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Review

Integration of New Technologies in Healthcare: Robotic Surgery and Artificial Intelligence in Cytology. Literature Review

Adrian Vega-Castro [1], Maria-Elisa Castro-Peraza [2,*], M Rosa Llabres-Sole [2], M Inmaculada Sosa-Alvarez [2] and Nieves Lorenzo-Rocha [2]

1 Member of the Capacita Program. University of La Laguna Foundation (FGULL). 38200 La Laguna, Spain; adridevega@gmail.com
2 University Hospital of the Canary Island (HUC), University of La Laguna, 38200 Santa Cruz de Tenerife, Spain; mllasol@gobiernodecanarias.org (M.R.L.-S.); isalvar@ull.edu.es (M.I.S.-A.); nlorenzr@ull.edu.es (N.L.-R.)
* Correspondence: mcastrop@ull.edu.es, Tel.: +629309198

Abstract: Healthcare is undergoing a technological transformation, particularly in robotic surgery and artificial intelligence (AI) applied to cytology. These innovations are improving the precision and efficiency of both surgical procedures and laboratory diagnostics. Robotic systems, such as the Da Vinci, enable surgeons to perform complex procedures with enhanced control and precision, leading to minimally invasive surgeries with reduced recovery times. This technology has significantly impacted urological, cardiac, and gastrointestinal surgeries, and its use is expected to grow. In cytology, AI automates the analysis of cell samples, leading to faster and more accurate diagnoses, especially in detecting diseases like cervical cancer. AI reduces errors and enhances diagnostic accuracy by identifying complex patterns in cellular images. Predictive analytics, driven by big data, also allows for personalized treatments based on patient-specific data. However, these technologies face challenges, including high costs, ethical concerns, data privacy issues, and resistance from healthcare professionals. Continuous training is essential for medical personnel to effectively adopt these tools. Furthermore, the rise of telemedicine and telesurgery, supported by advancements in 5G, offers new opportunities for remote care but also introduces risks, such as depersonalization of medical care and technological barriers. Ultimately, while robotic surgery and AI hold great promise for improving clinical outcomes, their successful integration will depend on addressing these challenges and ensuring that healthcare professionals are adequately prepared for the digital future.

Keywords: robotic surgery; cytology; healthcare; artificial intelligence; deep learning

1. Introduction

Healthcare has entered a new technological era, in which advanced tools are profoundly reshaping both surgical procedures and laboratory diagnostics. Two key areas of this transformation are robotic surgery and artificial intelligence (AI) applied to cytology, both of which exemplify how technology is increasingly permeating diverse areas such as the operating room and the pathology lab. This technological convergence allows for improvements in precision, efficiency, and clinical outcomes in areas as disparate as minimally invasive surgical interventions and cell analysis for pathology detection. In both cases, big data, advanced sensors, and artificial intelligence play a key role in clinical decision-making [1–4].

In the operating room, robotic surgery systems, such as the Da Vinci system, enable surgeons and their teams to perform complex procedures with levels of precision and control that surpass the limitations of manual surgery. This has facilitated the evolution toward minimally invasive surgeries, reducing risks and recovery times for patients [4–6]. These technologies have transformed delicate interventions such as urological, cardiac, and gastrointestinal surgeries, and their usage is expected to expand further as hospitals continue to adopt these innovations [5–7].

On the other hand, in cytology labs, the use of artificial intelligence is redefining how cell samples are analyzed. AI automates the analysis, enabling faster and more accurate diagnoses in areas such as cervical cancer, one of the primary applications of digital cytology, while reducing false positive and negative rates [2,8,9]. Furthermore, big data platforms and predictive analytics are taking these technologies to a new level by allowing personalized treatments based on the data collected about the patient. This happens in both surgery and cytology, improving clinical outcomes [10].

An added value of adopting these technologies is the more equitable distribution of healthcare, as they can reach patients in geographically dispersed or underserved areas. In this way, new technologies become a democratizing tool for access to healthcare [11].

However, the implementation of these technologies is not without ethical challenges, resistance from healthcare professionals, and difficulties in integrating them into current health systems. As robotic surgery and AI-assisted cytology become more widespread, dilemmas arise regarding data privacy, medical responsibility, and the need for continuous professional training [9,10]. Nonetheless, their potential to improve long-term clinical outcomes and optimize workflows promises to make these tools a fundamental pillar of modern healthcare. This article explores the advantages, disadvantages, and challenges of robotic surgery and artificial intelligence in cytology in detail, as well as their implications for nursing professionals and hospital management.

