Development, Validation, and Application of an Artificial Intelligence Algorithm for Automated Recognition of Surgical Instruments and Evaluation of Surgical Skills in Laparoscopic Procedures: A Retrospective, Multicenter Study

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Introduction

Laparoscopic surgery videos provide a comprehensive record of intraoperative activities, offering critical insights into surgical performance and skill assessment[1,2]. However, manual analysis is labor-intensive and impractical.

Artificial intelligence (AI) has shown great potential in automating the analysis of surgical videos, including the recognition of surgical phases[3], instruments[4], and anatomical structures[5], delivering objective and visualized intraoperative information.

Surgical instruments are highly standardized and exhibit strong generalizability across different surgical procedures. Given the commonality of surgical instruments across multiple surgical specialties and their strong correlation with surgical tasks and intraoperative events, they serve as universal indicators of surgical performance. Building upon our preliminary findings, this study aims to:

- Develop and validate a universal AI algorithm for laparoscopic surgical instrument recognition.
- Deploy the algorithm on the intelligent surgical platform, SurgSmart and evaluate its feasibility for surgical skill assessment.

Materials and Methods

- A total of 1,210 laparoscopic surgical videos were collected from 21 medical centers across China to develop and validate the AI algorithm.
- The algorithm was built on the Detection Transformer (DETR) architecture and enhanced with the Convolutional Block Attention Module (CBAM) to improve detection efficiency and accuracy and was then deployed on SurgSmart（Figure 1）.
- Additional 51 laparoscopic pancreaticoduodenectomy videos, scored using a customized mGOALS scale, were uploaded to SurgSmart for the automated analysis to generate visualized surgical instrument usage data.
- Analyzing the relationship between instrument usage data recorded by SurgSmart and mGOALS scores of surgical videos to explore the correlation between surgical instrument usage patterns and surgical skill levels.

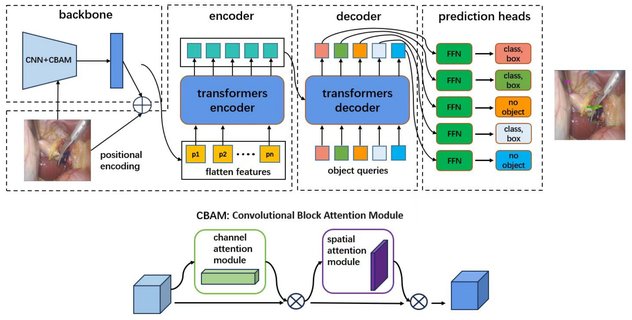


Figure 1. Graphic illustration of overall model structure. The model consists of four main components: the backbone, encoder, decoder, and prediction heads. The lower diagram details the CBAM, which integrates channel and spatial attention modules to improve feature representation quality.

Results

The AI algorithm achieved a mean average precision (mAP) of 80.31% across 21 types of surgical instruments.

Following the algorithm's deployment, SurgSmart enabled several key functionalities:

- Quick surgical review interface
- Surgical report
- Surgical instrument usage heatmap
- Surgical teaching interface

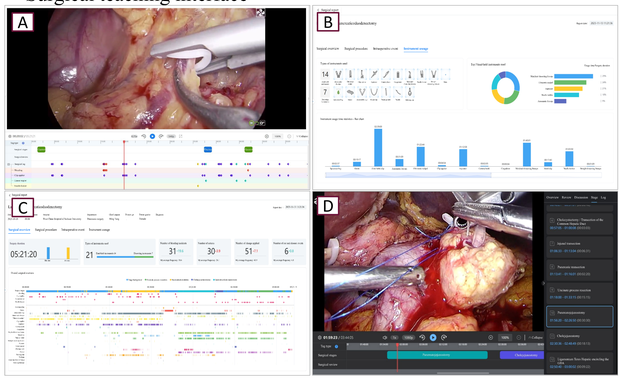


Figure 2. The illustration of the quick review interface, surgical reports, surgical usage instrument heatmap, and surgical teaching interface.

A. The utilization of three specific surgical instruments (clip applier, linear stapler, and needle holder) is automatically synchronized and displayed as key markers on the timeline below the video. Surgeons can click these markers to swiftly navigate to the corresponding video segments.

B. The surgical report provides detailed information on the types of instruments used, duration, frequency, and proportion of surgical instrument usage

C. Instrument usage throughout surgeries is visualized in surgical usage instrument heatmaps that illustrate the sequence and intensity of instrument usage over time.

D. In the surgical teaching interface, critical surgical phases and tasks are marked as timestamps on the video timeline. Users are able to swiftly access the relevant surgical scene by clicking the corresponding timestamp. Furthermore, the system facilitates online live streaming, real-time discussion, and remote interaction capabilities.

Based on the interquartile range of mGOALS scores, we divided the scores into two groups: incompetency group (ICP, score≤10, n=17) and competency group (CP, score>10, n=34). The two groups of surgeons exhibited some differences in the duration of instrument usage:

- Clip applier usage showed a significant difference: the ICP averaged 5.00 (3.50, 7.00) minutes, while the CP averaged 3.00 (2.00, 4.00) minutes ($P < 0.001$, Table 1).
- A negative correlation was found between clip applier usage duration and surgical scores ($r = -0.545$, $P < 0.001$).

Surgical Instrument	Incompetency group (Score≤10, n=17), Usage duration, [M(P25, P75), min]	Competency group (Score>10, n=34), Usage duration, [M(P25, P75), min]	*z*	*p*
Ultrasonic scalpel	102.00（87.50, 131.50）	92.00（73.25, 121.50）	-1.319	0.187
Linear stapler	4.00（3.00, 7.50）	3.00（2.00, 4.00）	-1.897	0.058
Needle holder	55.00（33.00, 80.50）	43.50（28.00, 54.25）	-1.939	0.053
Clip applier	5.00（3.50, 7.00）	3.00（2.00, 4.00）	-3.715	<0.001

Table 1. Statistical analysis results of the relationship between surgical instruments usage duration and mGOALS scores.

Conclusion

- A robust AI algorithm has been developed for accurate recognition of most surgical instruments in laparoscopic procedures.
- Its deployment on SurgSmart has demonstrated significant clinical potential, particularly in surgical skill assessment.
- With continued AI advancements, automated evaluation is expected to enhance the standardization and intelligence of laparoscopic surgical quality assessment.

Reference

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