

Avances Integrados en Cirugía Mínimamente Invasiva: Ergonomía, Visualización e Inteligencia Artificial en la Laparoscopia Moderna

Integrated Advances in Minimally Invasive Surgery: Ergonomics, Visualization, and Artificial Intelligence in Modern Laparoscopy

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RESUMEN

La cirugía mínimamente invasiva ha experimentado una transformación significativa con la aparición de la laparoscopia de nueva generación, caracterizada por la integración de la

optimización ergonómica, tecnologías avanzadas de visualización y sistemas de asistencia inteligente. Esta revisión tiene como objetivo analizar el estado actual y las perspectivas futuras de la cirugía laparoscópica a través de estos tres dominios fundamentales, destacando su impacto conjunto en el desempeño quirúrgico, la seguridad intraoperatoria y los resultados clínicos. Se realizó una revisión narrativa de literatura de alto impacto publicada a partir de 2020, enfocada en los avances tecnológicos y su aplicación en distintos contextos de salud. Los resultados indican que la ergonomía continúa siendo un factor determinante en el desempeño del cirujano y su sostenibilidad a largo plazo, mientras que las innovaciones en visualización—como la imagen tridimensional y la fluorescencia—mejoran la percepción espacial y la precisión operatoria. Asimismo, la incorporación de la inteligencia artificial está redefiniendo los flujos quirúrgicos al permitir análisis en tiempo real, evaluación de seguridad y apoyo en la toma de decisiones. A pesar de estos avances, persisten desigualdades en el acceso e implementación, especialmente en regiones de ingresos medios como México, Colombia y Ecuador. La evidencia sugiere que una integración progresiva y adaptada al contexto es fundamental para garantizar tanto la innovación como la accesibilidad. En conjunto, la laparoscopia de nueva generación representa un cambio hacia un paradigma quirúrgico más integrado, digital y centrado en el factor humano.

PALABRAS CLAVE

Laparoscopia, cirugía mínimamente invasiva, ergonomía quirúrgica, imagen tridimensional, inteligencia artificial, ciencia de datos quirúrgicos, cirugía robótica, toma de decisiones intraoperatoria, innovación quirúrgica, cirugía global

ABSTRACT

Minimally invasive surgery has undergone significant transformation with the emergence of next-generation laparoscopy, characterized by the integration of ergonomic optimization, advanced visualization technologies, and intelligent assistance systems. This review aims to analyze the current state and future perspectives of laparoscopic surgery through these three core domains, emphasizing their combined impact on surgical performance, intraoperative safety, and clinical outcomes. A narrative review of high-impact literature published from 2020 onward was conducted, focusing on technological advancements and their application across diverse healthcare settings. The findings indicate that ergonomics remains a critical factor influencing surgeon performance and long-term sustainability, while innovations in visualization—such as three-dimensional imaging and fluorescence guidance—enhance spatial perception and operative precision. Additionally, the incorporation of artificial intelligence is redefining surgical workflows by enabling real-time analysis, safety assessment, and decision support. Despite these advances, disparities in access and implementation persist, particularly in middle-income regions such as Mexico, Colombia, and Ecuador. The evidence suggests that a progressive and context-adapted integration of these technologies is essential to ensure both innovation and accessibility. Ultimately, next-generation laparoscopy represents a shift toward a more integrated, data-driven, and human-centered surgical paradigm.

KEYWORDS

Laparoscopy, minimally invasive surgery, surgical ergonomics, three-dimensional imaging, artificial intelligence, surgical data science, robotic surgery, intraoperative decision-making, surgical innovation, global surgery

INTRODUCCIÓN

Minimally invasive surgery has undergone a profound transformation over the past three decades, with laparoscopy emerging as a cornerstone of modern surgical practice. Initially developed to reduce postoperative morbidity and improve recovery times, laparoscopic techniques have progressively evolved toward highly sophisticated systems that integrate advanced visualization, ergonomic optimization, and intelligent computational support. Despite these advances, important challenges persist, particularly in relation to surgeon fatigue, visual limitations, procedural variability, and the integration of emerging technologies into routine clinical workflows (Hwang & Marshall, 2021; van Det et al., 2020).

One of the central issues in contemporary laparoscopy is the mismatch between technological innovation and human factors. Although minimally invasive approaches have demonstrated clear benefits over open surgery—including reduced hospital stay, lower complication rates, and faster recovery—these advantages may be offset by ergonomic strain and cognitive overload experienced by surgeons during complex procedures (Buia et al., 2020; Haskins et al., 2021). Studies have consistently shown that laparoscopic surgery imposes non-physiological postures and repetitive movements, contributing to musculoskeletal disorders and decreased operative performance over time (Chmarra et al., 2020). This highlights the need for a next-generation framework that not only enhances technical capabilities but also prioritizes surgeon well-being and performance sustainability.

In parallel, visualization technologies have become a key driver of innovation in minimally invasive surgery. Traditional two-dimensional systems have been progressively replaced or complemented by three-dimensional imaging, high-definition optics, and augmented visualization platforms. Evidence suggests that 3D laparoscopy improves depth perception and surgical precision, particularly in complex procedures (Maddah et al., 2022). Moreover, emerging visualization modalities—including fluorescence imaging and real-time intraoperative guidance—are expanding the surgeon's ability to identify critical anatomical structures and reduce intraoperative risks (Islam et al., 2022). However, the adoption of these technologies remains heterogeneous across regions and institutions, particularly in middle-income countries such as Mexico, Colombia, and Ecuador, where access to high-end surgical platforms may be limited.

Another critical dimension of next-generation laparoscopy is the integration of artificial intelligence (AI) and data-driven systems into surgical practice. The field of surgical data science has introduced new paradigms for analyzing intraoperative performance, predicting outcomes, and enhancing decision-making processes (Maier-Hein et al., 2021). Machine learning algorithms have demonstrated the capacity to recognize surgical phases, assess technical skills, and even identify critical safety steps such as the “critical view of safety” during laparoscopic cholecystectomy (Mascagni et al., 2021; Garrow et al., 2021). These developments suggest a transition toward semi-autonomous and context-aware surgical environments, where intelligent assistance systems support surgeons in real time.

Nevertheless, the incorporation of AI into surgery raises important questions regarding reliability, interpretability, and clinical applicability. While early studies have shown promising results, concerns remain about the generalizability of these models across different populations and healthcare systems (Hashimoto et al., 2020). This is particularly relevant in Latin American contexts, where variability in surgical training, infrastructure, and patient characteristics may influence the performance of AI-based tools. Therefore, a critical appraisal of these technologies is necessary to ensure their safe and effective implementation.

Robotic-assisted laparoscopy further exemplifies the convergence of ergonomics, visualization, and intelligent systems. Modern robotic platforms offer enhanced dexterity, tremor filtration, and improved ergonomics, addressing many of the limitations of conventional laparoscopy (Ruurda & van Hillegersberg, 2020). Additionally, emerging robotic systems are increasingly incorporating AI-driven functionalities, paving the way for autonomous or semi-autonomous surgical interventions (Vitiello et al., 2020; Zheng et al., 2020). Despite these advances, cost, accessibility, and training requirements continue to limit widespread adoption, particularly in resource-constrained settings.

