The Role of Artificial Intelligence in the Intraoperative Detection of Critical Structures in Laparoscopic Cholecystectomy

O Papel da Inteligência Artificial na Detecção Intraoperatória de Estruturas Críticas em Colecistectomia por Vídeo

El Papel de la Inteligencia Artificial en la Detección Intraoperatoria de Estructuras Críticas en la Colecistectomía Laparoscópica

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Como citar: Bastos ELC, Copenhagen BOS, Pereira WJS, Oliveira CS, Belem BLM, Filho MDMF, Victor GSL. The Role of Artificial Intelligence in the Intraoperative Detection of Critical Structures in Laparoscopic Cholecystectomy. REVISA. 2026; 15(Esp.4): 1-6. Doi: https://doi.org/10.36239/revisa.v15.nEsp4.p1a6

REVISÃO

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Recebido 27/01/2026
Aprovado: 22/03/2026

RESUMO

Objetivo: A colecistectomia laparoscópica (CL) é o tratamento padrão-ouro para colecistolitíase sintomática, mas ainda associada ao risco de lesão do ducto biliar (LDB), complicação de grande impacto clínico. A inteligência artificial (IA) vem sendo aplicada para aumentar a segurança intraoperatória, com destaque para o reconhecimento automático de estruturas críticas e a Visão Crítica de Segurança (CVS). Esta revisão integrativa na PubMed selecionou quatro artigos (2015–2025). Os estudos relataram acurácia média de 98% em modelos como GoNoGoNet e CholeNet, por vezes superando o julgamento humano. Além do uso clínico, a IA mostrou potencial no treinamento de residentes e na padronização. Persistem, contudo, limitações e necessidade de validação multicêntrica.

Palavras-chave: Colecistectomia laparoscópica; Inteligência artificial.

ABSTRACT

Objective: Laparoscopic cholecystectomy (LC) is the gold-standard treatment for symptomatic cholelithiasis but remains linked to bile duct injury (BDI), a severe complication with major clinical impact. Artificial intelligence (AI) has been applied to enhance intraoperative safety, mainly through automated recognition of critical structures and the Critical View of Safety (CVS). This integrative review in PubMed included four articles (2015–2025). Studies reported an average accuracy of 98% using models such as GoNoGoNet and CholeNet, sometimes outperforming surgeons. In addition to clinical applications, AI proved useful for resident training and standardization. Nevertheless, technical limitations persist and multicenter validation is required.

Keywords: Laparoscopic cholecystectomy; Artificial intelligence.

RESUMEN

Objetivo: La colecistectomía laparoscópica (CL) es el tratamiento de referencia para la colecistolitiasis sintomática, pero sigue asociada al riesgo de lesión del conducto biliar (LCB), una complicación de gran impacto clínico. La inteligencia artificial (IA) se ha aplicado para aumentar la seguridad intraoperatoria, especialmente mediante el reconocimiento automático de estructuras críticas y la Visión Crítica de Seguridad (CVS). Esta revisión integrativa en PubMed seleccionó cuatro artículos (2015–2025). Los estudios reportaron una precisión promedio del 98% en modelos como GoNoGoNet y CholeNet, en ocasiones superando el juicio humano. Además de su uso clínico, la IA mostró potencial en la formación de residentes y en la estandarización. Sin embargo, persisten limitaciones y necesidad de validación multicéntrica.

Palabras clave: Colecistectomía laparoscópica; Inteligencia artificial

Introdução

Artificial intelligence (AI) has emerged as a major ally for surgeons during laparoscopic cholecystectomy (LC), reducing typical iatrogenic injuries, such as bile duct injury (BDI), by improving surgical precision.[1] This reduction is justified by the better recognition of anatomical structures, often misinterpreted due to failures in human visual perception, and by the identification of operative phases through AI.

Although laparoscopic cholecystectomy is the gold standard for treating patients with symptomatic gallstones, iatrogenic injuries can cause irreversible damage to patients, which reinforces the importance of AI.[2] Furthermore, the application of this technology in the training of surgeons proves to be efficient in preparing young professionals, since it is possible to review and analyze the surgeries performed by reproducing videos.[2]

Finally, the use of intraoperative AI results in a greater reach of the critical view of safety (CVS) and safer dissections, but it still lacks greater standardization in its application and in the opinions of experts on the subject.[3]

Objectives

General objective:

1. To critically analyze the available evidence in the scientific literature regarding the use of artificial intelligence in the intraoperative detection of critical structures during laparoscopic cholecystectomy.

Specific objectives:

1. To map the approaches and models of artificial intelligence used for the intraoperative recognition of critical anatomical structures.
2. Describe how artificial intelligence has been applied in obtaining the Critical View of Safety (CVS) during laparoscopic cholecystectomy.
3. Explore the reported benefits of applying AI in surgical safety and technical performance, especially in training programs.
4. Identify the main limitations, challenges, and future perspectives for the use of real-time AI in the operating room environment.

