EnMcGAN: Adversarial Ensemble Learning for 3D Complete Renal Structures Segmentation

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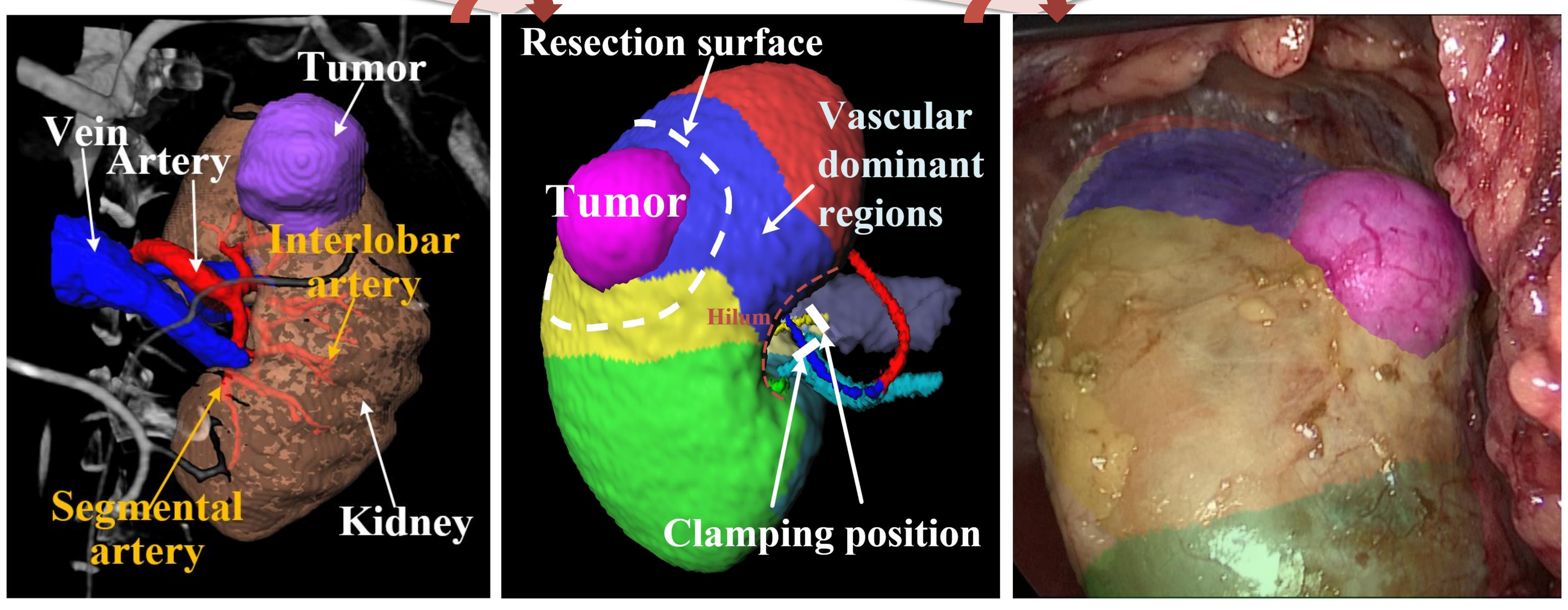
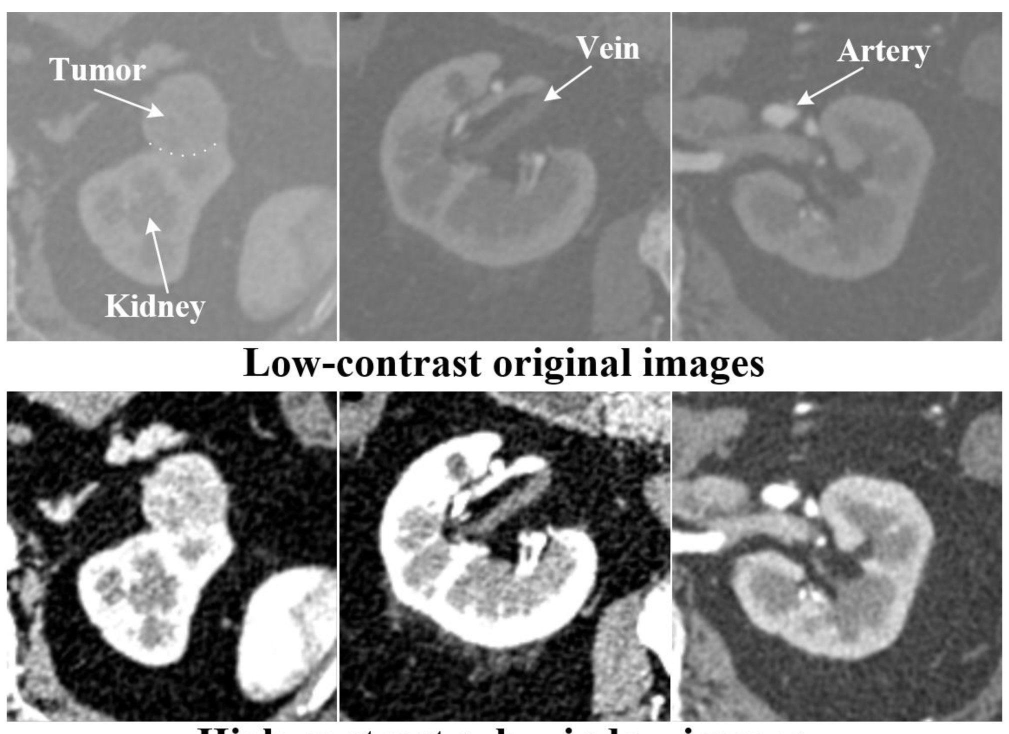
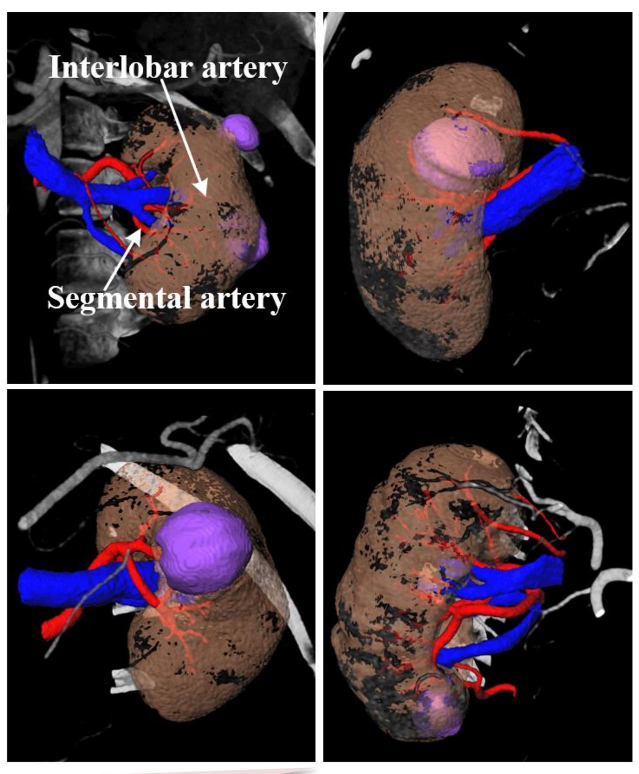
3D CRS visual model for computer-assisted LPN