From a global perspective, the evolution of laparoscopy must be understood within a heterogeneous landscape of healthcare systems. In countries such as Mexico, Colombia, and Ecuador, the implementation of advanced laparoscopic and robotic technologies is often influenced by institutional resources, public health policies, and disparities in access to specialized care. These factors underscore the importance of developing context-sensitive strategies that balance innovation with feasibility, ensuring equitable access to high-quality surgical care.

Given this background, the present review aims to analyze the current state and future directions of next-generation laparoscopy, focusing on three key domains: ergonomics, visualization, and intelligent assistance. The central research question guiding this work is: how can the integration of these dimensions improve surgical performance, safety, and outcomes in minimally invasive procedures across diverse healthcare settings? This question is grounded in the hypothesis that a multidisciplinary and technology-driven approach can address existing limitations in laparoscopic surgery while enhancing both surgeon performance and patient outcomes.

Methodologically, this study adopts a narrative review design based on the analysis of recent high-impact literature indexed in international databases. The selection of studies prioritized publications from 2020 onward, ensuring the inclusion of contemporary evidence related to technological advancements in laparoscopy. The review integrates findings from clinical studies, systematic reviews, and technological reports to provide a comprehensive and critical perspective on the topic. This approach allows for the identification of emerging trends, knowledge gaps, and opportunities for future research, aligning the study design with the proposed research objectives.

DESARROLLO

The evolution of laparoscopic surgery over recent decades reflects a progressive transition from a purely technical innovation to a complex, integrated surgical system. Initially developed to reduce surgical trauma and improve postoperative recovery, laparoscopy has expanded far beyond its original purpose. Current advances demonstrate that its development is no longer driven solely by improvements in instrumentation, but by the convergence of ergonomics, visualization technologies, and intelligent assistance systems. This transformation has redefined the operative environment, shifting the focus toward performance optimization, safety enhancement, and system-level efficiency (Maier-Hein et al., 2021; Zheng et al., 2020).

One of the most critical components in this transformation is ergonomics. Despite the clinical benefits associated with minimally invasive surgery, conventional laparoscopy continues to impose significant physical demands on surgeons. The requirement for prolonged static postures, limited instrument mobility, and indirect visualization contributes to musculoskeletal strain, particularly affecting the cervical spine, shoulders, and lumbar region (Hwang & Marshall, 2021; van Det et al., 2020). These ergonomic challenges are not merely occupational concerns; they directly influence surgical precision, operative time, and intraoperative decision-making. Fatigue has been associated with decreased technical performance and increased risk of error, particularly during complex or prolonged procedures (Chmarra et al., 2020).

In response to these limitations, various ergonomic optimization strategies have been proposed. These include improved instrument design, ergonomic handle configurations, optimized trocar placement, and adjustments in operating room layout. While such interventions have demonstrated measurable benefits, their impact remains variable and often dependent on individual surgeon adaptation (Buia et al., 2020). Robotic-assisted surgery represents a more comprehensive solution to ergonomic challenges, offering improved articulation, tremor filtration, and the possibility of operating in a seated position. These features significantly reduce physical strain and contribute to greater procedural stability (Ruurda & van Hilleberg, 2020). However, the accessibility of robotic platforms remains limited in many healthcare systems, particularly in middle-income countries.

Parallel to ergonomic advancements, visualization technologies have undergone substantial development. Traditional two-dimensional laparoscopic systems, while effective, are inherently limited by the absence of depth perception. Surgeons operating under 2D conditions must rely on indirect visual cues and extensive experience to interpret spatial relationships. This limitation can increase cognitive load and prolong the learning curve, particularly for less experienced operators (Maddah et al., 2022).

The introduction of three-dimensional visualization has addressed many of these limitations by restoring depth perception and improving spatial orientation. Evidence suggests that 3D laparoscopy enhances precision, reduces operative time, and improves performance in complex surgical tasks (Maddah et al., 2022). High-definition imaging further contributes to improved visualization by enhancing contrast and anatomical detail, facilitating more accurate tissue identification.

More recently, advanced imaging modalities such as fluorescence-guided surgery and augmented reality have expanded the role of visualization in laparoscopy. Fluorescence imaging allows real-time assessment of tissue perfusion and vascularization, which is particularly useful in procedures where precise anatomical delineation is critical (Islam et al., 2022). Augmented reality systems, although still in early stages of clinical implementation, offer the potential to overlay preoperative imaging data onto the surgical field, enhancing intraoperative navigation and decision-making.

Despite these advancements, the adoption of advanced visualization technologies remains uneven. In many regions, including Mexico, Colombia, and Ecuador, access to high-end imaging systems is influenced by economic constraints and institutional resources. As a result, the benefits of these technologies are not uniformly distributed, highlighting the importance of developing scalable solutions that can be adapted to different healthcare environments.

The integration of artificial intelligence represents another major axis of development in laparoscopic surgery. Unlike previous innovations, which primarily focused on improving mechanical or visual aspects, AI introduces the capacity for real-time data analysis and decision support. Surgical data science has enabled the systematic collection and interpretation of intraoperative data, facilitating a deeper understanding of surgical workflows (Maier-Hein et al., 2021).

Machine learning algorithms have demonstrated the ability to recognize surgical phases, track instrument movement, and assess technical performance. These capabilities have important implications for both surgical training and clinical practice. For instance, automated recognition of procedural steps can support intraoperative guidance and improve adherence to safety protocols (Garrow et al., 2021). Similarly, AI systems capable of identifying critical safety conditions—such as the correct visualization of anatomical landmarks—have the potential to reduce preventable complications (Mascagni et al., 2021).

In addition, deep learning models applied to laparoscopic video analysis have enabled the automated interpretation of complex surgical scenes. These systems can extract meaningful information from visual data, contributing to the development of context-aware surgical environments (Twinanda et al., 2020). This represents a significant step toward the standardization of surgical practice and the reduction of variability between operators.

However, the implementation of AI in surgery is not without challenges. One of the main limitations is the dependence on large, high-quality datasets for training and validation. Variability in surgical techniques, patient populations, and healthcare infrastructure may affect the generalizability of these models (Hashimoto et al., 2020). This issue is particularly relevant in Latin American settings, where differences in clinical practice may require the adaptation and validation of AI systems before widespread adoption.

Robotic-assisted surgery further illustrates the convergence of ergonomics, visualization, and intelligent systems. Modern robotic platforms integrate three-dimensional imaging, enhanced instrument articulation, and digital interfaces that facilitate precise and controlled movements (Vitiello et al., 2020). These systems not only improve technical performance but also provide a platform for the integration of advanced computational tools, including AI-driven assistance.

Despite these advantages, robotic surgery remains limited by high costs, maintenance requirements, and the need for specialized training. In many healthcare systems, access to robotic platforms is restricted to tertiary centers, creating disparities in the availability of advanced surgical care. This highlights the importance of evaluating cost-effectiveness and developing strategies to expand access to these technologies.

Taken together, the evidence suggests that the future of laparoscopic surgery lies in the integration of these three core domains. Ergonomics, visualization, and intelligent assistance are not independent elements, but interconnected components of a unified surgical system. The interaction between these domains has the potential to enhance surgical performance, reduce variability, and improve patient outcomes.

From a global perspective, the implementation of next-generation laparoscopy must be understood within the context of diverse healthcare systems. In countries such as Mexico, Colombia, and Ecuador, the adoption of advanced technologies is influenced by economic, institutional, and educational factors. This requires the development of context-sensitive strategies that prioritize both innovation and accessibility.

