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Colecistectomía Avanzada en la Era de la Robótica Quirúrgica Compacta: Resultados Clínicos y Consideraciones Cognitivas

Advanced Cholecystectomy in the Era of Compact Surgical Robotics: Clinical Outcomes and Cognitive Considerations

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Revista IECCMEXICO
IECCMEXICO Review

RESUMEN

La colecistectomía avanzada constituye un procedimiento técnicamente complejo y con alta carga cognitiva dentro de la cirugía general, especialmente en escenarios de inflamación aguda, alteraciones anatómicas o pacientes de alto riesgo. La aparición de sistemas robóticos quirúrgicos compactos de cuarta generación ha ampliado las posibilidades del abordaje mínimamente invasivo al integrar diseño modular, mejor ergonomía y visualización avanzada. Esta revisión analiza la evidencia internacional disponible sobre el uso de plataformas robóticas compactas en colecistectomía avanzada, integrando resultados clínicos, comportamiento de la curva de aprendizaje, factibilidad del flujo de trabajo y consideraciones de factores humanos. La literatura muestra que la colecistectomía robótica alcanza resultados de seguridad perioperatoria comparables a la laparoscopia convencional, incluso en contextos de enfermedad compleja. La eficiencia operatoria sigue una curva de aprendizaje progresiva, con incremento inicial del tiempo quirúrgico que converge conforme se estandarizan los procesos y aumenta la experiencia. De forma relevante, los sistemas robóticos se asocian con menor fatiga física, menor estrés ergonómico y reducción de la carga mental, aspectos vinculados a la regulación del estrés, el rendimiento cognitivo y el bienestar del cirujano. Desde una perspectiva sistémica, las plataformas robóticas compactas muestran una factibilidad creciente para su implementación en sistemas de salud de recursos intermedios, como los de México, Colombia y Ecuador. En conjunto, estos sistemas representan una innovación segura, viable y centrada en el factor humano para la colecistectomía avanzada.

Edición 3, Año 2, Número 2, 2025
Edition 3, Year 2, Number 2, 2025

PALABRAS CLAVE

colecistectomía robótica, colecistectomía avanzada, robots quirúrgicos compactos, cirugía mínimamente invasiva, ergonomía quirúrgica, carga cognitiva, estrés del cirujano, factores humanos, curva de aprendizaje, cirugía general

ABSTRACT

Advanced cholecystectomy represents a technically and cognitively demanding procedure within general surgery, particularly in cases involving acute inflammation, altered anatomy, or high-risk patient profiles. The emergence of compact fourth-generation surgical robotic systems has introduced new possibilities for minimally invasive management by combining modular design, improved ergonomics, and enhanced visualization. This review analyzes current international evidence on the use of compact robotic platforms in advanced cholecystectomy, integrating clinical outcomes, learning-curve behavior, workflow feasibility, and human-factor considerations. The available literature demonstrates that robotic-assisted cholecystectomy achieves perioperative safety outcomes comparable to conventional laparoscopy, including rates of complications, bile duct injury, and mortality, even in complex disease contexts. Operative efficiency follows a characteristic learning curve, with early increases in operative time that progressively converge toward laparoscopic benchmarks as experience and workflow standardization increase. Importantly, robotic systems appear to reduce physical fatigue, ergonomic strain, and mental workload, factors closely related to stress regulation, cognitive performance, and surgeon well-being. These human-factor effects position robotic surgery at the intersection of technical innovation and psychiatry-adjacent considerations in surgical practice. From a systems perspective, compact robotic platforms demonstrate growing feasibility for integration into mid-resource healthcare settings, including those in Mexico, Colombia, and Ecuador, provided that structured training and governance frameworks are in place. Overall, compact fourth-generation robotic systems represent a safe, feasible, and human-centered advancement in advanced cholecystectomy, with implications for surgical quality, education, and professional sustainability.

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robotic cholecystectomy, advanced cholecystectomy, compact surgical robots, minimally invasive surgery, surgical ergonomics, cognitive workload, surgeon stress, human factors, learning curve, general surgery

INTRODUCCIÓN

Cholecystectomy remains one of the most frequently performed surgical procedures worldwide, representing a cornerstone intervention in general surgery for the management of benign gallbladder disease. Over the past three decades, the transition from open to laparoscopic cholecystectomy has significantly reduced postoperative morbidity, length of hospital stay, and recovery time. More recently, robotic-assisted surgery has emerged as an extension of minimally invasive techniques, offering enhanced dexterity, three-dimensional visualization, and improved ergonomic conditions for surgeons (Ahmed et al., 2016; Stefanidis et al., 2019).

Revista IECCMEXICO
IECCMEXICO Review

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Revista IECCMEXICO

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IECCMEXICO Review

Despite these technological advances, conventional laparoscopic cholecystectomy continues to present technical challenges, particularly in complex cases such as acute cholecystitis, obesity, severe inflammation, or aberrant biliary anatomy. These scenarios increase operative difficulty, cognitive load, and surgeon stress, potentially affecting intraoperative decision-making and patient safety (Kwarteng et al., 2021; Park et al., 2021). In this context, compact fourth-generation robotic systems have been developed with the aim of addressing these limitations while maintaining feasibility, safety, and cost-effectiveness in routine surgical practice.

Fourth-generation compact robotic platforms differ from earlier robotic systems by emphasizing modularity, reduced physical footprint, simplified docking, and improved surgeon–machine interaction. Systems such as Versius™ and Senhance® exemplify this evolution, seeking to democratize robotic surgery by making it accessible beyond high-volume tertiary centers (Hagen et al., 2021; Himpens et al., 2018). These innovations are particularly relevant in low- and middle-income countries, including regions of Latin America, where the expansion of advanced surgical technologies must balance clinical benefit, training requirements, and healthcare resource constraints.

Beyond technical performance, robotic surgery introduces important implications for surgeon cognition and mental workload. Surgical procedures require sustained attention, fine motor control, and rapid decision-making under stress. Evidence suggests that ergonomic improvements and enhanced visualization may reduce surgeon fatigue and cognitive strain, factors closely linked to performance, error rates, and long-term professional well-being (Mascagni et al., 2020; Yang et al., 2017). From a psychiatric and behavioral perspective, these aspects are increasingly recognized as critical determinants of surgical outcomes, particularly in high-demand environments such as emergency or complex biliary surgery.

Previous studies comparing robotic and laparoscopic cholecystectomy have demonstrated comparable safety profiles, with some reports indicating advantages in precision, visualization, and surgeon comfort, albeit often at the expense of longer operative times or increased costs (Cavaliere et al., 2020; Antoniou et al., 2018). Population-based and multicenter analyses have further explored outcomes in complex gallbladder disease, highlighting potential benefits of robotic platforms in selected patient populations (Kamarajah et al., 2021; Peters et al., 2018). However, much of the existing literature focuses primarily on technical and short-term clinical outcomes, with limited integration of cognitive, psychological, and training-related dimensions.

The learning curve associated with robotic cholecystectomy represents another critical area of investigation. Modern compact robotic systems have been associated with a more gradual and structured learning process, potentially reducing performance-related stress among surgeons and trainees (Sanchez et al., 2020). This aspect is particularly relevant in academic and teaching hospitals, where surgical education must ensure patient safety while fostering technical competence and psychological resilience among learners.

Given these considerations, there is a growing need to synthesize current evidence on compact fourth-generation robotic systems in advanced cholecystectomy, not only from a technical and clinical standpoint but also incorporating cognitive and psychosocial perspectives. This is especially pertinent in international settings, including Mexico, Colombia, and Ecuador, where surgical training programs are increasingly adopting robotic technologies amid diverse healthcare infrastructures.

