Review of clinical problems and ongoing technical challenges in development of computer assisted interventions for laparoscopic cholecystectomy

Franciszek Nowak
NIHR Central London PSRC

Background: Laparoscopic cholecystectomy (LC) is one of the most frequently performed surgical procedures globally. Despite its prevalence and benefits, such as shorter hospital stays, the procedure carries a persistent risk of severe complications, most notably bile duct injury (BDI). The incidence rates of BDI have remained troublingly stagnant, unaffected by advances in surgical training, instrumentation, or imaging techniques. Artificial intelligence (AI) and computer vision (CV) have emerged as promising avenues to enhance surgical safety, yet many current models are suboptimal.

Objectives: This narrative review aims to serve as a guide for developing more effective computer vision systems for LC by bridging the gap between clinical challenges and technical implementation. The objective is to move beyond surface-level performance reporting and conduct a deeper analysis of the clinical realities and technical hurdles that cause AI models to fail or underperform in real-world surgical environments. The work synthesizes pressing clinical needs, existing technical solutions, and their limitations to provide recommendations for future research.

Main Findings: The analysis indicates that a majority of surgical errors, with some studies attributing up to 97% of bile duct injuries, stem from visual misperception. These errors are most prevalent in difficult cases driven by patient-specific conditions like severe inflammation or anomalous anatomy. Current AI development is often misaligned with this reality, as most research avoids these complex scenarios, leading to translational failures. This review argues that simple pattern-matching solutions are insufficient. To create clinically impactful tools, future work must focus on methods grounded in the physical and geometric principles of the procedure. This includes developing AI capable of analysing tissue structures to identify safe dissection planes. Furthermore, development should focus on integrating preoperative anatomical information from CT or MRCP scans as priors, creating patient-specific models that can guide surgeons through challenging anatomies.

Identifying Limitations of Artificial Intelligence Algorithms for Laparoscopic Cholecystectomy

Franciszek Nowak, Dr. Evangelos Mazomenos, Prof. Brian Davidson, Prof. Matthew Clarkson

NIHR Central London – Patient Safety Research Collaboration, UCL Department of Medical Physics and Biomedical Engineering

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Laparoscopic Cholecystectomy

~60,000 cases per year in the UK

- Duration of hospital stays ⇩
- Convalescence period ⇩

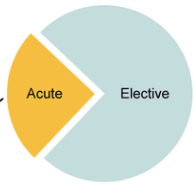
Complications' rate 5-6.7% - **doesn't reduce over time**!

Patients and the procedure

- Women (~68%)
- Mean age 53 years
- Elevated BMI
- Main cause: Gallstones

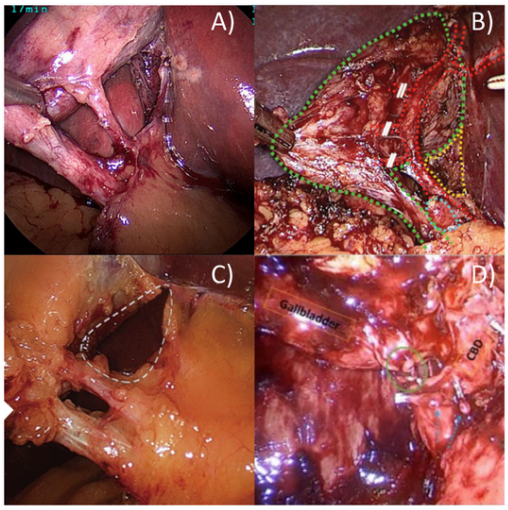
3.2x as likely to result in conversion to open!

Emergency?



Why mistakes happen?

1 in 6 gallbladders are 'difficult'



What makes a case hard?
A) Example, 'easy' case
B) Aberrant anatomy
C) Fatty Environment
D) Scarring and Inflammation

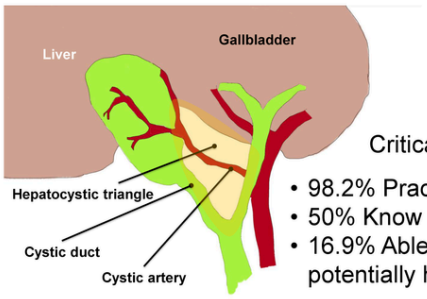
Excess adipose tissue increase difficulty in identification of structures

Abnormal anatomies found in ~20% of the patients

Excessive adhesion and neovascularisation complicate dissection

Severe inflammation makes tissue friable and prone to tearing

Management



Critical View of Safety

- 98.2% Practice CVS
- 50% Know steps
- 16.9% Able to identify potentially harmful methods

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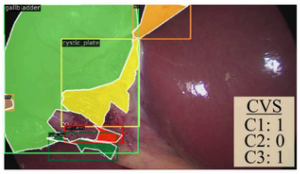
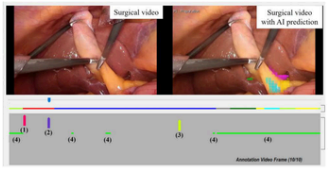
Only 20-32.4% of Bile Duct Injury are identified during the surgery!

AI for Laparoscopic Cholecystectomy

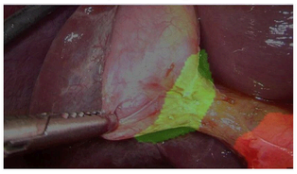
CVS Detection



Phase Detection



Safe operating areas



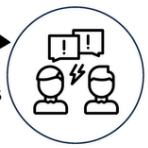
Case difficulty stratification

Main problems of AI for Laparoscopic Cholecystectomy

Small datasets
- GDPR policies
- Recruitment difficulties

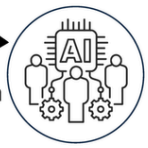
Limited datasets
- No pre-op data
- Limits range of investigations

Easy datasets
- Surgeons rarely make mistakes in easy cases
- Translational failures



Annotations
- Inconsistent annotations subjective to interpretation

Difficult Design
- Flawed approach to architecture design
- Natural image research requires adaptation



Visual complexity
- No sharp edges
- Low contrast, smoke, blood
- Patient variability

Validation
- ML metrics VS clinical relevance
- No ecologically validated testing

Poor explainability
- Models act as a black-box
- Unexpected predictions on out of distribution examples

Conclusions:

Clinical focus → Understanding limitations of small datasets → Constraining and simplifying algorithms → Accounting for real-life difficulties → Validating against human performance

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UCL Hawkes Institute

i4health intelligent integrated imaging

franciszek.nowak.23@ucl.ac.uk

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