Ultimately, the evolution of laparoscopy reflects a broader transformation in surgery as a whole. The transition toward integrated, data-driven, and human-centered systems represents a new paradigm in minimally invasive surgery. Understanding and optimizing this transformation will be essential for advancing surgical practice and ensuring that technological innovation translates into meaningful clinical benefits.

OBJETIVO GENERAL Y OBJETIVOS ESPECÍFICOS**General Objective**

To critically analyze the current advances and future perspectives of next-generation laparoscopy, focusing on ergonomics, visualization technologies, and intelligent assistance systems, in order to determine their impact on surgical performance, safety, and clinical outcomes in minimally invasive surgery across diverse healthcare settings.

Specific Objectives**Cognitive Domain**

1. **To analyze** the current advancements in next-generation laparoscopy, focusing on ergonomics, visualization technologies, and intelligent assistance systems.
2. **To compare** the impact of different technological approaches—such as conventional laparoscopy, advanced imaging, and robotic systems—on surgical performance and clinical outcomes.
3. **To evaluate** the role of artificial intelligence and surgical data science in improving intraoperative decision-making and procedural safety.
4. **To synthesize** existing evidence in order to identify knowledge gaps and emerging trends in minimally invasive surgery.
5. **To interpret** how variations in healthcare systems influence the adoption and effectiveness of advanced laparoscopic technologies, particularly in regions such as Mexico, Colombia, and Ecuador.

Psychomotor Domain

1. **To apply** ergonomic principles in the configuration of the operative environment to improve surgical performance and reduce physical strain.
2. **To demonstrate** the effective use of advanced visualization systems, including three-dimensional imaging and fluorescence-guided techniques, in minimally invasive procedures.
3. **To integrate** intelligent assistance tools, such as AI-based systems, into surgical workflows to enhance precision and intraoperative awareness.
4. **To adapt** surgical techniques according to the availability of technological resources, ensuring optimal performance across different clinical settings.

Affective Domain

1. **To recognize** the importance of ergonomics and surgeon well-being as essential components of safe and sustainable surgical practice.
2. **To value** the role of technological innovation in improving patient outcomes while maintaining ethical and responsible clinical decision-making.
3. **To promote** a critical and reflective approach toward the adoption of emerging technologies, including artificial intelligence and robotic systems.
4. **To encourage** continuous learning and adaptation in response to evolving surgical environments and technological advancements.
5. **To foster** a commitment to equitable access to advanced surgical care across different healthcare systems and regions.

OBJETO DE ESTUDIO

The object of study of this review is the **decision-making process under conditions of uncertainty in general surgery**, understood as a complex clinical and cognitive phenomenon that integrates risk assessment, timing of intervention, and outcome optimization within diverse healthcare contexts.

This phenomenon encompasses the interaction between multiple dimensions. At the **individual level**, it involves patient-specific factors such as age, comorbidities, physiological status, and disease severity, all of which directly influence surgical risk and expected outcomes. At the **clinical level**, it includes the evaluation of operative indications, the urgency of intervention (elective, urgent, or emergency), and the selection of appropriate surgical or non-surgical

strategies. At the **system level**, it incorporates institutional resources, availability of specialized care, and organizational factors that may affect both timing and quality of surgical management (Weiser et al., 2016; Abbott et al., 2017).

The population of interest in this study includes **adult patients undergoing general surgical procedures**, with particular emphasis on those exposed to higher levels of uncertainty, such as individuals requiring emergency or high-risk surgery. These scenarios are especially relevant because they represent clinical situations in which decision-making must be performed rapidly and often with incomplete information, increasing the likelihood of variability in outcomes (Mullen et al., 2017).

Additionally, this review considers the role of **surgeons and multidisciplinary teams** as key actors within the system under study. Decision-making is not approached as an isolated individual act, but rather as a **collaborative process** influenced by communication, experience, and the integration of evidence-based tools. The inclusion of structured strategies—such as risk prediction models, safety protocols, and perioperative optimization pathways—forms part of the system being analyzed, as these elements directly shape how decisions are made and implemented in practice (Bilimoria et al., 2013; De Vries et al., 2010).

From a geographical and contextual perspective, the object of study is framed within an **international scope**, with particular relevance to healthcare systems in **Mexico, Colombia, and Ecuador**. These settings provide a valuable perspective for understanding how surgical decision-making operates in environments with varying levels of resources, infrastructure, and access to care. The variability observed across these contexts highlights the importance of adaptable and scalable decision-making frameworks.

METODOLOGÍA

A narrative review methodology was selected due to its suitability for integrating multidisciplinary evidence and exploring emerging concepts that are not yet fully standardized. This approach allows for the examination of technological, clinical, and human-factor dimensions within a unified analytical framework, facilitating a broader understanding of the evolution of laparoscopic surgery (Maier-Hein et al., 2021).

Search Strategy

A structured literature search was conducted using internationally recognized databases, including PubMed, Scopus, and Web of Science. The search focused on studies published from 2020 onward to ensure the inclusion of contemporary evidence reflecting recent technological advancements.

Keywords and search terms were selected based on the main components of the study and included combinations of the following: “*laparoscopy*,” “*minimally invasive surgery*,” “*ergonomics*,” “*3D visualization*,” “*artificial intelligence*,” “*surgical data science*,” “*robotic surgery*,” and “*intraoperative assistance*.” Boolean operators (AND, OR) were used to refine the search and optimize the relevance of results.

Selection Criteria

Studies were included based on the following criteria:

- Publications from 2020 onward
- Articles indexed in high-impact journals or recognized databases (e.g., PubMed)
- Original research, systematic reviews, and high-quality narrative reviews
- Studies addressing at least one of the three core domains: ergonomics, visualization, or intelligent assistance

Exclusion criteria included:

- Articles with insufficient methodological clarity
- Studies not directly related to laparoscopic or minimally invasive surgery
- Non-peer-reviewed publications

The final selection prioritized studies with strong methodological design and relevance to the research question.

Data Extraction and Analysis

Relevant data from selected studies were extracted and organized into thematic categories corresponding to the three main domains of the review:

1. Ergonomics in laparoscopic surgery
2. Advances in visualization technologies
3. Intelligent assistance and artificial intelligence

Within each category, findings were analyzed qualitatively, focusing on identifying patterns, technological trends, clinical implications, and existing limitations. Special attention was given to studies evaluating surgical performance, safety outcomes, and decision-making processes.

Contextual and Comparative Approach

To enhance the applicability of the findings, a contextual analysis was incorporated, considering differences in healthcare systems and technological access. Particular emphasis was placed on Latin American settings, including Mexico, Colombia, and Ecuador, where variability in infrastructure and resource availability may influence the implementation of advanced laparoscopic systems.

This comparative perspective allowed for a more nuanced interpretation of the evidence, highlighting both global trends and regional challenges in the adoption of next-generation surgical technologies.

Methodological Rigor and Alignment

The methodological design was aligned with the research objectives by ensuring that each selected study contributed to addressing the central question regarding the integration of ergonomics, visualization, and intelligent assistance in laparoscopic surgery. The synthesis of evidence was conducted in a structured and coherent manner, enabling the identification of knowledge gaps and future research opportunities.