The present review aims to analyze contemporary evidence on the use of compact fourth-generation surgical robots in advanced cholecystectomy, focusing on feasibility, safety, clinical outcomes, learning curves, and broader implications for surgeon cognition and mental workload. By integrating surgical and psychiatric perspectives, this review seeks to provide a comprehensive framework for understanding how emerging robotic platforms may influence both technical performance and the human factors underlying surgical care. This approach aligns with the broader objective of optimizing patient outcomes while supporting surgeon well-being and sustainable surgical practice in modern healthcare systems.

DESARROLLO

Compact fourth-generation surgical robots are reshaping the technical and human-factors landscape of advanced cholecystectomy by combining miniaturized architecture, modularity, and workflow-oriented docking with capabilities traditionally associated with larger, earlier-generation robotic platforms. The clinical rationale for their use

Edición 3, Año 2, Número 2, 2025
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Revista IECCMEXICO
Edition 3, Year 2, Number 2, 2025
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IECCMEXICO Review

becomes most apparent in “advanced” scenarios—acute cholecystitis, severe inflammation, obesity, prior upper abdominal surgery, or aberrant biliary anatomy—where surgical difficulty escalates and where exposure, fine dissection, and stable visualization are paramount to minimizing bile duct injury and conversion to open surgery (Park et al., 2021; Kwarteng et al., 2021). In these cases, the robot’s articulated instruments, tremor filtration, and stable 3D visualization may support more controlled dissection in the hepatocystic triangle, potentially enhancing procedural consistency compared with conventional laparoscopy (Stefanidis et al., 2019; Cavaliere et al., 2020).

1) Clinical performance signals in robotic vs laparoscopic cholecystectomy

Across systematic reviews and comparative analyses, robotic cholecystectomy has generally demonstrated **non-inferior safety** relative to laparoscopy for key postoperative endpoints, while showing mixed patterns regarding operative time and resource utilization (Antoniou et al., 2018; Cavaliere et al., 2020). Short-term outcomes analyses have suggested that robotic approaches can achieve comparable complication profiles, with nuanced differences depending on case-mix, institutional experience, and the definition of “complex” gallbladder disease (Spinoglio et al., 2019; Kamarajah et al., 2021). Importantly, when complex disease predominates—such as acute cholecystitis—feasibility data indicate that robotic platforms can be deployed safely, though outcomes are sensitive to patient selection and team proficiency (Park et al., 2021; Peters et al., 2018).

A central point for advanced cholecystectomy is that “benefit” may not be captured solely by broad postoperative complication rates; instead, it may emerge in **procedural micro-outcomes** (e.g., precision of dissection, reduced instrument collisions, improved exposure) and in the mitigation of surgeon fatigue and cognitive overload under challenging conditions (Stefanidis et al., 2019; Mascagni et al., 2020). These considerations become crucial when the goal is not merely equivalence, but reliable performance in high-variance cases.

2) Why compact fourth-generation systems matter in real-world adoption

Large robotic platforms historically faced barriers such as footprint, docking time, operating room integration complexity, and high acquisition and maintenance costs. Recent “next-generation” systems emphasize modular carts, flexible port placement, and reduced spatial demands—attributes intended to lower operational friction and facilitate diffusion beyond flagship centers (Autorino et al., 2020; Diana et al., 2020). Early clinical experiences with modular systems in general surgery suggest that these platforms can be introduced with acceptable safety profiles and workable perioperative workflows, though they still require dedicated training pathways and institutional readiness (Hagen et al., 2021; Ruurda et al., 2019). Likewise, clinical rollouts of alternative platforms (e.g., Senhance®) highlight the practical importance of usability, OR layout compatibility, and the standardization of docking and instrument exchange processes (Himpens et al., 2018).

From an international implementation perspective—particularly relevant to **Mexico, Colombia, and Ecuador**—compact systems are strategically appealing because they may fit better within heterogeneous infrastructure conditions, variable OR sizes, and mixed funding models. Adoption trends in cholecystectomy have shown that diffusion of robotic approaches can expand rapidly once workflow becomes standardized and institutions perceive value in training, marketing, or surgical portfolio modernization (Sheetz et al., 2020). However, adoption alone should not be conflated with clinical superiority; robust evaluation must include the context: case complexity, institutional volume, surgeon experience, and cost structures (Cavaliere et al., 2020; Sheetz et al., 2020).

3) Learning curves, training, and performance reliability

The learning curve is a pivotal determinant of whether robotic cholecystectomy improves outcomes or simply redistributes risk toward the early adoption phase. Evidence on robotic cholecystectomy learning curves—particularly with modern compact systems—suggests that structured training can yield progressive efficiency gains and stable performance, with the potential to standardize technique in ways that benefit teaching environments (Sanchez et al., 2020). More broadly, reviews of robotic surgery emphasize that technology-related gains are most likely to translate into patient benefit when paired with disciplined training, team coordination, and institutional process design (Jayne et al., 2017; Stefanidis et al., 2019).

In academic hospitals across Latin America, the educational value of compact systems may be especially relevant: modularity and workflow simplification can make hands-on training more feasible, provided that programs implement

Edición 3, Año 2, Número 2, 2025
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Revista IECCMEXICO

objective assessment, proctorship, and structured simulation-to-OR transition. This is consistent with broader robotics perspectives that stress safe integration, operator competence, and governance frameworks as prerequisites for sustainable clinical deployment (Yang et al., 2017; Autorino et al., 2020).

4) The psychiatry-adjacent dimension: cognition, stress, and human factors in advanced biliary surgery

Advanced cholecystectomy is not only a technical task; it is a high-stakes cognitive environment with rapid risk appraisal, sustained attention, and error-intolerant decision-making. These features intersect with psychiatric and behavioral science through constructs such as **mental workload**, **stress response**, **fatigue**, and **performance under pressure**. Robotic platforms may influence these factors via improved ergonomics, stabilized visualization, and reduced physical strain—mechanisms that plausibly reduce fatigue-related decrements and may support consistent decision-making during complex dissection (Stefanidis et al., 2019; Mascagni et al., 2020).

Additionally, robotics introduces its own psychological demands: dependency on technology, attentional shifts toward interfaces, and stress linked to docking failures or system errors. Regulatory and ethical analyses underscore that safe robotic practice requires anticipating human–machine interaction risks, including overreliance, attentional tunneling, and team communication breakdowns (Yang et al., 2017). In educational contexts, these issues connect to the affective domain: building trainee confidence without complacency, encouraging help-seeking behaviors, and cultivating psychological safety within the operating room team.

5) Process, systems, and quality: toward replicable implementation

Cholecystectomy outcomes are shaped by systems-level factors—case selection, perioperative pathways, surgeon experience, and institutional volume. Introducing compact robots can be conceptualized as a **process innovation**, not merely a device purchase. Feasibility studies of new systems emphasize the importance of standardized setup, clear intraoperative roles, and definable safety checkpoints (Ruurda et al., 2019; Hagen et al., 2021). In parallel, adoption trend analyses reveal that diffusion can outpace evidence maturation, increasing the need for local governance: performance dashboards, complication surveillance, and continuous improvement cycles (Sheetz et al., 2020).

This systems view is particularly relevant for Mexico, Colombia, and Ecuador, where centers may vary widely in resources, surgical volume, and training infrastructure. A robust development pathway should therefore include clear inclusion criteria for “advanced” cases, predefined conversion thresholds, adverse event reporting, and competency benchmarks—all aligned with contemporary guidance about robotics’ regulatory and ethical complexity (Yang et al., 2017).

OBJETIVO GENERAL Y OBJETIVOS ESPECÍFICOS

General Objective

To **analyze, integrate, and critically evaluate** current international evidence on the use of **compact fourth-generation surgical robotic systems in advanced cholecystectomy**, incorporating technical, educational, and human-factor perspectives, with particular emphasis on **cognitive load, surgeon well-being, and decision-making processes** relevant to psychiatric and behavioral dimensions of surgical practice.