Method

This is an integrative literature review conducted by searching for scientific articles obtained through electronic research in the PUBMED database. The descriptors were chosen based on the Medical Subject Headings (MeSH), and the controlled terms were combined using Boolean operators: "artificial intelligence" AND "cholecystectomy, laparoscopic". The inclusion criteria included publications with full and free access in digital format, written in English, linked to the MEDLINE database, covering articles published in the last ten years (2015-2025) and involving studies with human subjects. Duplicated materials, dissertations, theses, editorial opinion articles, debates, and incomplete texts were excluded. The titles and abstracts of all articles were analyzed and evaluated during the online search to determine their inclusion or exclusion in the study. This process resulted in the identification of 29 articles, of which 4 were selected for being most relevant to the topic addressed.

Results

Laparoscopic cholecystectomy has been confirmed as the standard treatment for symptomatic cholelithiasis, with a risk of bile duct injury between 0.4% and 1.5%, higher than with the open technique.[3,1]

The use of artificial intelligence showed an average accuracy of 98% in identifying biliary structures, with an overlap of 0.5 to 0.7 compared to expert markings. In approximately 27% of cases, there was disagreement between surgeons and AI, with 70% of the system's suggestions considered safer.[3]

Furthermore, semantic segmentation models, such as GoNoGoNet and CholeNet, have also proven effective in delineating safe zones and identifying anatomical structures.[4]

Thus, the application of artificial intelligence in laparoscopic cholecystectomy has demonstrated significant benefits, such as the ability to recognize surgical phases, identify critical biliary structures, and delineate safe dissection zones with high precision, which contributes to reducing the risk of bile duct injury.[3,4]

Discussion

Laparoscopic cholecystectomy (LC) has become the gold standard treatment for symptomatic cholelithiasis and is now one of the most frequently performed surgical procedures worldwide, both in elective and emergency settings.[3]

Despite this, the technique is not without risks. The most feared complication is bile duct injury (BD), an iatrogenic event with an incidence of between 0.4 and 1.5% in LC, higher than that observed in open cholecystectomy. This type of complication is associated not only with considerable morbidity, but also with the need for additional surgical, endoscopic or radiological interventions, increasing hospital costs and compromising the patient's quality of life.[3,1]

To mitigate this risk, technical strategies have been proposed, such as the Critical View of Safety (CVS), described by Strasberg in 1995, which is based on three fundamental principles: adequate dissection of Calot's triangle, mobilization of the gallbladder fundus, and identification and dissection only of the cystic duct and artery. The European Association for Endoscopic Surgery recommends the systematic adoption of CVS as the best approach for LC.[1]

However, even with its widespread dissemination, the practical achievement of CVS is still inconsistent. Studies show that, under ideal conditions, it can be achieved in 90% of surgeries, reducing the risk of bile duct injury to low rates (2 per 1,000,000 operations). However, in clinical practice, much lower success rates have been observed, such as in Strasbourg, where only 15.9% of cases achieved complete CVS. This discrepancy reveals flaws in training standardization and highlights the need for innovative training and intraoperative support strategies.[2]

In this context, Artificial Intelligence (AI) is emerging as a tool with the potential to revolutionize the safety and teaching of clinical skills. AI, defined as "a discipline that develops algorithms capable of learning and decision-making in complex scenarios," has already been successfully applied in other areas of medicine, such as in the interpretation of radiological images and in the recognition of basic surgical actions, such as sutures and knots.[1]

The most recent use of this technology during surgery aims to identify surgical phases, recognize critical anatomical structures, and delineate safe and unsafe dissection zones, with the goal of reducing perceptual errors that underlie almost all cases of bile duct injury.[3]

One of the most relevant and recent advancements in artificial intelligence used for surgical procedures is the application of computer vision, a branch of AI focused on the analysis of images and videos. Instead of using rectangular bounding boxes, more common in simple tracking tasks, new models apply semantic segmentation, capable of delineating anatomical structures pixel by pixel, creating visual overlays between the patient's anatomy and the developed model during surgery.[4]

This new approach, explored by Madani et al., gave rise to GoNoGoNet, which differentiates safe (Go) and dangerous (No-Go) dissection areas within the hepatocystic triangle. In addition, there is the ChiletNet program, which maps anatomical structures such as the liver, gallbladder, and cystic duct. These techniques are employed through probabilistic heat maps to represent the relative safety of the observed regions.[4]

The models created were developed to match the reasoning methods of expert surgeons, which are almost never binary. In other words, most professionals think in probabilistic predictions and rarely work with fixed boundaries, but rather with degrees of risk. Therefore, broad zones are created, within which there are indeterminate regions because, even in the most routine cholecystectomies, there is rarely a precise boundary between safe and dangerous areas of dissection.[4]