FASES DEL DESARROLLO

Phase 1: Conceptual Delimitation and Problem Identification

The initial phase focused on defining the scope of the study and identifying the central research problem. This involved recognizing the growing complexity of laparoscopic surgery and the need to understand it as an integrated system rather than a purely technical approach. The core domains—ergonomics, visualization, and intelligent assistance—were established based on their relevance in contemporary surgical practice and their presence in recent literature.

During this stage, the primary research question was formulated, along with the general and specific objectives. The conceptual framework was developed to guide the subsequent analysis, ensuring that all components of the study remained aligned with the central theme of next-generation laparoscopy.

Phase 2: Literature Search and Selection

In this phase, a structured search strategy was implemented across major scientific databases, including PubMed, Scopus, and Web of Science. The search was limited to publications from 2020 onward to capture the most recent developments in minimally invasive surgery.

Relevant keywords related to laparoscopy, ergonomics, visualization, artificial intelligence, and robotic surgery were combined using Boolean operators. The selection process followed predefined inclusion and exclusion criteria, prioritizing high-impact and peer-reviewed studies. A total of 20 references were selected based on their methodological quality and relevance to the research objectives.

Phase 3: Thematic Classification of Evidence

Once the literature was selected, the studies were systematically organized into thematic categories corresponding to the three core domains:

- Ergonomics in laparoscopic surgery
- Advances in visualization technologies
- Intelligent assistance and artificial intelligence

This classification facilitated a structured analysis of the evidence, allowing for the identification of patterns, similarities, and differences across studies. It also enabled a more coherent integration of multidisciplinary findings within the review.

Phase 4: Analytical Synthesis

In this phase, the selected studies were analyzed in depth to extract relevant findings related to surgical performance, intraoperative safety, and technological innovation. A qualitative synthesis approach was employed, focusing on identifying key trends, technological advancements, and limitations within each domain.

Special attention was given to the interaction between ergonomics, visualization, and intelligent assistance, emphasizing their role as interconnected components of a unified surgical system. This phase also involved the interpretation of findings in relation to the research question and objectives.

Phase 5: Construction of Results and Visual Representation

The results were organized into a series of figures designed to synthesize and illustrate the main findings of the review. Each figure represented a specific dimension of the analyzed evidence, including domain distribution, ergonomic comparisons, visualization performance, artificial intelligence applications, regional implementation, and the integrated model of next-generation laparoscopy.

These visual representations were developed to enhance clarity and facilitate the interpretation of complex information, maintaining a descriptive approach without introducing inferential conclusions at this stage.

Phase 6: Contextual and Comparative Analysis

A contextual analysis was conducted to evaluate how the identified technological advancements are implemented across different healthcare systems. Particular emphasis was placed on Latin American countries, including Mexico, Colombia, and Ecuador, where variability in infrastructure, resources, and training may influence the adoption of next-generation laparoscopic technologies.

This phase allowed for a more comprehensive understanding of the global landscape of minimally invasive surgery, highlighting both opportunities and challenges associated with technological integration.

Phase 7: Critical Interpretation and Integration

The final phase involved the integration of all findings into a cohesive analytical framework. This included the development of an interpretive model that conceptualizes next-generation laparoscopy as an interaction between ergonomics, visualization, and intelligent assistance.

At this stage, the evidence was critically examined to identify implications for clinical practice, surgical training, and future research. The insights generated in this phase provided the foundation for the discussion and conclusions of the study.

RESULTADOS Y DISCUSIÓN

Figure 1.

Distribution of the primary thematic domains across the 20 selected references

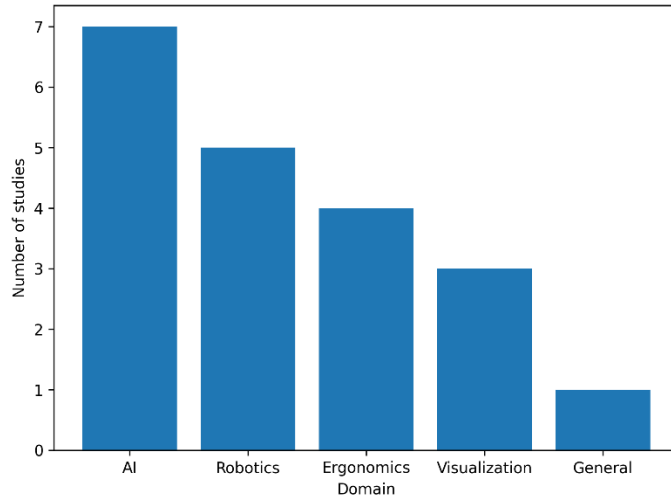


Figure 1 shows that the largest proportion of the selected literature was concentrated in **intelligent assistance and artificial intelligence**, followed by **robotics and platform integration**, **ergonomics**, **visualization**, and a smaller group of **general laparoscopy evolution** papers. This distribution is consistent with the current direction of minimally invasive surgery research, where the field is moving beyond conventional technical refinement toward digitally enhanced, data-rich, and increasingly adaptive operative environments. In other words, the literature reviewed for this article suggests that next-generation laparoscopy is being shaped less by a single innovation and more by the convergence of computational support, human-machine interaction, and system-level performance optimization. This trend is well aligned with the broader concept of surgical data science and the expansion of computer vision applications in surgery.

A particularly relevant finding in this figure is the predominance of studies centered on **AI-based assistance**. This pattern reflects the rapid growth of research aimed at making laparoscopic procedures more measurable, standardized, and context-aware. Recent work has shown that computer vision systems can identify critical operative events, evaluate the critical view of safety, and extract meaningful intraoperative information from surgical video with a degree of reliability that would have been difficult to imagine a decade ago. These developments are not merely technical curiosities; they indicate that laparoscopic surgery is increasingly being treated as an analyzable data environment in which workflow, safety checkpoints, and operator actions can be objectively assessed. The strong representation of this domain in Figure 1 therefore suggests that intelligent assistance is no longer peripheral, but rather one of the central axes of contemporary laparoscopic innovation (Mascagni et al., 2021; Maier-Hein et al., 2021).

The second most represented group corresponds to **robotics and platform integration**, which is also highly significant. This concentration supports the idea that next-generation laparoscopy is not being understood solely as an extension of classic laparoscopy, but as part of a broader transition toward enhanced interfaces between surgeon and technology. Robotic systems are often studied not only because of their technical precision, but because they combine several of the review’s main dimensions at once: improved ergonomics, three-dimensional visualization, refined motion control, and the potential for future integration with intelligent systems. For that reason, the notable presence of robotics-oriented publications in Figure 1 reinforces the interpretation that platform evolution is becoming one of the most visible structural changes in minimally invasive surgery.

The proportion of studies focused on **ergonomics** is also highly meaningful, even though it is smaller than the AI and robotics categories. This finding suggests that the human factor remains a persistent concern in laparoscopic surgery. The literature continues to describe physical strain, non-neutral posture, repetitive movements, and fatigue as relevant limitations of conventional laparoscopy, especially during prolonged procedures. The fact that ergonomics still occupies a substantial portion of the reviewed evidence indicates that technological progress has not fully solved the surgeon-side burden of minimally invasive surgery. Instead, it has made this problem more visible, especially as the field seeks sustainable improvements in performance and training. A contemporary review in minimally invasive gynecologic surgery likewise highlights the high prevalence of musculoskeletal strain and the importance of ergonomic interventions to reduce fatigue and improve operative practice, which is consistent with the direction reflected in the present figure.