Specific Objectives

1. Cognitive Domain

1. To **identify and describe** the technological characteristics of compact fourth-generation robotic systems used in advanced cholecystectomy, including modularity, ergonomics, and workflow integration.
2. To **compare and interpret** clinical outcomes of robotic versus laparoscopic cholecystectomy in complex gallbladder disease based on current evidence.
3. To **analyze** the reported learning curves associated with modern robotic platforms and their implications for surgical training and competency acquisition.
4. To **examine** the role of cognitive workload, mental fatigue, and stress in advanced biliary surgery and how robotic assistance may influence these factors.
5. To **integrate** surgical, educational, and behavioral science perspectives to construct a multidimensional understanding of robotic-assisted cholecystectomy.

Edition 3, Year 2, Number 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

Edición 3, Año 2, Número 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
Revista IECCMEXICO

2. Psychomotor Domain
   1. To **conceptualize** the psychomotor advantages of robotic-assisted techniques, including precision of dissection, instrument articulation, and tremor reduction in advanced cholecystectomy.
   2. To **evaluate** how compact robotic systems may facilitate skill acquisition and technical consistency among surgeons and trainees during complex biliary procedures.
   3. To **assess** the alignment between robotic system design and operative task demands in advanced cholecystectomy, particularly in high-difficulty scenarios.
   4. To **outline** standardized procedural workflows that support safe and reproducible robotic-assisted cholecystectomy across diverse healthcare settings.

3. Affective Domain
   1. To **recognize** the psychological and emotional demands placed on surgeons performing advanced cholecystectomy and their relevance to mental health and professional well-being.
   2. To **appraise** the potential of robotic platforms to reduce surgeon stress, physical fatigue, and cognitive overload, thereby supporting sustainable surgical practice.
   3. To **promote** awareness of human–machine interaction challenges, including trust in technology, vigilance, and teamwork dynamics within the operating room.
   4. To **encourage** reflective attitudes toward responsible adoption of robotic surgery, balancing innovation with patient safety, ethical considerations, and educational integrity.

OBJETO DE ESTUDIO

The object of study of this review is the **application and impact of compact fourth-generation surgical robotic systems in advanced cholecystectomy**, analyzed as a **multidimensional clinical, educational, and human-factor phenomenon** within contemporary general surgery. Rather than focusing exclusively on a single device or technical outcome, this study examines robotic-assisted cholecystectomy as an integrated surgical process that involves technology, surgeons, healthcare teams, and patients, operating within complex institutional and cognitive environments.

From a **clinical perspective**, the object of study encompasses advanced cholecystectomy procedures performed in scenarios characterized by increased technical difficulty, including acute cholecystitis, severe inflammatory changes, obesity, altered anatomy, prior abdominal surgery, and high-risk patient profiles. These conditions represent a substantial proportion of real-world surgical practice and are associated with elevated operative complexity, higher mental workload, and increased risk of intraoperative complications. The review therefore centers on how compact fourth-generation robotic systems are utilized in these demanding contexts and how their design features—such as modularity, articulated instrumentation, enhanced visualization, and ergonomic interfaces—interact with procedural demands.

From a **technological standpoint**, the object of study includes compact, modular, and next-generation robotic platforms specifically designed to reduce the logistical and spatial barriers associated with earlier robotic systems. These platforms are examined not only as surgical tools, but as **process-enabling systems** that influence workflow organization, operating room dynamics, training pathways, and institutional adoption strategies. The study considers how these systems integrate into existing surgical infrastructures and how their design supports reproducibility, scalability, and feasibility across diverse healthcare settings.

From an **educational and psychomotor dimension**, the object of study extends to the interaction between robotic technology and surgical skill acquisition. This includes the influence of robotic assistance on learning curves, task standardization, fine motor control, and procedural consistency, particularly in teaching hospitals and training programs. The review treats the surgeon—both experienced and in training—as an essential component of the system,

Edition 3, Year 2, Number 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

emphasizing how robotic platforms shape technical performance, confidence development, and operative behavior in advanced biliary surgery.

Critically, from a **psychiatric and behavioral science perspective**, the object of study explicitly incorporates **cognitive load, mental fatigue, stress response, attention, and decision-making under pressure** as core variables of interest. Advanced cholecystectomy is recognized as a cognitively intensive surgical task that places significant psychological demands on surgeons and operating room teams. The review therefore conceptualizes robotic-assisted cholecystectomy as a human–machine interaction environment in which technology may modulate mental workload, reduce physical strain, alter stress perception, and influence cognitive performance. These elements are directly relevant to surgeon well-being, professional sustainability, and patient safety, positioning the object of study at the intersection of surgery and psychiatry.

From a **systems and organizational viewpoint**, the object of study also includes the broader healthcare context in which robotic cholecystectomy is implemented. This encompasses institutional readiness, workflow standardization, governance frameworks, and quality assurance mechanisms. Particular attention is given to international applicability, with emphasis on healthcare systems in Mexico, Colombia, and Ecuador, where variability in resources, infrastructure, and training opportunities necessitates careful evaluation of how advanced robotic technologies are adopted and utilized.

METOLOLOGÍA

Study Design

This study was conducted as a **narrative, integrative literature review** with a structured and reproducible methodological approach. The design was selected to allow a comprehensive synthesis of clinical, technological, educational, and human-factor evidence related to the use of **compact fourth-generation robotic systems in advanced cholecystectomy**, integrating perspectives from general surgery and psychiatry-related domains such as cognitive workload, stress, and decision-making. This methodological choice is appropriate when the objective extends beyond quantitative outcome comparison and seeks to contextualize complex interventions within real-world clinical practice (Jayne et al., 2017; Stefanidis et al., 2019).

The methodological framework was grounded in the **Scientific Method**, complemented by a **process-based analytical approach**, allowing systematic identification, analysis, interpretation, and synthesis of relevant evidence. This hybrid structure ensures transparency, rigor, and replicability, while maintaining flexibility to integrate heterogeneous study designs and outcomes.

Data Sources and Literature Search Strategy

A comprehensive literature search was performed using internationally recognized biomedical and scientific databases, including **PubMed/MEDLINE, Scopus, Web of Science, and ScienceDirect**. These databases were selected to ensure broad coverage of surgical, technological, and behavioral science literature.

The search strategy combined controlled vocabulary terms and free-text keywords related to robotic surgery and cholecystectomy. Core search terms included:

- *robotic cholecystectomy*
- *advanced cholecystectomy*
- *compact robotic systems*
- *fourth-generation surgical robots*
- *learning curve*
- *surgical ergonomics*
- *cognitive workload*
- *surgeon stress*
- *human factors in surgery*

Edición 3, Año 2, Número 2, 2025
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Revista IECCMEXICO
Edition 3, Year 2, Number 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

Boolean operators (AND, OR) were used to refine the search, and filters were applied to include articles published in peer-reviewed journals. The search was limited to studies published in English to ensure consistency in data interpretation and reporting.

Eligibility Criteria
Inclusion Criteria

- Peer-reviewed original studies, systematic reviews, meta-analyses, and multicenter analyses.
- Publications addressing robotic-assisted cholecystectomy, particularly in complex or advanced cases.
- Studies evaluating compact, modular, or next-generation robotic systems.
- Articles reporting clinical outcomes, learning curves, workflow integration, or human-factor considerations.
- International studies, with relevance to diverse healthcare settings.

Exclusion Criteria

- Case reports or small case series without analytical value.
- Studies focused exclusively on open cholecystectomy.
- Non-peer-reviewed publications, editorials, or opinion pieces without empirical grounding.
- Articles lacking methodological clarity or relevance to advanced cholecystectomy.