Target: 3D complete renal structures (CRS) segmentation on CTA image targets on segmenting the kidneys, tumors, renal arteries and veins, once successful, it will provide *preoperative plans* and *intraoperative guidance* for laparoscopic partial nephrectomy (LPN).



CRS segmentation | Clinical requirements | Intraoperative guidance





The arteries have tree-like shape while the tumors have ball-like shape. The model has to represent their features simultaneously resulting in a ***difficult feature extraction process*** and limiting its generalization ability.

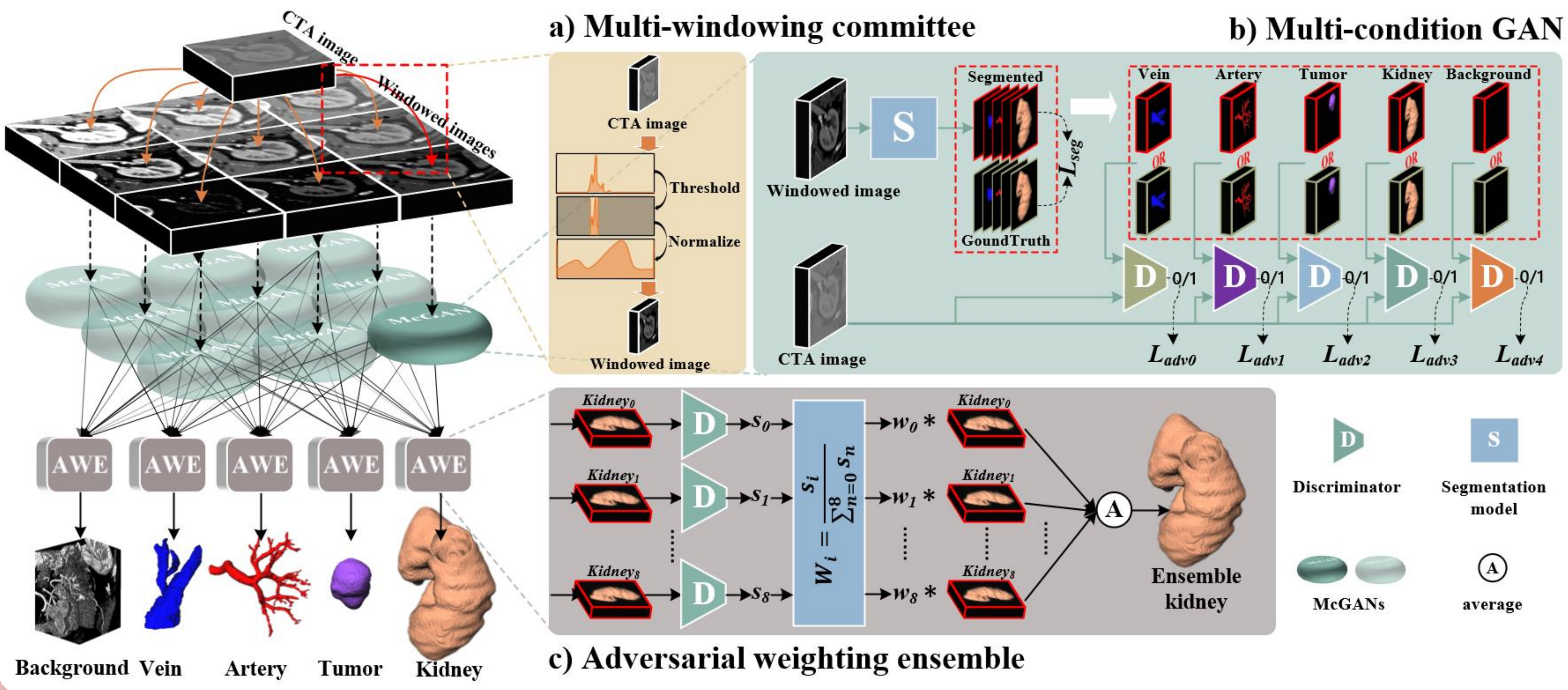
CT image has a large gray range, but renal structures are in a narrow range. the segmentation network will be unable to perceive the fine-grained pattern in such a ***narrow distribution***.