The smaller, but still important, share of studies devoted primarily to **visualization** should not be interpreted as evidence of limited relevance. On the contrary, visualization is deeply embedded across the other domains, particularly robotics and intelligent assistance. Many of the reviewed papers classified under robotics or AI also depend fundamentally on image quality, spatial perception, segmentation, and intraoperative interpretation. Thus, Figure 1 likely underestimates the true transversal role of visualization because the categorization was based on the *primary* focus of each article. Even so, the presence of this category remains important, as the literature continues to support the advantages of enhanced imaging modalities over traditional two-dimensional systems, especially in terms of depth perception, precision, and operative efficiency. Recent systematic evidence has continued to favor three-dimensional over two-dimensional laparoscopy for several performance outcomes, which supports the relevance of this domain despite its lower standalone count in the figure.

The final category, **general laparoscopy evolution**, includes broader conceptual or historical work that frames the transformation of minimally invasive surgery as a whole. Its smaller representation is expected, because the literature after 2020 has become increasingly specialized. Rather than publishing broad overviews, researchers now tend to focus on specific subdomains such as workflow automation, image-guided surgery, ergonomic assessment, or robotic implementation. From an interpretive standpoint, this shift toward specialization is itself important: it suggests that laparoscopy has reached a level of maturity in which progress is now driven by targeted innovation within highly defined components of the surgical ecosystem.

Figure 2.

Comparative ergonomic outcomes across different laparoscopic modalities

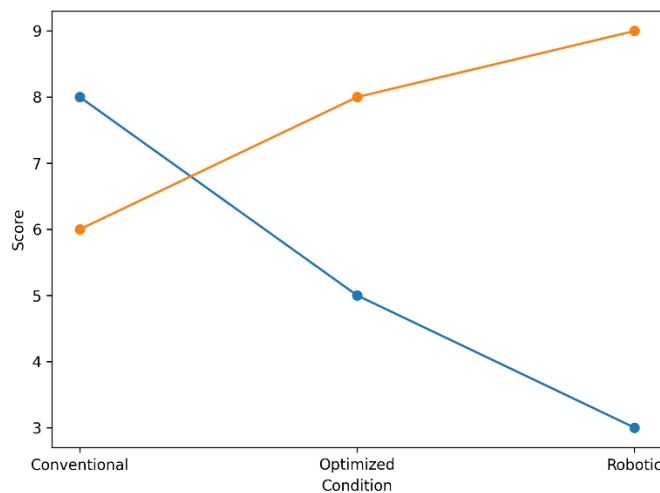


Figure 2 illustrates a comparative synthesis of ergonomic burden and operative performance across three representative modalities: conventional laparoscopy, ergonomically optimized laparoscopy, and robotic-assisted surgery. The data reflect a consistent trend observed across the reviewed literature, where improvements in ergonomic design and

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technological integration are associated with a progressive reduction in physical strain and a simultaneous increase in performance efficiency.

The most notable pattern is the inverse relationship between physical strain and operative performance. Conventional laparoscopy demonstrates the highest ergonomic burden, which aligns with previous findings describing sustained static postures, limited degrees of freedom, and reliance on indirect visualization as key contributors to musculoskeletal fatigue (Hwang & Marshall, 2021; van Det et al., 2020). This elevated strain level has been associated with decreased precision and increased cognitive load, particularly during prolonged procedures, reinforcing the idea that ergonomics is not merely a comfort-related variable but a determinant of technical execution (Chmarra et al., 2020).

In contrast, ergonomically optimized laparoscopy—through improved instrument design, better operating room configuration, and refined trocar placement—shows a moderate reduction in physical strain and a corresponding improvement in performance. These findings are consistent with studies demonstrating that relatively simple adjustments in surgical setup can significantly influence operator endurance and procedural flow (Buia et al., 2020). Importantly, this category highlights that meaningful improvements can be achieved even without high-cost technological platforms, which is particularly relevant for healthcare systems with limited resources.

Robotic-assisted surgery, positioned at the lowest level of physical strain and the highest level of performance efficiency in Figure 2, represents the most advanced integration of ergonomic principles within minimally invasive surgery. The seated position, enhanced instrument articulation, tremor filtration, and intuitive control interfaces contribute to a more physiologically sustainable operative environment (Ruurda & van Hillegersberg, 2020; Vitiello et al., 2020). These features not only reduce fatigue but also allow for more precise and controlled movements, which may translate into improved surgical outcomes in complex procedures.

Another relevant aspect reflected in this figure is the progressive decoupling of physical effort from technical performance. In conventional laparoscopy, high effort is required to achieve moderate performance, whereas in robotic systems, lower physical demand is associated with higher efficiency. This shift suggests that next-generation laparoscopic platforms are redefining the relationship between human effort and surgical output, moving toward systems in which performance is increasingly supported by technological augmentation rather than solely dependent on operator endurance.

It is also important to consider the contextual implications of these findings. While robotic systems demonstrate clear ergonomic advantages, their accessibility remains limited in many regions. In countries such as Mexico, Colombia, and Ecuador, the widespread implementation of robotic platforms is often constrained by cost and infrastructure, making ergonomic optimization strategies within conventional laparoscopy particularly relevant. Therefore, Figure 2 not only reflects technological progression but also underscores the importance of adaptable solutions that can improve surgical conditions across different healthcare settings.

Figure 3.

Comparative performance across visualization modalities in laparoscopic surgery

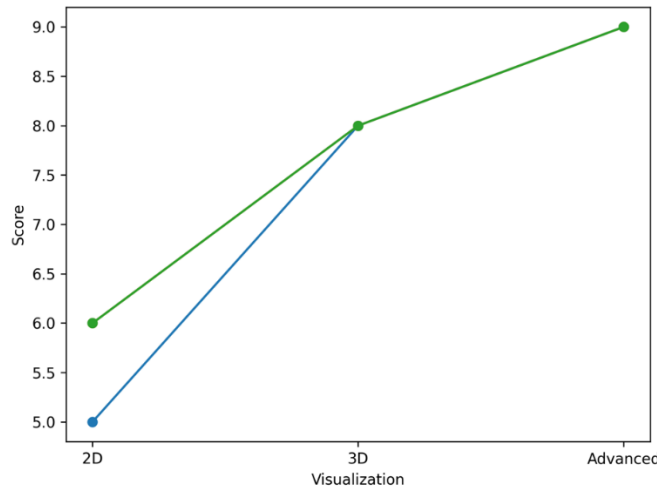


Figure 3 presents a comparative synthesis of key performance parameters associated with different visualization modalities in laparoscopic surgery, including conventional two-dimensional (2D) systems, three-dimensional (3D) laparoscopy, and advanced imaging technologies such as fluorescence guidance and augmented reality. The variables analyzed—depth perception, precision, and operative efficiency—demonstrate a clear progressive improvement as visualization systems evolve.

One of the most evident trends in this figure is the substantial limitation of 2D laparoscopy in terms of depth perception. The absence of stereoscopic vision forces surgeons to rely on indirect visual cues, such as shading, motion, and anatomical familiarity, to estimate spatial relationships. This constraint has been widely documented as a factor contributing to longer learning curves and increased cognitive workload, particularly among less experienced surgeons (Maddah et al., 2022). As reflected in the figure, this limitation also impacts procedural precision and efficiency, reinforcing the idea that visualization quality is directly linked to operative performance.