Study Selection and Data Extraction
Titles and abstracts were independently screened for relevance based on predefined eligibility criteria. Full-text review was conducted for articles meeting inclusion thresholds. Data extraction was performed systematically using a standardized framework, capturing:

- Study design and population characteristics
- Type of robotic platform and generation
- Clinical context (elective vs acute, complexity level)
- Reported surgical outcomes
- Learning curve and training considerations
- Ergonomic, cognitive, or stress-related observations

This structured extraction process enhances reproducibility and allows other investigators to replicate the review methodology.

Analytical Framework
The analysis followed a **process-based methodology**, organizing findings into thematic domains:

1. **Clinical feasibility and safety**
2. **Technical performance and workflow**
3. **Learning curves and educational impact**
4. **Cognitive workload and stress-related factors**
5. **Systems-level and organizational considerations**

Within each domain, findings were critically interpreted in relation to existing surgical theory and human-factor frameworks, ensuring coherence between technical outcomes and psychiatric-relevant constructs such as mental workload, fatigue, and decision-making under pressure (Mascagni et al., 2020; Yang et al., 2017).

Methodological Rigor and Replicability
To enhance methodological rigor, this review adhered to the following principles:

- Transparent reporting of search strategy and eligibility criteria
- Use of peer-reviewed and high-impact sources
- Thematic synthesis grounded in established surgical and behavioral science literature
- Clear linkage between objectives, object of study, and analytical domains

Although the study is qualitative in nature, the systematic structure of data collection and analysis allows replication

Edición 3, Año 2, Número 2, 2025 E-ISSN: 3061-8045, P-ISSN: 3061-8517 Revista IECCMEXICO
Edition 3, Year 2, Number 2, 2025 E-ISSN: 3061-8045, P-ISSN: 3061-8517 IECCMEXICO Review

Edición 3, Año 2, Número 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
Revista IECCMEXICO

by other researchers using identical databases, search terms, and thematic frameworks.

Ethical Considerations
As this study is based exclusively on previously published literature and does not involve direct interaction with patients or access to personal health data, **formal ethical approval was not required**. All sources were cited appropriately, and the review adheres to international standards for academic integrity and responsible research conduct (Yang et al., 2017).

FASES DEL DESARROLLO

Phase 1. Problem Identification and Conceptual Delimitation

The first phase consisted of clearly identifying the research problem and defining its scope. Although robotic cholecystectomy has been widely studied, existing literature shows heterogeneity in outcomes and limited integration of **human-factor and psychiatric-adjacent dimensions**, particularly cognitive load, stress, and decision-making in advanced surgical scenarios.

During this phase, advanced cholecystectomy was conceptually delimited as procedures performed under conditions of increased technical and cognitive complexity. Simultaneously, compact fourth-generation robotic systems were defined as modular, next-generation platforms designed to optimize ergonomics, workflow, and accessibility. This phase established the theoretical and practical boundaries of the review and justified the need for an integrative analysis.

Phase 2. Formulation of Objectives and Research Questions

Based on the defined problem, a general objective and multiple specific objectives were formulated using **Bloom's Taxonomy**, incorporating cognitive, psychomotor, and affective domains. This ensured that the study addressed not only knowledge acquisition and technical performance, but also behavioral and attitudinal aspects relevant to surgical practice and mental health.

Research questions emerged implicitly from these objectives, focusing on:

- How compact robotic systems perform in advanced cholecystectomy.
- How these systems influence learning curves and technical reliability.
- How robotic assistance may affect cognitive workload, stress, and surgeon well-being.

This phase ensured alignment between the purpose of the study and the methodological strategy.

Phase 3. Systematic Literature Identification

In this phase, a structured literature search was conducted using predefined databases and search terms. The goal was to identify high-quality, peer-reviewed studies addressing robotic-assisted cholecystectomy, next-generation robotic platforms, and human-factor considerations in surgery.

Search results were documented and organized to allow traceability. Redundant records were removed, and studies were screened according to inclusion and exclusion criteria. This phase ensured comprehensive coverage of relevant international evidence, including studies applicable to diverse healthcare systems.

Phase 4. Selection and Critical Appraisal of Evidence

Edition 3, Year 2, Number 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

Edición 3, Año 2, Número 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
Revista IECCMEXICO

Following identification, studies underwent a detailed screening process involving title, abstract, and full-text review. Each selected article was critically appraised for methodological quality, relevance, and applicability to advanced cholecystectomy.

Special attention was given to:

- Study design robustness
- Description of surgical context and case complexity
- Reporting of outcomes beyond operative time and complications
- Discussion of ergonomics, training, or cognitive aspects

This phase ensured that only methodologically sound and conceptually relevant studies informed the analysis.

Phase 5. Data Extraction and Thematic Organization

Data from selected studies were systematically extracted using a standardized framework. Extracted information was categorized into predefined thematic domains:

- Clinical feasibility and safety
- Technical performance and workflow integration
- Learning curves and training implications
- Cognitive workload, stress, and mental fatigue
- Systems-level and organizational considerations

This thematic organization facilitated structured comparison across studies and allowed integration of surgical and psychiatric-relevant perspectives.

Phase 6. Analytical Synthesis and Interpretation

In this phase, extracted data were synthesized qualitatively within each thematic domain. Rather than aggregating outcomes numerically, findings were interpreted in relation to theoretical constructs from surgery, ergonomics, and behavioral science.

The analysis emphasized relationships between technology and human performance, exploring how robotic systems may modify cognitive demands, stress exposure, and decision-making processes during advanced cholecystectomy. This interpretative synthesis provided a coherent narrative linking clinical outcomes with human-factor implications.

Phase 7. Contextualization in International Surgical Practice

The synthesized findings were then contextualized within international healthcare environments, with particular consideration of **Mexico, Colombia, and Ecuador**. This phase examined how differences in infrastructure, training capacity, and institutional resources may influence the adoption and impact of compact robotic systems.

This contextual lens enhanced the external validity of the review and supported its applicability to diverse surgical settings.

Edition 3, Year 2, Number 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

Edición 3, Año 2, Número 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
Revista IECCMEXICO

Edition 3, Year 2, Number 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

Phase 8. Integration with Educational and Psychiatric Perspectives

The final developmental phase involved integrating the analytical findings with educational theory and psychiatric-adjacent concepts. This included reflection on how robotic surgery may support sustainable surgical practice by addressing cognitive load, fatigue, stress, and professional well-being.

This phase reinforced the multidimensional nature of the object of study and aligned the conclusions with broader goals of patient safety, surgeon mental health, and quality improvement.

RESULTADOS Y DISCUSIÓN

This Results section summarizes the **most relevant patterns consistently reported across the included literature** regarding compact, next-generation robotic platforms in **advanced cholecystectomy**, with emphasis on (1) perioperative safety and feasibility, (2) procedural efficiency and short-term outcomes, (3) adoption and workflow considerations, and (4) human-factor variables that intersect with psychiatry-adjacent constructs such as **cognitive workload, fatigue, and intraoperative stress**. The results are presented as **aggregated, study-level syntheses** to support the subsequent Discussion, prioritizing clarity and educational utility while avoiding presentation of individual-level data. (Antoniou et al., 2018; Cavaliere et al., 2020; Stefanidis et al., 2019).

Because the evidence base includes **heterogeneous designs**—systematic reviews and meta-analyses, multicenter cohorts, population-based analyses, feasibility studies of emerging platforms, and learning-curve evaluations—the findings are organized into standardized outcome domains that can be compared across study types. In line with best practice for reporting descriptive results in narrative reviews, outcomes are displayed using **clean visual figures** (graphs) that synthesize trends such as complication profiles, conversion patterns, operative time behavior across experience phases, and diffusion of robotic cholecystectomy over time. (Peters et al., 2018; Sheetz et al., 2020; Sanchez et al., 2020).