Renal vessels have uncertain branch numbers and growth topology, and the location of the tumors and their damage to the kidneys are uncertain. These anatomical variation makes it ***difficult to cover all variation.***

Challenge: 1) Complex shapes of renal structures.; 2) Coarse-grained pattern and low contrast; 3) Large anatomical variation.

Contribution: We propose the ***adversarial ensemble learning*** which equips the ***ensemble segmentation** model* with ***adversarial learning***, and propose the ***EnMcGAN*** for 3D CRS segmentation which will play an important role in preoperative planning and intraoperative guidance of LPN.

EnMcGAN is trained for 3D complete renal structures segmentation assisting the LPN

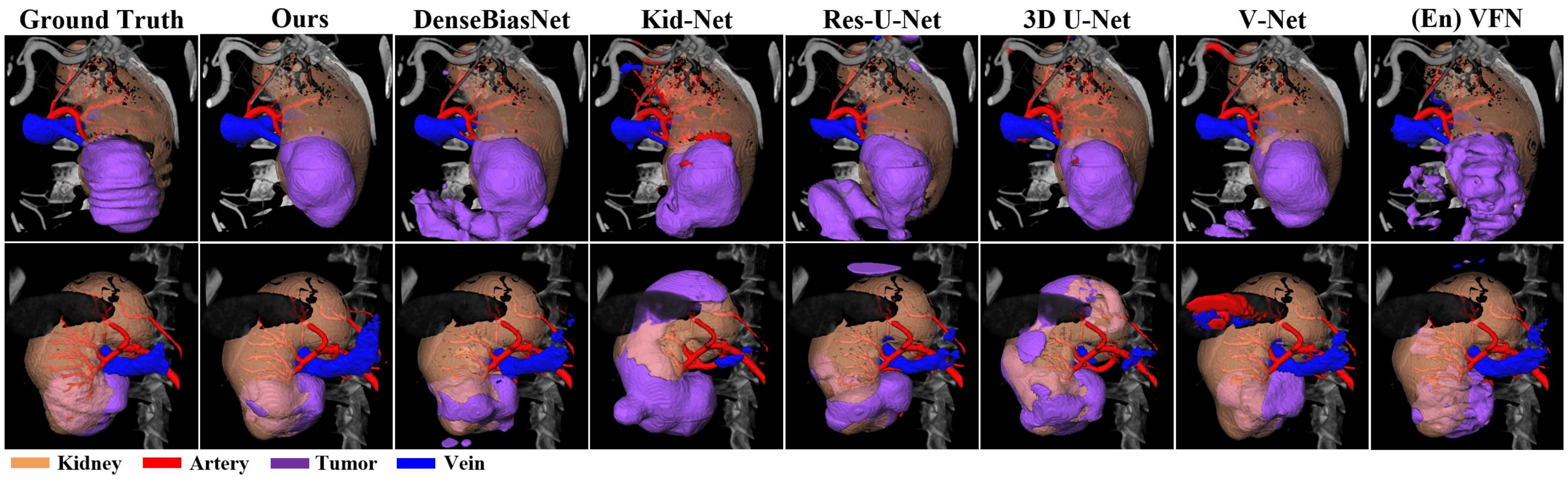


Innovations:

