DEEP LEARNING-BASED INTRAOPERATIVE VISUAL GUIDANCE MODEL FOR URETER IDENTIFICATION IN LAPAROSCOPIC SIGMOIDECTOMY

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ABSTRACT

BACKGROUND: Identifying the left ureter is a key step while performing laparoscopic sigmoid resection to prevent intraoperative injury and postoperative complications.

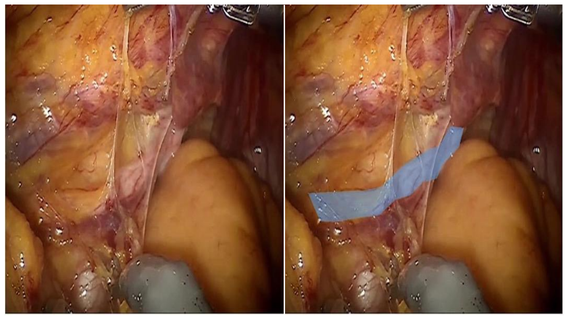
OBJECTIVE: To evaluate the real-time performance of a deep learning-based computer vision model in identifying the left ureter during laparoscopic sigmoid resection.

METHODS: A total of 1237 images were extracted and annotated from laparoscopic sigmoid resection recordings by colorectal surgeons at King Abdulaziz University Hospital (KAUH). Deep learning You Only Look Once (YOLO) versions 8 and 11 models were applied for ureteral identification. Five-fold cross-validation is used to evaluate model performance.

RESULTS: Experiments showed high results with a mean Average Precision (mAP50) of 0.92 for the Intersection over Union (IoU) threshold greater than or equal to 0.5. The precision, recall, and Dice Coefficient (DC) evaluation metrics are 0.94, 0.88, and 0.90, respectively. The model operated at a speed of 32 Frames Per Second (FPS), indicating it can work in real-time.

MATERIALS

- KAUH_Col dataset is divided into 80% for training (988 images) and 20% for validation (249 images).
- Three colorectal surgeons (GE, AS, NM) manually annotated the ureter using the polygon annotation tool in the "Supervisely" software available online [1]
- **Figure 1** shows a screenshot of the manual annotation work performed by the colorectal team.



(A) (B)

Figure 1: A screenshot from "Supervisely" platform displaying the selected frames by the colorectal surgeons: (A) the original image of the Left ureter, (B) the annotated image of the Left ureter

METHODS

- This study aims to identify the ureter by applying YOLOv8x-seg and YOLO11x-seg deep learning models, respectively [2] [3].
- All experiments were trained and validated using Google Cloud virtual machine computing units with GPU acceleration provided by Google Colab Pro+ [4].
- Evaluation Metrics applied in this study:
  - Precision (P)
  - Recall (R)
  - Mean Average Precision (mAP) at Intersection over Union (IoU) thresholds of 0.5 and 0.5-0.95.
  - Dice Coefficient (DC)
- Five-fold cross-validation technique is followed to assess the model and obtain more reliable results from our limited datasets.
- This process involves dividing the dataset into five balanced subsets: four subsets are merged to create the training set (80%), while the remaining subset serves as the validation set (20%).
- The primary goal is to train and validate various dataset combinations, repeated five times, to calculate each fold's performance outcomes and evaluate the average semantic segmentation results.
- **Figure 2** illustrates the split of the five-fold cross-validation of our dataset.

		Dataset Subsets				
		1st	2nd	3rd	4th	5th
Cross-Validation	1st	Train	Train	Train	Train	Validation
	2nd	Train	Train	Train	Validation	Train
	3rd	Train	Train	Validation	Train	Train
	4th	Train	Validation	Train	Train	Train
	5th	Validation	Train	Train	Train	Train

Figure 2: Five-fold Cross Validation Technique

RESULTS

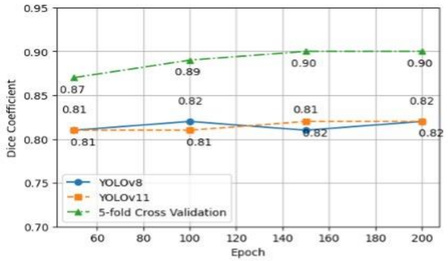


Figure 3: Dice Coefficient by YOLOv8x-seg, YOLO11x-seg, and 5-Fold Cross Validation

RESULTS (continue)