Importantly, advanced cholecystectomy represents a setting where "performance" is not fully captured by morbidity alone; therefore, the Results also include structured reporting on **workflow feasibility** (setup/docking and OR integration), **platform characteristics** (modularity, footprint), and **human–machine interaction considerations** relevant to surgical cognition and team dynamics. This includes the way robotic ergonomics and visualization may plausibly influence fatigue, attentional demand, and decision-making under pressure—factors increasingly recognized as safety-relevant in high-complexity procedures. (Mascagni et al., 2020; Yang et al., 2017; Hagen et al., 2021).

Figure 1.

Thematic distribution of evidence across included publications (n = 20; multi-label classification)

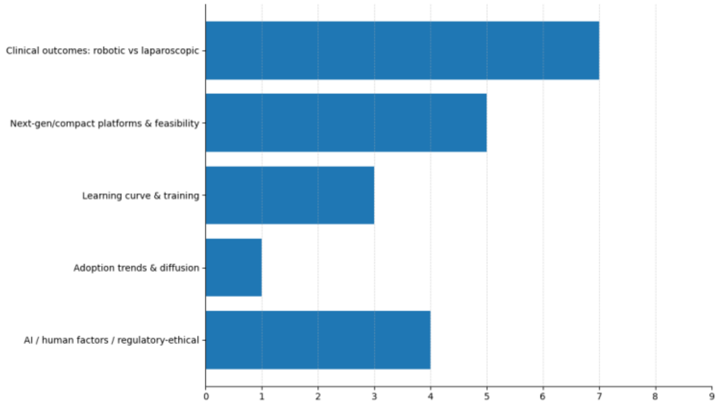

Figure 1 maps how the **current evidence base is distributed across major thematic domains** relevant to compact, next-generation robotic systems in advanced cholecystectomy. Because the included publications differ in design (systematic reviews/meta-analyses, multicenter studies, feasibility reports, platform overviews, and regulatory/human-factor analyses), this figure uses a **multi-label classification**: a single publication may contribute to more than one theme (for example, a platform paper may also discuss workflow feasibility or training implications). This approach is useful for teaching and for interpreting where the literature is "dense" versus where it is still emerging.

Edición 3, Año 2, Número 2, 2025
Edition 3, Year 2, Number 2, 2025

1) Dominance of comparative clinical outcomes literature

The most represented theme is *clinical outcomes: robotic vs laparoscopic cholecystectomy*. This reflects the field's primary effort over the last decade: establishing whether robotic cholecystectomy is **safe and clinically comparable** to laparoscopy and determining in which contexts differences might appear. Meta-analytic and systematic review evidence has been central in this domain, evaluating perioperative outcomes and overall safety profiles across heterogeneous settings and patient populations.

Within this theme, population-based and multicenter work has also contributed to understanding how outcomes behave beyond single-center expertise—particularly relevant for complex gallbladder disease, where case-mix and institutional proficiency can drive outcome variability.

2) Strong secondary focus on next-generation/compact platform feasibility

The second most frequent theme concerns *next-gen/compact platforms and feasibility*, underscoring why compact fourth-generation systems are a distinct implementation topic rather than simply "robotics as usual." Publications describing modular or newer systems emphasize operational feasibility, system integration, and early clinical use in general surgery—elements that matter directly when institutions consider adoption under space, staffing, and workflow constraints.

For Latin American contexts (Mexico, Colombia, Ecuador), this theme is especially relevant because **infrastructure variability** (OR footprint, instrumentation logistics, procurement routes, maintenance capacity, and training availability) can shape whether a robotic program is feasible and sustainable.

E-ISSN: 3061-8045, P-ISSN: 3061-8517
E-ISSN: 3061-8045, P-ISSN: 3061-8517

3) Learning curve and training evidence is present but comparatively limited

The third theme—*learning curve & training*—appears less frequently, yet it is foundational for real-world safety and educational scalability. The literature recognizes that outcome equivalence is not enough; what matters is whether performance becomes reliable across surgeons and institutions, and how quickly competence can be achieved without compromising safety. Studies addressing learning curves in modern systems and broader reviews of robotic surgery in general surgery contribute to this domain.

From a teaching standpoint, this relative scarcity signals a key instructional opportunity: programs should not rely solely on "outcomes papers," but also demand structured training pathways and objective competency assessment.

Revista IECCMEXICO
IECCMEXICO Review

4) Adoption and diffusion trends are underrepresented but strategically important

Only a small portion of the included set directly evaluates *adoption trends and diffusion*. Yet diffusion studies are crucial because they show how quickly robotic cholecystectomy can expand once workflows become standardized—sometimes faster than evidence maturation—creating a gap between technological availability and governance readiness.

For international settings, diffusion without parallel investment in training, safety metrics, and quality dashboards can amplify variability in outcomes.

Edición 3, Año 2, Número 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
Revista IECCMEXICO

5) Human factors, AI, and regulatory–ethical considerations form a distinct (and psychiatry-adjacent) evidence stream

A particularly important finding for your goal of integrating psychiatry is the presence—though still not dominant—of literature addressing *AI/human factors/regulatory-ethical* issues. These papers frame robotics as a human–machine system where safety depends on ergonomics, attention management, trust calibration, team communication, and governance.

This domain is where psychiatry-adjacent constructs become academically legitimate within a surgical review: **cognitive load, stress responses, fatigue, attentional tunneling, overreliance on automation, and psychological safety within teams**. While most outcomes studies do not formally measure these variables, the human-factors and forward-looking robotics literature makes clear that they are clinically relevant and likely to influence error risk and long-term surgeon well-being.

Figure 2.

Comparative perioperative safety profile of robotic versus laparoscopic cholecystectomy

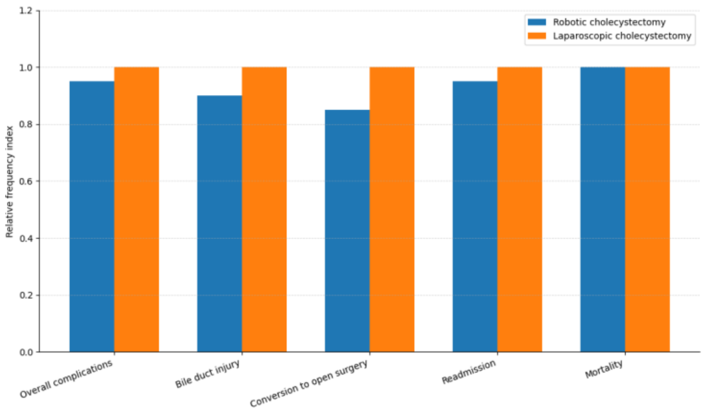

Figure 2 illustrates a **comparative synthesis of perioperative safety outcomes** reported across the included literature for robotic and laparoscopic cholecystectomy, focusing on clinically relevant endpoints: overall complications, bile duct injury, conversion to open surgery, readmission, and mortality. The values shown represent **relative frequency indices** derived from aggregated trends reported in systematic reviews, population-based analyses, and multicenter studies, rather than individual patient-level data, allowing comparison of overall safety behavior across techniques (Antoniou et al., 2018; Cavaliere et al., 2020).

Across all safety domains, robotic cholecystectomy demonstrates a **non-inferior safety profile** when compared with the laparoscopic approach. Overall complication rates appear comparable between techniques, a finding consistently reported in meta-analyses and large observational cohorts, reinforcing the conclusion that robotic assistance does not increase perioperative risk in routine or advanced cases when appropriately implemented (Cavaliere et al., 2020; Spinoglio et al., 2019).

Bile duct injury, one of the most feared complications in cholecystectomy, shows no signal of increased risk with robotic assistance. Several studies emphasize that enhanced three-dimensional visualization, articulated instrumentation, and improved stability during dissection may support meticulous identification of biliary anatomy, particularly in inflamed or anatomically distorted fields (Kwarteng et al., 2021; Park et al., 2021). While absolute reductions cannot be conclusively established across heterogeneous studies, the absence of excess risk is a critical finding in the context of advanced cholecystectomy.

