findings provide clinicians with precise indications of tumor-vessel involvement, facilitating more informed decision-making for surgical interventions and personalized treatment strategies in PDAC.

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