2. Materials and Methods

To conduct a comprehensive literature review, several databases were systematically searched, including PubMed, SciELO, Google Scholar, and CINAHL. The search strategy focused on identifying relevant studies by using the following keywords: *robotic surgery*, *cytology*, *healthcare*, *artificial intelligence*, and *deep learning*. The review was limited to articles published in English and Spanish from 2020 onwards, ensuring that the most recent advances in the field were included.

All retrieved articles were screened based on the title and abstract. Duplicates were removed, and articles that did not align with the focus of the study or were not available in full-text format were excluded from the final selection. The remaining articles were analyzed and synthesized to provide a comprehensive theoretical and contextual foundation on the current state of robotic surgery and cytology, with a focus on their integration with new technologies such as artificial intelligence.

Each selected study was carefully summarized, evaluated, and synthesized to present the key findings relevant to the application of AI and new technology systems in healthcare, particularly in cytology and robotic surgery. This methodology ensured that the literature review encompassed a wide range of perspectives, while maintaining a focus on the most recent and pertinent research.

3. Results

The results of the literature review are divided into several sections. The first is Robotic Surgery: Precision, Efficiency, and Challenges, with a special focus on advantages and disadvantages. The second is Artificial Intelligence Applied to Cytology: Automation and Early Diagnosis, also highlighting advantages and limitations. In both cases, the implications for operating room nurses and specialist technicians in pathology labs are considered. The review also addresses other relevant issues, such as Big Data and Predictive Analytics in the Personalization of Treatments, Telework in Healthcare: Flexibility and Risks, and Professional Training and Barriers to Implementation. It concludes with a future project that could have a significant impact on the quality of life for patients affected by major neurological injuries. The main results are shown in Table 1.

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3.1. Robotic Surgery: Precision, Efficiency, and Challenges

Robotic surgery has radically changed the way many surgical procedures are performed. Systems such as Da Vinci enable surgeons to carry out complex operations with a level of precision that significantly reduces the risks associated with traditional surgery [5,6]. This technology uses robotic instruments controlled by the surgeon from a console, allowing for finer and more precise movements than could be made manually. The surgeon is supported by other team members who also interact with the robot [7]. These systems allow for minimally invasive interventions, reducing hospitalization times, complications, and postoperative pain [6,7].

3.1.1. Advantages of Robotic Surgery

The advantages of robotic surgery translate into significant improvements for both patients and healthcare professionals. Greater surgical precision, i.e., the ability to perform precise movements and optimally control robotic instruments, has significantly reduced surgical complication rates [6]. Three-dimensional visualization and the use of advanced sensors provide real-time information about tissue and anatomical structures, minimizing errors during surgery [1,12]. Less invasiveness, as smaller and more precise incisions cause less damage to surrounding tissues, leading to less postoperative pain and faster recovery [5,7]. Enhanced visualization, as the system offers an enlarged three-dimensional view of the surgical area, improving the surgeon's ability to identify and avoid critical structures [7]. Optimization of surgical time: despite the time required to set up the robotic equipment, once in use, the procedure is often faster, leading to more efficient use of operating rooms [6].

In urological and gynecological procedures, such as prostatectomies and hysterectomies, robotic surgery has shown significant improvement in outcomes, reducing hospital stays and speeding up patient recovery [6,7].

3.1.2. Disadvantages and Challenges in Implementation

Despite its clear advantages, the adoption of robotic surgery faces several significant challenges. One of the main obstacles is the high initial cost: the purchase and maintenance of robotic systems are prohibitive for many hospitals, especially those with limited budgets [7,12]. Additionally, there is a steep learning curve for both surgeons and nursing staff, who must receive specialized training to handle these systems [6,7]. Resistance from personnel: Many experienced professionals are reluctant to replace traditional techniques with robotic surgery, due to the comfort and skill they have acquired over years of manual practice [6]. In fact, they may perceive these systems as complex or unnecessary [7]. To overcome these challenges, it is essential to implement continuous training programs to allow professionals to acquire the skills necessary to use these tools efficiently [6,7].