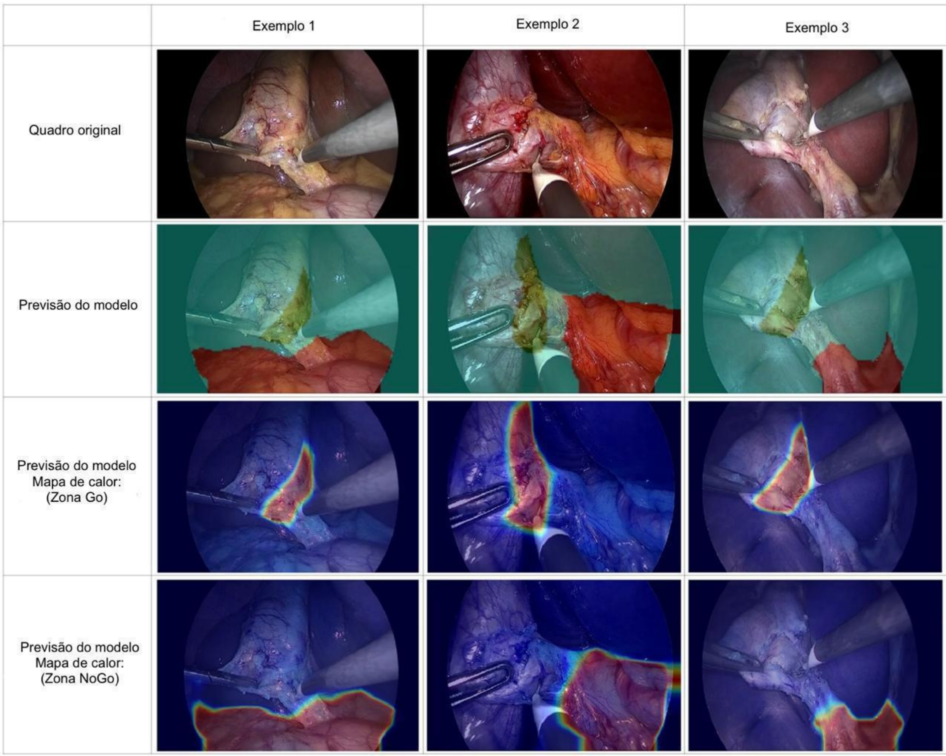

Figure 1 – Model predictions for GoNoGoNet. Three distinct examples of GoNoGoNet predictions compared to the original frames, displayed as overlays of the safe zone (*Go zone*, in green) and the risk zone (*No-Go* zone, in red), as well as probabilistic heatmaps. **Source:** Adapted from MADANI et al., 2022.

Studies show that the use of artificial intelligence can significantly alter intraoperative conduct. According to an analysis by CORALLINO et al., in 27% of the surgeries performed during the research, the AI's annotations differed from those made by the surgeons, with 70% of the changes suggested by the technology being considered safer. The average accuracy for detecting biliary structures reached 98%, with overlap indices between 0.5 and 0.7, meaning that in more than half of the critical area, the AI was able to correctly delineate the structure of interest. This performance is already comparable and, in some contexts, superior to human judgment, especially in situations that are difficult to visualize, such as in obese patients or those with acute cholecystitis.[3]

Nevertheless, significant limitations remain. In several studies, AI performance was hampered by the presence of smoke, bile leakage, anatomical variations obscured by adipose and fibrous tissue, or even by changes in the angle of the laparoscopic optics. In these situations, safe and unsafe zones could be misinterpreted by the model, requiring further refinement in the training of the algorithms.[1]

In addition to clinical applications, AI has shown promise as a teaching tool. The SmartCoach program, based on the SurgSmart algorithm, was evaluated in a randomized clinical trial that compared the performance of residents with and without access to the resource. The group that received AI-based coaching showed significant improvement in CVS achievement rate, increased technical proficiency, and increased satisfaction with learning, in contrast to the self-study group, which did not show significant progress. All participants who used the program stated that it was superior to traditional methods, such as lectures or video reviews. This reinforces that AI can play a central role in the training of young surgeons, reducing the learning curve and increasing the standardization of results.[2]

Final Considerations

The application of artificial intelligence in laparoscopic cholecystectomy represents an advancement in surgical safety, especially in the prevention of bile duct injuries. Studies demonstrate its effectiveness in anatomical recognition, obtaining the Critical View of Safety, and supporting training, shortening the learning curve and standardizing teaching.

Despite the benefits, there are still technical challenges in complex scenarios, as well as the need for standardized protocols, multicenter validation, and hospital integration to ensure safe and cost-effective use.

Thus, although still in development, AI shows promise for clinical practice and surgical training, with the potential to redefine safety standards for laparoscopic cholecystectomy, provided it is supported by continuous research and more robust systems.

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