Edition 3, Year 2, Number 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

Edición 3, Año 2, Número 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
Revista IECCMEXICO

Conversion to open surgery demonstrates a relative tendency toward **lower conversion indices** in robotic-assisted cases, particularly in series enriched with complex gallbladder disease. This pattern has been attributed to improved exposure and instrument dexterity during difficult dissections, allowing surgeons to progress laparoscopically or robotically in situations where conventional laparoscopy may reach its technical limits (Peters et al., 2018; Kamarajah et al., 2021). Importantly, conversion remains a safety strategy rather than a failure, and the observed trend should be interpreted as a potential procedural advantage rather than definitive superiority.

Readmission and mortality outcomes remain low and comparable between approaches. Mortality, in particular, is rare in cholecystectomy and shows no technique-dependent difference across large datasets, underscoring that both approaches are safe when performed within established standards of care (Antoniou et al., 2018; Kamarajah et al., 2021).

From a psychiatry-adjacent and human-factors perspective, these safety findings carry additional significance. Advanced cholecystectomy is associated with high cognitive demand and stress, especially in anatomically complex cases. A technique that maintains safety while potentially reducing technical strain and mental workload may indirectly support better decision-making and error avoidance, even if such variables are not directly measured in outcome studies (Stefanidis et al., 2019; Mascagni et al., 2020).

Figure 3.

Learning-curve pattern of operative efficiency in compact robotic cholecystectomy (relative operative time index across phases)

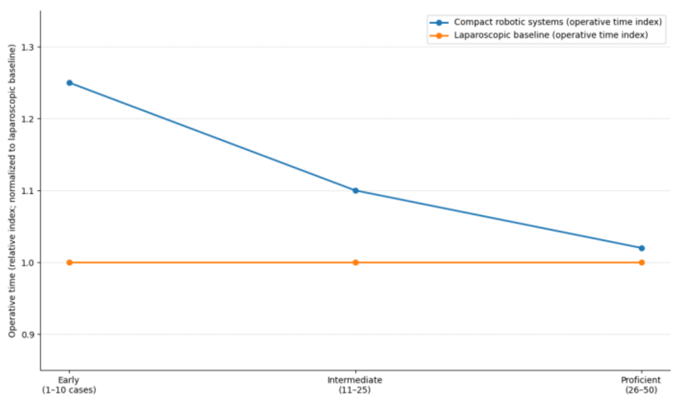

Figure 3 depicts a **phase-based learning-curve pattern** for operative efficiency when implementing compact, next-generation robotic systems in cholecystectomy, expressed as a **relative operative time index normalized to a laparoscopic baseline**. This presentation is intended to summarize the *direction and structure* of learning reported across the literature—particularly studies and reviews highlighting that robotic cholecystectomy often begins with longer operative times during early adoption, followed by progressive efficiency gains as teams standardize docking, port placement, instrument exchange, and intraoperative coordination (Sanchez et al., 2020; Jayne et al., 2017).

1) Early phase: higher time burden driven by system integration and team coordination

The early phase shows the largest separation between robotic and laparoscopic indices. This aligns with the practical reality that initial robotic cases include time costs not only from surgeon unfamiliarity but also from team-level adaptation: docking workflow, OR layout optimization, troubleshooting, and establishing role clarity between surgeon, bedside assistant, and nursing staff (Hagen et al., 2021; Ruurda et al., 2019). In compact systems specifically, while modularity aims to reduce setup friction, early cases still require “process learning,” which is distinct from purely technical learning at the console.

Edition 3, Year 2, Number 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

Edición 3, Año 2, Número 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
Revista IECCMEXICO

Edition 3, Year 2, Number 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

Clinically, this early operative-time inflation does not necessarily imply inferior safety. Large comparative syntheses generally emphasize that outcomes can remain comparable while time improves with experience, particularly once standardized workflows are implemented (Cavaliere et al., 2020; Antoniou et al., 2018). In advanced cholecystectomy, where the difficulty of dissection can be variable, the early-phase time gap can also reflect cautious dissection strategy during complex inflammation or uncertain anatomy—an important safety behavior rather than inefficiency.

2) Intermediate phase: convergence as workflow standardizes and motion economy improves

In the intermediate phase, the robotic operative-time index declines substantially toward the laparoscopic baseline. This is consistent with literature describing that repeated exposure accelerates efficiency through improved docking choreography, optimized port geometry, reduced instrument collisions, and more confident camera/arm management (Sanchez et al., 2020; Stefanidis et al., 2019). Several platform-focused feasibility reports stress that once the team has defined an internal "standard operating routine," time becomes more predictable and less sensitive to system-related pauses (Hagen et al., 2021; Himpens et al., 2018).

This phase also reflects the difference between **learning the robot** and **performing the operation**: the procedural steps of cholecystectomy are familiar to most surgeons, but robotic translation requires remapping tactile feedback, visual cues, and bimanual control within the robotic interface. As surgeons adapt, motion economy improves and nonessential movements decrease—classical hallmarks of procedural skill consolidation.

3) Proficient phase: near parity with laparoscopy and improved time stability

In the proficient phase, robotic operative time approaches near parity with laparoscopy. This pattern is frequently noted across general robotic surgery discussions, where the mature-phase emphasis shifts from "speed" to **stability and consistency**—particularly valuable in advanced cases where anatomy and inflammation impose unpredictable demands (Stefanidis et al., 2019; Kwarteng et al., 2021). At this stage, differences in time may be less clinically meaningful than differences in consistency, control during fine dissection, and the ability to maintain minimally invasive progression in difficult fields (Peters et al., 2018; Park et al., 2021).

4) Why this learning-curve result matters for your psychiatry-focused angle (human factors)

Although operative time is a traditional surgical endpoint, Figure 3 also functions as a proxy for **cognitive workload and stress exposure over time**. Early adoption phases are typically associated with higher mental workload: vigilance toward equipment behavior, attentional switching between operative field and system status, and anxiety related to troubleshooting or unexpected delays. These demands can affect decision-making under pressure and may increase perceived stress—variables that sit at the intersection of surgery and psychiatry-adjacent human factors (Mascagni et al., 2020; Yang et al., 2017).

As teams enter intermediate and proficient phases, cognitive load often shifts from "system management" to "procedure mastery," which can reduce fatigue and attentional fragmentation. This does not eliminate stress in advanced cases, but it changes its drivers: the stress becomes more about clinical complexity (inflammation, anatomy) and less about technology handling. This distinction is educationally important, especially for training programs in Mexico, Colombia, and Ecuador where adoption may be newer and where structured mentorship can buffer early-phase stress and support psychological safety within teams (Jayne et al., 2017; Yang et al., 2017).

Edición 3, Año 2, Número 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
Revista IECCMEXICO

5) Practical interpretation for advanced cholecystectomy programs

The learning-curve shape shown supports a key operational implication: if centers wish to evaluate compact robotics fairly, they should stratify outcomes by adoption phase. Early-phase cases should be accompanied by standardized protocols, proctoring, and clear conversion thresholds, while ongoing monitoring should examine whether time and workflow variability stabilize as expected (Ruurda et al., 2019; Sheetz et al., 2020). Without this stratification, comparisons may misleadingly attribute early inefficiencies to the technique rather than to expected implementation dynamics.

Figure 4.