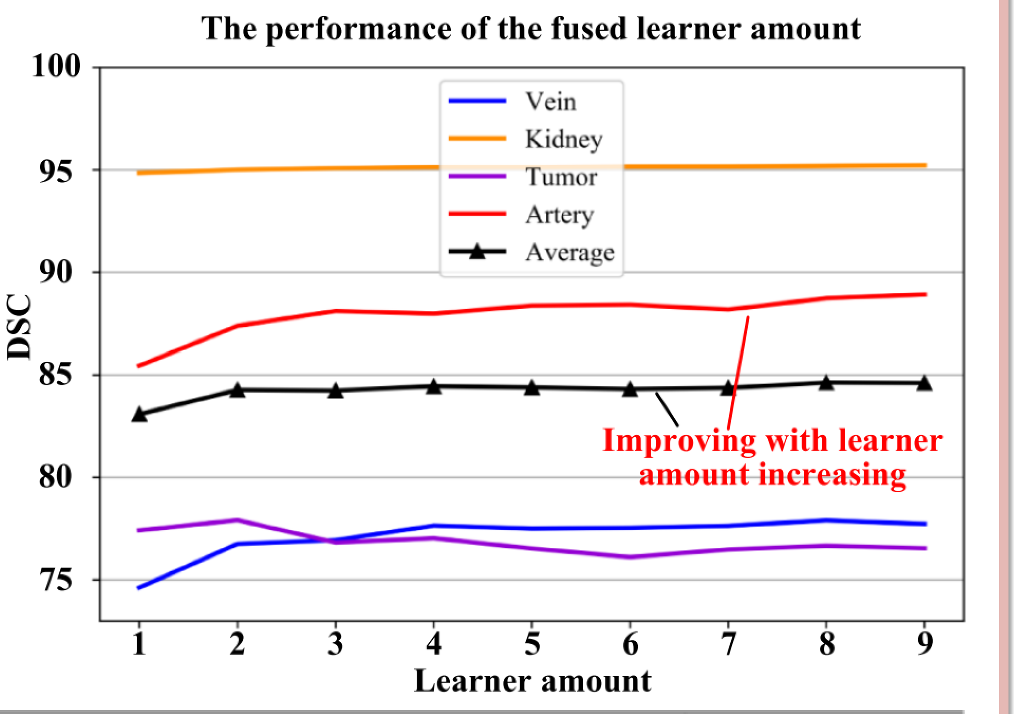
- **Multi-windowing committee** for *representation of fine-grained pattern* via windowing in multiple sub-windows;
- **Multi-condition GAN** for *shape constrains* via adversarial training;
- **Adversarial weighting ensemble** for *personalized fine fusion* via dynamic weights from trained discriminators.

Experiments: Our EnMcGAN brings the ***fine-grained pattern*** and significant regions, ***embeds shape priori knowledge*** into segmentation model and ***bridge the representation preferences*** caused by large anatomical variations thus achieving the excellent 3D complete renal structures segmentation.

Result 1: Our proposed framework has powerful visual superiority which will provide visual guidance for surgery.



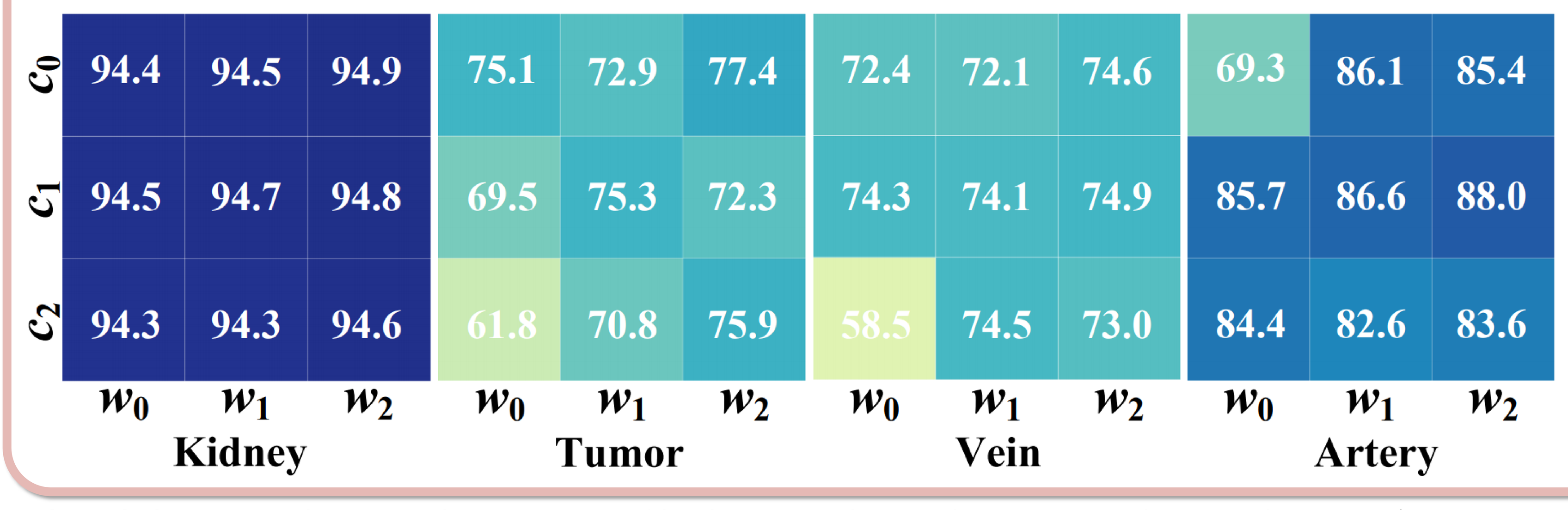
Results 4: With the amount of the fused learners increasing, the ensemble DSC will increase, and the structures have different sensitivity to the increasing of the learners.