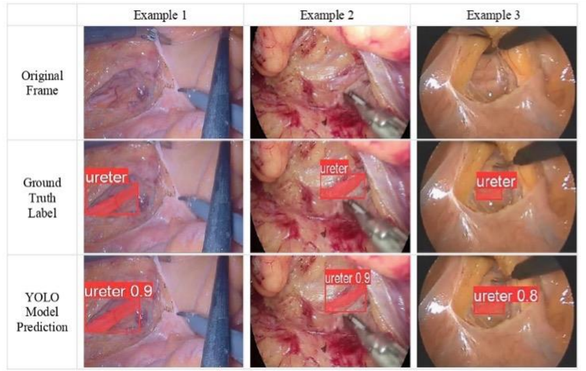


Figure 4: YOLOv8x-seg Ureter Identification Highest IoU Results Examples

Table 1: Ureter Identification Results by YOLOv8x-seg Model

Epochs	Box				Mask				
	P*	R*	mAP50	mAP50-95	P*	R*	mAP50	mAP50-95	DC
50	0.781	**0.803**	0.835	0.543	0.868	**0.763**	0.841	0.45	0.81
100	0.848	0.761	0.832	0.564	0.895	0.755	0.832	0.479	0.82
150	0.883	0.719	0.837	0.577	0.898	0.731	0.86	**0.492**	0.81
200	0.851	0.731	0.835	**0.583**	0.888	0.759	0.837	0.475	0.82
300	**0.904**	0.72	**0.847**	0.577	**0.929**	0.74	**0.862**	0.477	0.82

*R denotes Recall, P denotes Precision, mAP denotes mean Average Precision, DC denotes Dice Coefficient

Table 2: Ureter Identification Results by YOLO11x-seg Model

Epochs	Box				Mask				
	P*	R*	mAP50	mAP50-95	P*	R*	mAP50	mAP50-95	DC
50	0.853	0.727	0.821	0.513	0.878	0.747	0.839	0.425	0.81
100	0.812	**0.783**	**0.855**	0.561	0.823	**0.791**	0.855	0.47	0.81
150	0.865	0.718	0.829	0.578	0.926	0.743	**0.859**	**0.487**	**0.82**
200	**0.879**	0.735	0.831	**0.58**	**0.937**	0.735	0.841	0.481	**0.82**

*R denotes Recall, P denotes Precision, mAP denotes mean Average Precision, DC denotes Dice Coefficient

Table 3: YOLO11x-seg five-fold cross-validation average results

Epoch No.	P*	R*	mAP50	mAP50-95	DC*	FPS*
50	0.906	0.8386	0.8966	0.4774	0.872	**32.4**
100	0.9152	**0.8824**	**0.92**	0.5092	0.898	33.8
150	0.939	0.8716	**0.9202**	0.5284	**0.902**	34.2
200	**0.9404**	0.8692	0.9168	**0.5308**	**0.902**	33.2

*P denotes Precision, R denotes Recall, mAP denotes mean Average Precision, DC denotes Dice Coefficient, and FPS denotes Frame Per Second

Discussion

YOLO models exhibited high performance, achieving a maximum mAP50 (IoU=0.5) score of 0.92. Mask precision results reached 94%, indicating that the model predictions are high for all positive frames in the dataset. Mask recall maximum results reached 88%, which indicates that the model correctly identified the ureter in an above-average number of frames, showing encouraging sensitivity. When five-fold cross-validation is applied, DC significantly increases from 82% to 90%. These results have proven YOLO models can identify the correct anatomical planes of the left ureter.

According to the model inference time result, the frame rate will be between 32 and 34 FPS, which proves that the suggested YOLO model satisfies real-time performance. That concludes that the deep learning model can provide real-time intraoperative visual guidance to the surgeon on where to locate the left ureter.

CONCLUSIONS

This study is the first to use YOLO for semantic segmentation to evaluate the real-time performance of left ureter identification during laparoscopic sigmoid resection. This preliminary study provided by the YOLO models is promising. The obtained results are in the acceptable range in the surgical field. The DL model's ability to locate and identify the left ureter in real-time can assist surgeons in intraoperative decision-making, saving operative time and reducing accidental ureter injuries, ultimately benefiting the patients. This study allows colorectal surgeons to engage in deep-learning models using their expertise in intraoperative image navigation.

REFERENCES

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