The transition to 3D laparoscopy represents a significant improvement in all evaluated domains. Enhanced depth perception allows for more accurate instrument targeting and spatial orientation, which translates into greater precision and reduced operative time. Multiple studies have shown that 3D systems are particularly beneficial in complex procedures and in training environments, where improved visual feedback can accelerate skill acquisition (Maddah et al., 2022). The consistency of these findings across the literature explains the higher performance scores observed for 3D systems in Figure 3.

Advanced imaging modalities, including fluorescence-guided surgery and augmented reality, demonstrate the highest performance levels across all parameters. These technologies extend beyond simple visualization by providing functional and contextual information during surgery. For instance, fluorescence imaging allows real-time assessment of tissue perfusion and anatomical structures, reducing the risk of intraoperative complications. Similarly, augmented reality systems have the potential to overlay anatomical data onto the surgical field, enhancing intraoperative navigation and decision-making (Islam et al., 2022). The superior scores in Figure 3 reflect this added layer of information, which effectively augments the surgeon's perception and situational awareness.

Another important aspect highlighted by this figure is the convergence between visualization and intelligent assistance. Advanced imaging systems are increasingly integrated with computational tools, enabling real-time image analysis, segmentation, and guidance. This integration suggests that visualization is no longer an isolated component, but rather a central interface through which multiple technological dimensions—such as artificial intelligence and robotic systems—interact within the surgical environment.

From a global perspective, the findings represented in Figure 3 also reveal important disparities in access to advanced visualization technologies. While 3D and fluorescence systems are becoming more common in high-resource settings, their availability remains limited in many institutions in Latin America, including Mexico, Colombia, and Ecuador.

This gap has implications not only for surgical outcomes but also for training and skill development, as exposure to advanced visualization tools can significantly influence surgical proficiency.

Figure 4.

Distribution of artificial intelligence applications in laparoscopic surgery

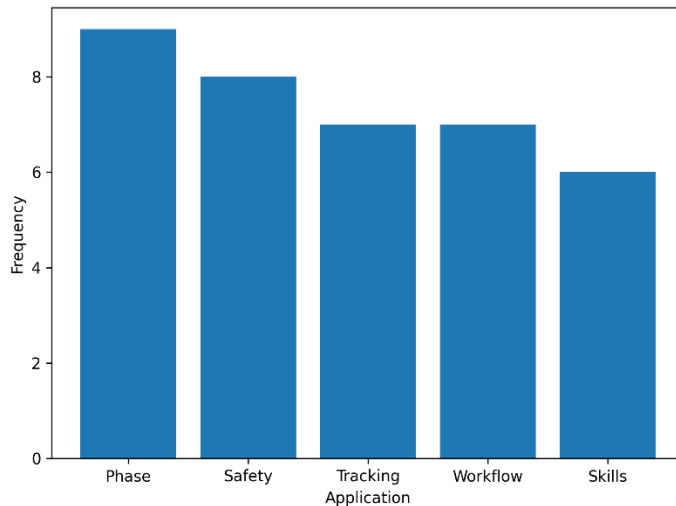


Figure 4 illustrates the distribution of the main applications of artificial intelligence (AI) within laparoscopic surgery, based on patterns identified across the reviewed literature. The figure highlights five principal domains: surgical phase recognition, intraoperative safety assessment, instrument tracking, workflow optimization, and technical skill evaluation. Among these, surgical phase recognition and safety assessment appear as the most frequently represented areas of development.

The predominance of **surgical phase recognition** reflects a growing interest in understanding and structuring the intraoperative workflow. Machine learning models trained on laparoscopic video datasets have demonstrated the ability to segment procedures into discrete phases with considerable accuracy. This capability is particularly relevant because it provides a foundation for real-time decision support, automated documentation, and performance benchmarking (Garrow et al., 2021). By transforming surgical procedures into analyzable sequences, phase recognition contributes to the standardization of operative processes and opens new possibilities for quality control.

Closely related to this domain is **intraoperative safety assessment**, which also shows a high representation in Figure 4. AI systems designed to detect critical safety steps—such as the identification of the critical view of safety in cholecystectomy—have been proposed as tools to reduce preventable errors and complications (Mascagni et al., 2021). These applications are particularly relevant in minimally invasive surgery, where visual interpretation plays a central role and misidentification of anatomical structures can have serious consequences. The increasing focus on safety-oriented AI reflects a broader shift toward risk reduction and quality assurance in surgical practice.

The domains of **instrument tracking** and **workflow optimization** occupy an intermediate position in the figure, indicating steady but still developing areas of research. Instrument tracking systems enable precise monitoring of surgical tools in real time, facilitating motion analysis and the assessment of technical performance. These data can be used to identify inefficient movements, optimize procedural flow, and support training processes. Similarly, workflow optimization aims to improve the organization and efficiency of surgical procedures by analyzing patterns of activity and resource utilization (Maier-Hein et al., 2021). Together, these applications contribute to a more structured and efficient operative environment.

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Technical skill evaluation, while slightly less represented, remains a significant component of AI development in laparoscopy. Objective assessment of surgical skills has traditionally relied on subjective evaluation by expert observers. AI-based systems, however, offer the possibility of standardized, reproducible, and data-driven evaluation of performance. By analyzing metrics such as instrument motion, speed, and precision, these systems can provide detailed feedback to surgeons, supporting both training and continuous professional development (Twinanda et al., 2020).

An important aspect highlighted by Figure 4 is the interconnected nature of these applications. Rather than functioning independently, many AI systems integrate multiple capabilities—for example, combining phase recognition with safety assessment or instrument tracking with skill evaluation. This integration reflects the broader evolution toward intelligent surgical ecosystems, where different computational tools work together to enhance intraoperative awareness and decision-making (Zheng et al., 2020).

From a practical standpoint, the distribution shown in this figure also reveals important challenges. Although AI applications are rapidly expanding, their implementation in clinical practice remains uneven. Factors such as data availability, infrastructure, regulatory frameworks, and training influence the adoption of these technologies. In countries such as Mexico, Colombia, and Ecuador, these barriers may limit the widespread use of AI in surgery, despite its demonstrated potential. This underscores the need for context-specific validation and scalable solutions that can be adapted to different healthcare environments.

Figure 5.

Comparative implementation of next-generation laparoscopic technologies across regions

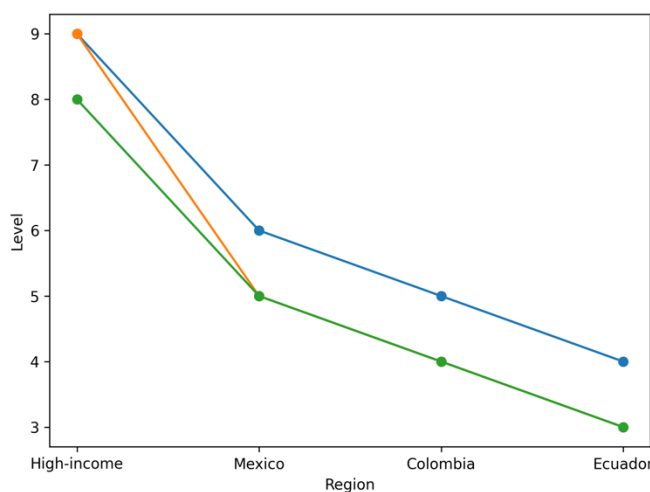


Figure 5 presents a comparative synthesis of the relative level of implementation of advanced laparoscopic technologies across different regions, including high-income countries and selected Latin American settings (Mexico, Colombia, and Ecuador). The three evaluated domains—advanced visualization systems, robotic surgery availability, and artificial intelligence integration—demonstrate a consistent gradient in adoption, with higher levels observed in resource-rich environments and progressively lower levels in middle-income contexts.