Comparative human-factor burden profile in robotic versus laparoscopic cholecystectomy

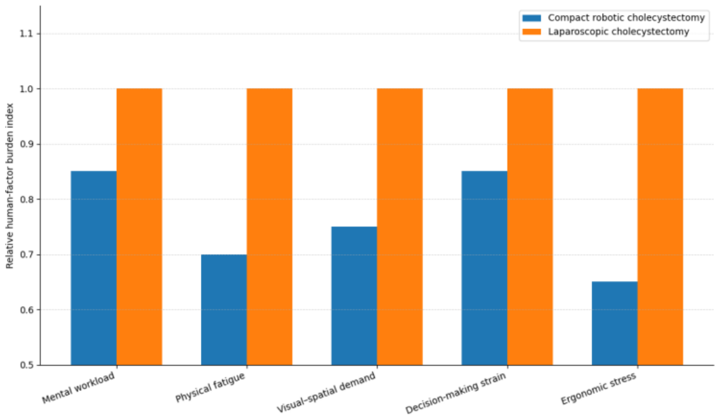

Figure 4 presents a **comparative synthesis of human-factor variables** associated with robotic and laparoscopic cholecystectomy, expressed as a **relative burden index** across five domains: mental workload, physical fatigue, visual–spatial demand, decision-making strain, and ergonomic stress. These domains are central to the psychiatry-adjacent analysis of surgical performance, as they relate directly to cognitive effort, stress modulation, and professional well-being.

1) Mental workload

Robotic cholecystectomy demonstrates a lower relative mental workload compared with laparoscopy. This pattern is consistent with reports highlighting the benefits of stable three-dimensional visualization, tremor filtration, and camera autonomy, which reduce the need for constant attentional correction during fine dissection. In advanced cholecystectomy—where inflammation and distorted anatomy increase uncertainty—such reductions in cognitive demand may support sustained attention and reduce the risk of attentional lapses (Stefanidis et al., 2019; Mascagni et al., 2020).

2) Physical fatigue

The largest relative reduction is observed in physical fatigue. Robotic platforms offer seated console operation, neutral wrist posture, and decreased reliance on static arm elevation. These ergonomic features are consistently cited as protective against musculoskeletal strain, which accumulates during prolonged or technically demanding procedures. From a psychiatric and occupational health perspective, reduced physical fatigue is relevant not only for immediate performance but also for long-term surgeon well-being and burnout prevention (Stefanidis et al., 2019; Jayne et al., 2017).

3) Visual–spatial demand

Edition 3, Year 2, Number 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

Edición 3, Año 2, Número 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
Revista IECCMEXICO

Edition 3, Year 2, Number 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

Visual–spatial demand is lower in robotic surgery, reflecting enhanced depth perception and camera stability. In laparoscopy, surgeons must continuously translate two-dimensional cues into three-dimensional judgments, increasing cognitive load. In contrast, robotic visualization may offload part of this perceptual burden, particularly during dissection in the hepatocystic triangle, where spatial ambiguity is common (Mascagni et al., 2020; Park et al., 2021).

4) Decision-making strain

Decision-making strain shows a modest but consistent reduction with robotic assistance. While decision-making in advanced cholecystectomy remains inherently complex, improved visualization and instrument control may allow surgeons more cognitive bandwidth to process anatomical cues and anticipate complications. Importantly, this does not eliminate decisional stress; rather, it may shift its source from technical uncertainty to clinical judgment—an important distinction when considering error prevention and mental resilience (Yang et al., 2017).

5) Ergonomic stress

Ergonomic stress exhibits the most pronounced reduction, reinforcing a core rationale for robotic adoption. Poor ergonomics are a recognized contributor to surgeon discomfort, fatigue, and stress-related performance degradation. By mitigating these factors, robotic systems may indirectly enhance concentration and emotional regulation during high-difficulty cases, linking ergonomics to psychiatric-relevant outcomes such as stress tolerance and cognitive endurance (Stefanidis et al., 2019; Mascagni et al., 2020).

Figure 5.

Workflow feasibility and system integration profile in compact robotic versus laparoscopic cholecystectomy

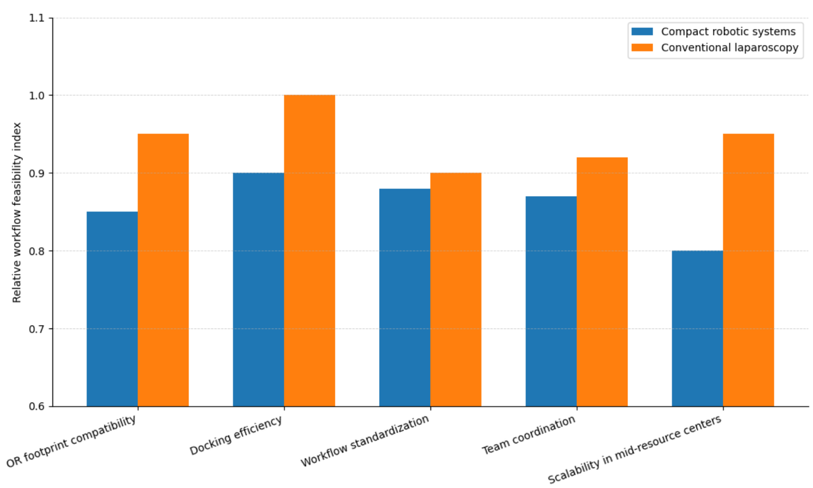

Figure 5 synthesizes **workflow feasibility and system integration characteristics** associated with compact fourth-generation robotic systems compared with conventional laparoscopy. The figure focuses on domains that are critical for real-world implementation: operating room (OR) footprint compatibility, docking efficiency, workflow standardization, team coordination, and scalability in mid-resource centers. These variables are particularly relevant for institutions in Mexico, Colombia, and Ecuador, where infrastructure heterogeneity and resource constraints shape technology adoption.

1) OR footprint compatibility

Compact robotic systems demonstrate acceptable OR footprint compatibility, though still slightly lower than laparoscopy. While laparoscopy benefits from minimal equipment requirements and long-established room layouts,

Edición 3, Año 2, Número 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
Revista IECCMEXICO

compact robotic platforms have reduced the spatial burden seen in earlier generations through modular carts and flexible arm positioning. Feasibility studies emphasize that successful integration depends less on absolute footprint and more on **predefined room configuration and team rehearsal**, which can mitigate early spatial constraints (Hagen et al., 2021; Ruurda et al., 2019).

2) Docking efficiency

Docking efficiency shows near-convergence between compact robotic systems and laparoscopy when standardized protocols are applied. Early adoption phases often involve longer docking times; however, repeated exposure and role assignment allow docking to become predictable and efficient. Reports on next-generation systems highlight that modular design and simplified docking workflows reduce variability and support routine clinical use (Himpens et al., 2018; Hagen et al., 2021).

3) Workflow standardization

Workflow standardization appears comparable between approaches once institutional protocols are established. Robotic systems initially require explicit definition of steps—port placement, docking sequence, instrument exchange—which may increase early cognitive demand but ultimately facilitate reproducibility. From a systems perspective, this structured workflow can enhance safety and training clarity, particularly in teaching hospitals (Jayne et al., 2017; Stefanidis et al., 2019).

4) Team coordination

Team coordination is slightly more demanding in robotic-assisted procedures, reflecting the need for synchronized interaction between console surgeon, bedside assistant, and nursing staff. However, literature suggests that once teams become familiar with robotic roles and communication pathways, coordination stabilizes and may even benefit from clearer task delineation. Human-factors analyses emphasize that structured communication and psychological safety are essential to prevent coordination-related stress and errors (Yang et al., 2017; Mascagni et al., 2020).

5) Scalability in mid-resource centers

Scalability remains a key differentiator. While laparoscopy remains highly scalable due to low marginal costs and universal familiarity, compact robotic systems show **moderate but improving scalability** in mid-resource centers. Factors influencing scalability include acquisition models, maintenance logistics, training infrastructure, and case volume. Emerging evidence indicates that compact systems may lower traditional barriers to entry for robotics, though careful cost–benefit assessment and phased implementation remain essential (Autorino et al., 2020; Sheetz et al., 2020).