Result 2: Evaluation on renal structures reveal powerful performance of our framework.

Method	Kidney		Tumor		Vein		Artery			Mean DSC
	DSC	MSD	DSC	MSD	DSC	MSD	DSC	MCD	MSD	±std
V-Net [11]	94.1±2.3	1.17±0.72	67.5±26.8	7.01±6.36	66.9±14.8	4.57±6.35	83.0±8.2	3.21±2.66	2.03±2.81	77.9±7.8
3D U-Net [2]	91.9±10.9	1.11±0.60	72.1±26.3	5.22±6.12	65.4±20.8	2.41±1.60	80.5±9.9	1.93±1.06±	1.30±1.28	77.5±12.2
Res-U-Net [9]	92.5±3.8	1.63±0.95	51.2±29.7	13.02±16.73	63.4±17.7	3.00±1.73	81.9±6.1	2.95±2.00	1.91±2.00	72.2±7.9
Kid-Net [23]	91.0±11.5	1.49±1.14	69.4±23.2	7.63±7.07	57.2±21.8	3.70±2.71	73.9±12.9	3.76±2.35	1.91±1.94	72.9±11.1
DenseBiasNet [6]	94.1±2.4	1.31±0.87	67.0±26.9	8.51±8.70	71.8±14.8	2.13±1.81	87.1±6.5	2.00±1.18	0.97±0.85	80.0±7.1
VFN (En) [24]	94.3±2.2	1.47±0.76	66.2±27.0	8.50±12.16	70.3±16.3	3.07±2.39	88.5±5.6	**1.36±0.64**	**0.53±0.46**	80.0±8.5
Ours (En)	**95.2±1.9**	**0.94±0.55**	**76.5±22.9**	**5.18±7.11**	**77.7±12.1**	**1.38±0.95**	**89.0±6.8**	1.66±0.89	0.69±0.66	**84.6±6.7**

Result 3: The learners have segmentation superiorities (DSC) in different narrow-window images.



Ablation study: Our innovations cope with the challenges in CRS segmentation and improves the segmentation performance.

McGAN	MWC	AWE	DSC(%)±std				
			Kidney	Tumor	Vein	Artery	AVG
			94.1±2.4	67.0±26.9	71.8±14.8	87.1±6.5	80.0±7.1
✓			94.7±2.4	75.0±22.7	72.8±12.8	87.6±8.1	82.5±7.1
✓	✓		94.8±2.2	75.8±21.1	75.3±12.9	**89.3±4.7**	83.8±6.7
✓	✓	✓	**95.2±1.9**	**76.5±22.9**	**77.7±12.1**	89.0±6.8	**84.6±6.7**

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