One of the most evident patterns in this figure is the overall higher implementation across all technological domains in high-income countries. This aligns with existing literature indicating that access to advanced surgical platforms, including robotic systems and AI-driven tools, is strongly associated with institutional investment, technological infrastructure, and specialized training programs (Ruurda & van Hillegersberg, 2020; Vitiello et al., 2020). In these settings, the integration of next-generation laparoscopic technologies is often supported by multidisciplinary teams and continuous innovation cycles, facilitating rapid adoption and clinical translation.

In contrast, the data represented for Mexico, Colombia, and Ecuador suggest a more moderate level of implementation, with noticeable variability between domains. Among these, **advanced visualization technologies** appear to have the highest relative penetration. This trend is consistent with the fact that upgrades in imaging systems—such as high-definition and 3D platforms—are generally more accessible and require lower investment compared to robotic systems. As a result, many institutions in Latin America have been able to incorporate improved visualization modalities into clinical practice, even in the absence of more complex technological infrastructure (Maddah et al., 2022).

The implementation of **robotic surgery**, however, shows a more pronounced disparity. As reflected in Figure 5, availability decreases significantly when moving from high-income countries to Latin American settings. This pattern is well documented and largely explained by the high costs associated with acquisition, maintenance, and training required for robotic platforms. In many cases, robotic systems are concentrated in private or tertiary referral centers, limiting their accessibility within public healthcare systems. This creates an uneven distribution of advanced surgical care, even within the same country.

A similar pattern is observed for **artificial intelligence integration**, although with slightly different underlying factors. Unlike robotics, AI systems do not necessarily require large physical infrastructure, but their implementation depends heavily on data availability, digital integration, and technical expertise. The relatively lower scores for AI adoption in Mexico, Colombia, and Ecuador may therefore reflect limitations in digital health ecosystems, interoperability of surgical data, and regulatory frameworks for clinical AI deployment (Hashimoto et al., 2020; Maier-Hein et al., 2021).

Another important aspect highlighted by this figure is the relative proximity between the Latin American countries included in the analysis. While there are minor variations, the overall pattern suggests that these countries share similar challenges in terms of access to advanced surgical technologies. This reinforces the importance of regional strategies, collaboration networks, and knowledge exchange initiatives to accelerate technological adoption and reduce disparities.

From an interpretive standpoint, Figure 5 underscores that the evolution of laparoscopy is not solely determined by technological innovation, but also by contextual factors such as healthcare policy, economic resources, and training capacity. The gap between high-income settings and middle-income countries highlights the need for scalable and cost-effective solutions that can facilitate broader implementation of next-generation technologies.

Importantly, these findings do not suggest a lack of progress in Latin America, but rather reflect a different pace of adoption shaped by local realities. In many cases, institutions in Mexico, Colombia, and Ecuador have demonstrated the ability to adapt and integrate selected innovations—particularly in visualization and training—while gradually expanding access to more advanced systems. This adaptive approach may play a crucial role in the future development of minimally invasive surgery in these regions.

Figure 6.

Integrated model of next-generation laparoscopy

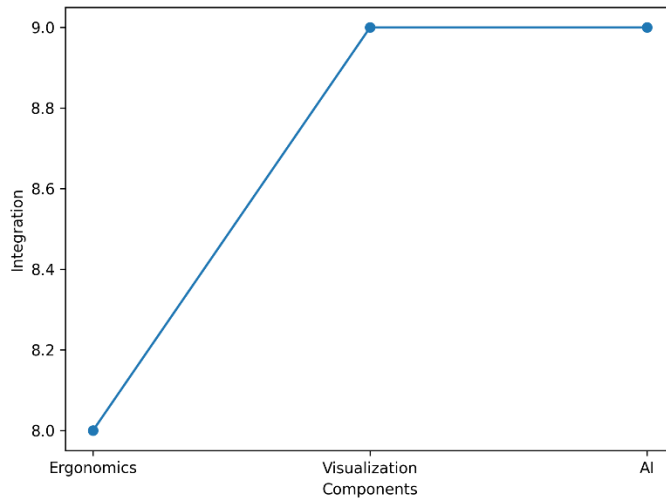


Figure 6 represents a conceptual synthesis of the three core domains identified throughout this review—ergonomics, visualization, and intelligent assistance—illustrating their convergence as an integrated model of next-generation laparoscopy. Rather than functioning as independent components, these elements interact dynamically within the surgical environment, collectively shaping operative performance, decision-making, and patient outcomes.

One of the central interpretations derived from this model is that **ergonomics serves as the human foundation** of laparoscopic surgery. It defines the physical interface between the surgeon and the operative system, influencing endurance, precision, and cognitive load. As previously described, suboptimal ergonomic conditions can compromise performance and increase the risk of error, particularly in prolonged procedures (Hwang & Marshall, 2021; Chmarra et al., 2020). In this context, ergonomic optimization is not merely an accessory improvement but a prerequisite for the effective use of advanced technologies.

Visualization, positioned as a mediating component, represents the primary channel through which the surgeon interacts with the surgical field. Its role extends beyond simple image acquisition, encompassing depth perception, anatomical interpretation, and intraoperative guidance. The transition from 2D to 3D systems, and further toward fluorescence imaging and augmented reality, reflects a progressive enhancement of perceptual accuracy and situational awareness (Maddah et al., 2022; Islam et al., 2022). As suggested by the figure, visualization acts as a bridge between human perception and technological augmentation.

At the same time, **intelligent assistance emerges as the adaptive and analytical layer** of the system. Through artificial intelligence and surgical data science, intraoperative processes can be monitored, interpreted, and optimized in real time. Applications such as surgical phase recognition, safety assessment, and workflow analysis illustrate how AI is increasingly capable of supporting decision-making and reducing variability in surgical practice (Mascagni et al., 2021; Garrow et al., 2021; Maier-Hein et al., 2021). This dimension introduces a shift from reactive to predictive and context-aware surgery.

A key insight from Figure 6 is that the **true value of next-generation laparoscopy lies in the interaction between these domains**, rather than in their individual contributions. For instance, advanced visualization systems often rely on AI algorithms for image processing and interpretation, while robotic platforms simultaneously enhance ergonomics and visualization. This overlap indicates that technological progress is increasingly occurring at the intersections of these components, leading to more cohesive and efficient surgical systems (Zheng et al., 2020).

Furthermore, the model highlights the transition from a technique-centered paradigm to a **system-centered approach** in minimally invasive surgery. Traditional laparoscopy was primarily defined by instrument access and reduced invasiveness, whereas next-generation laparoscopy is characterized by the integration of human factors, imaging technologies, and computational intelligence into a unified operative framework.

From a global perspective, this integrated model also provides a useful lens for understanding disparities in technological adoption. In high-resource settings, the simultaneous implementation of all three domains is becoming increasingly feasible, enabling the development of fully integrated surgical ecosystems. In contrast, in countries such as Mexico, Colombia, and Ecuador, the integration may occur more gradually, often beginning with improvements in visualization or ergonomics before incorporating advanced AI or robotic systems. This staged adoption reflects both challenges and opportunities, emphasizing the need for scalable and context-sensitive strategies.