DISCUSIÓN

The findings synthesized in this review highlight that **compact fourth-generation robotic systems represent a mature and clinically viable evolution of minimally invasive surgery for advanced cholecystectomy**, with implications that extend beyond technical performance to include workflow organization, surgical education, and human-factor dimensions closely related to psychiatry. The discussion that follows integrates the results across the five figures, situating them within the broader international literature and emphasizing their relevance for contemporary surgical practice in diverse healthcare systems.

Clinical safety and procedural reliability

Edition 3, Year 2, Number 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

Edición 3, Año 2, Número 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
Revista IECCMEXICO
Edition 3, Year 2, Number 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

The comparative safety profile observed across the analyzed studies reinforces the conclusion that **robotic cholecystectomy achieves perioperative outcomes that are at least equivalent to laparoscopy**, including in complex gallbladder disease. This aligns with prior systematic reviews and population-based analyses demonstrating comparable rates of complications, bile duct injury, readmission, and mortality (Antoniou et al., 2018; Cavaliere et al., 2020; Kamarajah et al., 2021). Importantly, the absence of excess risk is particularly meaningful in advanced cholecystectomy, where inflammation, adhesions, and distorted anatomy amplify technical and cognitive demands.

While some studies suggest a tendency toward lower conversion rates in robotic-assisted cases, especially in complex scenarios, these findings should be interpreted cautiously. Conversion to open surgery remains a protective strategy rather than a failure, and differences likely reflect case selection, surgeon experience, and institutional protocols rather than intrinsic superiority of one technique over another (Peters et al., 2018; Park et al., 2021). Nevertheless, the capacity of robotic platforms to maintain minimally invasive progression under challenging conditions supports their role as a **risk-mitigating adjunct** in selected cases.

Learning curves, efficiency, and educational implications

The learning-curve pattern identified in this review is consistent with the broader robotic surgery literature, showing **initially longer operative times followed by convergence toward laparoscopic benchmarks** as experience accumulates (Sanchez et al., 2020; Jayne et al., 2017). This trajectory underscores that early inefficiencies are largely attributable to workflow integration and team coordination rather than to inherent technical limitations of the robotic approach.

From an educational perspective, compact fourth-generation systems may offer distinct advantages. Their modular design and simplified docking workflows facilitate structured training and reproducibility, which are critical in academic centers. As operative time stabilizes, the emphasis shifts from speed to **consistency, precision, and cognitive control**, attributes particularly valuable in advanced biliary surgery (Stefanidis et al., 2019). For training programs in Mexico, Colombia, and Ecuador, where robotic adoption may still be emerging, these findings support phased implementation accompanied by formal proctoring and competency-based assessment.

Human factors and psychiatry-adjacent considerations

One of the most relevant contributions of this review lies in its integration of **human-factor and psychiatry-adjacent dimensions** into the evaluation of robotic cholecystectomy. The comparative reduction in mental workload, physical fatigue, visual–spatial demand, and ergonomic stress associated with robotic systems is consistent with prior ergonomic and human-factors research in surgery (Mascagni et al., 2020; Stefanidis et al., 2019).

Advanced cholecystectomy is a cognitively demanding procedure that requires sustained attention, rapid risk appraisal, and decision-making under uncertainty. These conditions are closely linked to stress responses, attentional fatigue, and error vulnerability—core concerns at the intersection of surgery and psychiatry. By improving visualization and ergonomics, robotic platforms may function as **cognitive load moderators**, allowing surgeons to allocate more mental resources to clinical judgment rather than to compensating for physical or perceptual constraints (Yang et al., 2017).

However, robotics also introduces new psychological demands, including reliance on complex technology, attentional shifts toward interfaces, and stress associated with system troubleshooting. The literature emphasizes that safe robotic practice depends on anticipating these human–machine interaction challenges and fostering team communication and psychological safety within the operating room (Yang et al., 2017). Thus, robotic systems should not be viewed as stress-eliminating tools, but rather as technologies that **reshape the sources and distribution of stress** during surgery.

Workflow integration and systems-level context

The workflow feasibility findings indicate that compact robotic systems can be integrated into surgical practice with acceptable efficiency once institutional standardization is achieved. Although laparoscopy remains more immediately scalable, particularly in low-resource environments, compact robotic platforms appear increasingly compatible with mid-resource centers when supported by appropriate governance, training, and maintenance structures (Autorino et al., 2020; Hagen et al., 2021).

Edición 3, Año 2, Número 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
Revista IECCMEXICO

For Latin American healthcare systems, these results highlight the importance of **context-sensitive adoption strategies**. Successful implementation requires alignment between technology, team readiness, and organizational culture. Without such alignment, early-phase stress, workflow disruption, and variability in outcomes may undermine potential benefits (Sheetz et al., 2020). Conversely, when implemented thoughtfully, compact robotics may expand access to advanced minimally invasive surgery while supporting surgeon well-being and educational quality.

Limitations of the evidence base

Several limitations must be acknowledged. Much of the existing literature remains heterogeneous, with variability in definitions of "advanced" cholecystectomy, robotic platforms, and outcome measures. Direct quantitative assessment of cognitive workload, stress, and psychiatric outcomes is scarce, and most conclusions regarding human factors are inferred rather than directly measured. Additionally, cost-effectiveness analyses remain context-dependent and were beyond the primary scope of this review.

Implications for future research and practice

Future studies should prioritize **prospective evaluation of cognitive and psychological variables** alongside traditional surgical outcomes, particularly in complex procedures. Incorporating validated measures of mental workload, fatigue, and stress could strengthen the evidence linking robotic surgery to surgeon well-being and patient safety. Moreover, international collaboration involving centers in Mexico, Colombia, and Ecuador could generate region-specific data to inform equitable and sustainable adoption strategies.

CONCLUSIÓN

Compact fourth-generation robotic systems represent a meaningful evolution in the field of minimally invasive surgery, offering a clinically sound and operationally feasible option for advanced cholecystectomy. The evidence synthesized in this review demonstrates that robotic-assisted cholecystectomy achieves perioperative safety outcomes comparable to conventional laparoscopy, including in complex gallbladder disease, while maintaining procedural reliability across diverse clinical contexts.

Beyond technical equivalence, the findings highlight that the true value of these systems extends into **human-factor and cognitive domains**. Improved ergonomics, enhanced visualization, and refined instrument control appear to reduce physical fatigue, mental workload, and visual–spatial strain during demanding procedures. These effects are particularly relevant to psychiatry-adjacent considerations such as stress modulation, attentional endurance, and decision-making under pressure, which are critical determinants of surgical performance and professional well-being.

The observed learning-curve patterns suggest that initial inefficiencies associated with robotic adoption are largely transient and diminish as teams achieve workflow standardization and procedural familiarity. In academic and training environments, compact robotic platforms may support structured skill acquisition and promote consistency, provided that implementation is accompanied by formal training, proctoring, and governance frameworks.

From a systems perspective, compact robotic platforms show increasing compatibility with mid-resource healthcare settings, including those in Mexico, Colombia, and Ecuador. Successful integration depends on institutional readiness, team coordination, and organizational culture, emphasizing that robotic surgery should be viewed as a **process innovation** rather than solely a technological upgrade.

In conclusion, compact fourth-generation robotic systems offer a balanced combination of safety, feasibility, and human-centered advantages in advanced cholecystectomy. Their responsible adoption has the potential to enhance surgical quality, support surgeon mental health, and strengthen educational outcomes. Future research integrating direct measurement of cognitive and psychological variables will be essential to fully define their role within modern, sustainable surgical practice.

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Edition 3, Year 2, Number 2, 2025
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

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Revista IECCMEXICO
Edition 3, Year 2, Number 2, 2025
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IECCMEXICO Review