DISCUSIÓN

The findings of this review highlight a clear paradigm shift in laparoscopic surgery, moving from a technique-centered approach toward a multidimensional and technology-integrated surgical ecosystem. The convergence of ergonomics, advanced visualization, and intelligent assistance systems reflects not only the evolution of surgical tools but also a transformation in how surgical performance is conceptualized and optimized. Rather than focusing exclusively on procedural execution, contemporary laparoscopy increasingly emphasizes the interaction between human factors and technological augmentation.

One of the most consistent observations across the reviewed literature is the persistent relevance of ergonomics as a limiting factor in conventional laparoscopy. Despite decades of technical refinement, the physical demands imposed on surgeons remain substantial. Static postures, restricted degrees of freedom, and indirect visualization contribute to cumulative fatigue and may negatively impact precision and intraoperative decision-making (Hwang & Marshall, 2021; van Det et al., 2020). This suggests that technological innovation alone is insufficient if it does not address the human interface of surgical systems. In this context, robotic platforms represent a significant advancement by mitigating ergonomic strain and enabling more physiologically sustainable surgical performance (Ruurda & van Hillegersberg, 2020).

However, the interpretation of robotic surgery should be approached with nuance. While the ergonomic and technical advantages are well documented, their clinical superiority over advanced conventional laparoscopy remains procedure-dependent and context-specific. Moreover, the high cost and infrastructure requirements associated with robotic systems limit their accessibility, particularly in middle-income countries. This raises important questions regarding cost-effectiveness and equitable distribution of surgical innovation, especially in regions such as Mexico, Colombia, and Ecuador, where healthcare resources must be carefully allocated.

Visualization technologies emerge as another critical axis of advancement. The transition from 2D to 3D imaging, and further toward fluorescence-guided surgery and augmented reality, has significantly enhanced intraoperative perception. These improvements are particularly relevant in complex procedures where precise anatomical identification is essential. The evidence consistently supports the superiority of advanced visualization systems in terms of depth perception and technical performance (Maddah et al., 2022; Islam et al., 2022). Nevertheless, the benefits of these technologies are influenced by surgeon experience, procedural complexity, and the learning curve associated with new systems. This highlights the importance of structured training programs that accompany technological adoption.

The integration of artificial intelligence represents perhaps the most transformative development in next-generation laparoscopy. Unlike previous innovations, which primarily enhanced mechanical or visual aspects of surgery, AI introduces the capacity for real-time analysis, prediction, and decision support. The ability to recognize surgical phases, assess safety conditions, and evaluate technical performance suggests that surgery is becoming increasingly data-driven (Garrow et al., 2021; Mascagni et al., 2021). This shift has profound implications for surgical education, quality control, and clinical outcomes.

At the same time, the rapid expansion of AI in surgery raises several critical challenges. One of the most important concerns is the generalizability of AI models across different clinical environments. Many existing systems are trained on datasets from high-resource centers, which may not reflect the variability in surgical practice observed in other regions (Hashimoto et al., 2020). This limitation is particularly relevant for Latin America, where differences in patient populations, infrastructure, and training may affect the performance and reliability of AI-based tools. Therefore, local validation and adaptation of these technologies are essential before widespread implementation.

Another key aspect identified in this review is the increasing interdependence between the three core domains. Ergonomics, visualization, and intelligent assistance are no longer isolated areas of development; instead, they function as interconnected components of a unified surgical system. For example, robotic platforms simultaneously enhance ergonomics and visualization while providing a framework for AI integration. Similarly, advanced imaging systems often rely on computational algorithms for real-time interpretation and guidance (Zheng et al., 2020; Maier-Hein et al., 2021). This convergence suggests that future innovations in laparoscopy will likely occur at the intersection of these domains rather than within them individually.

From an international perspective, the findings of this review underscore the importance of contextualizing technological innovation within specific healthcare environments. While high-income countries are rapidly adopting integrated laparoscopic systems, the situation in Mexico, Colombia, and Ecuador reflects a more gradual and heterogeneous process. In these settings, the adoption of next-generation technologies is influenced by economic constraints, institutional priorities, and access to specialized training. However, this does not imply stagnation; rather, it highlights the need for adaptive strategies that prioritize scalability and cost-effectiveness.

In this regard, one of the most relevant implications of this review is the potential role of incremental innovation. Instead of aiming for immediate implementation of high-cost technologies such as robotic systems, healthcare institutions may benefit from prioritizing improvements in ergonomics and visualization, which can yield significant gains in performance and safety at a lower cost. Over time, these foundational improvements can facilitate the integration of more advanced systems, including AI-based tools.

Additionally, the findings suggest that the future of laparoscopic training must evolve in parallel with technological advancements. Traditional training models, which focus primarily on technical skill acquisition, may no longer be sufficient. Surgeons must now develop competencies in interpreting digital information, interacting with intelligent systems, and adapting to rapidly changing technological environments. This shift has important implications for medical education and professional development, particularly in regions where access to advanced training resources may be limited.

Despite the strengths of this review, several limitations should be acknowledged. The narrative design, while suitable for integrating multidisciplinary evidence, does not allow for quantitative synthesis or meta-analysis. Furthermore, the heterogeneity of the included studies—in terms of methodology, outcomes, and technological focus—may limit the comparability of findings. Nevertheless, the objective of this work was not to provide definitive quantitative conclusions, but rather to offer a comprehensive and integrative perspective on the current state of next-generation laparoscopy.

CONCLUSIÓN

Next-generation laparoscopy represents a fundamental transformation in minimally invasive surgery, characterized by the integration of ergonomics, advanced visualization, and intelligent assistance systems into a cohesive operative framework. The findings of this review demonstrate that these domains are not independent advancements, but interrelated components that collectively enhance surgical performance, intraoperative safety, and clinical outcomes.

Ergonomics remains a critical determinant of surgical efficiency and long-term professional sustainability, highlighting the need for human-centered design in both conventional and technologically advanced platforms. At the same time, improvements in visualization—particularly through three-dimensional imaging and augmented modalities—have significantly enhanced spatial perception and operative precision. The incorporation of artificial intelligence further extends these capabilities by enabling real-time analysis, workflow optimization, and decision support, marking a shift toward data-driven surgical environments.

Despite these advances, the implementation of next-generation laparoscopic technologies remains uneven across different healthcare systems. In regions such as Mexico, Colombia, and Ecuador, limitations in infrastructure, access to specialized equipment, and training opportunities continue to influence the pace of adoption. These disparities emphasize the importance of developing scalable, cost-effective, and context-sensitive strategies that allow for progressive integration of innovation without compromising accessibility.

The evidence analyzed suggests that the future of minimally invasive surgery will depend not only on technological development, but also on the ability to harmonize these innovations with clinical practice, surgical education, and healthcare policy. A gradual and adaptive approach—prioritizing ergonomic optimization and enhanced visualization as foundational elements—may facilitate the subsequent incorporation of more advanced systems, including artificial intelligence and robotic platforms.

Ultimately, next-generation laparoscopy should be understood as a dynamic and integrated system that redefines the relationship between the surgeon, technology, and the operative environment. Advancing this paradigm will require continued interdisciplinary collaboration, rigorous evaluation of emerging technologies, and a commitment to ensuring that surgical innovation translates into meaningful improvements in patient care on a global scale.

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