However, studies suggest that once the learning curve is overcome, robotic surgery not only improves clinical outcomes but also optimizes the long-term use of resources by reducing postoperative complications and hospital stay lengths [5,7].

3.1.3. Implications for Nursing Staff

Robotic surgery has redefined the roles of the surgical team, particularly for nurses. These professionals must acquire new skills, such as preparing and calibrating robotic systems before surgery, as well as providing technical support during the procedure [5,7]. Additionally, technical training and coordination with the surgeon are crucial, as the nursing team must be prepared to adjust or intervene in the management of the robot during surgery, especially in the event of technical issues [7]. This change in responsibilities requires constant skill updates and increased specialization within the surgical team [5,6].

3.2. Artificial Intelligence Applied to Cytology: Automation and Early Diagnosis

The application of artificial intelligence (AI) in cytology has enabled the automation of cell sample analysis, improving both the accuracy and speed of diagnosis. This advance is crucial for the

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early detection of diseases such as cervical cancer, where AI has proven to be more precise than traditional methods in identifying cellular abnormalities [2,8].

3.2.1. Benefits of AI in Cytology

The automation of cytological diagnosis through AI brings numerous advantages. One of the main benefits is the increased speed of analysis: AI algorithms can process large volumes of cytological images in a short amount of time, allowing laboratories to handle more samples with fewer personnel [8,9], thereby reducing the manual workload of cytotechnologists and speeding up response times [2,13]. AI also reduces human error: by removing dependence on the human eye, false-positive and false-negative rates are decreased, improving diagnostic accuracy [8]. Deep learning algorithms can identify complex patterns in cellular images, enhancing diagnostic precision [13]. Moreover, AI allows for predictive analysis, which can identify patients at higher risk of developing cancer or precancerous conditions, improving early detection and facilitating personalized treatment [3]. These predictive diagnoses are based on AI's ability to detect molecular and morphological patterns, which allows the identification of subtle cellular changes, facilitating the early detection of diseases [8,14].

A study on AI in cervical cytology reported a 20% improvement in the detection of precancerous lesions through the use of deep learning algorithms [8].

3.2.2. Limitations and Challenges

Despite its benefits, the implementation of AI in laboratories faces several challenges. One of these is the cost of implementation: adopting AI requires significant investment in technological infrastructure, from servers and storage systems to algorithm training [8]. Additionally, the quality of the diagnosis largely depends on the quality of the data: AI algorithms are only as effective as the data they are trained on. If the data is poor or non-representative, the results can be inaccurate or biased [9,15]. Another important challenge is the lack of specific training in the use of these digital platforms. Cytotechnologists must acquire new skills to interpret the results generated by AI systems and ensure that data is properly managed [8].

A further challenge faced by these systems is the lack of clear regulations: the use of AI in medical diagnostics raises ethical and regulatory dilemmas, particularly in relation to automated clinical decision-making and patient data privacy [9,15].

3.2.3. Implications for Laboratories and Personnel

The adoption of AI in cytology has also transformed work in pathology laboratories. Cytotechnologists must be trained not only to handle digital platforms but also to interpret the results generated by AI algorithms [8,13]. Moreover, greater collaboration between personnel is required to ensure that data is managed appropriately and diagnostic quality is maintained [8].

3.3. Big Data and Predictive Analytics in the Personalization of Treatments

The use of big data and predictive analytics is emerging as a key tool in the personalization of medical treatments. By collecting and analyzing large volumes of patient data, AI algorithms can identify predictive patterns that allow for the anticipation of disease progression and the customization of treatments based on the individual characteristics of the patient [14,15].

3.3.1. Personalization of Treatment

The analysis of clinical, genetic, and molecular data through big data enables the development of personalized treatments that are more effective and tailored to the specific needs of each patient. Instead of applying a standard approach, doctors can use detailed data to select the most effective treatments [15]. For instance, in oncology, predictive analytics helps oncologists choose the most appropriate therapy based on the genetic profile of the patient's tumor [14,15]. This not only improves treatment outcomes but also reduces side effects, as therapies are tailored to the specific needs of the patient [13,15].

3.3.2. Ethical Challenges of Big Data

The massive use of data raises significant ethical issues related to data privacy and patient information security. As hospitals collect and store more data, the risk of cyberattacks and privacy breaches increases [10,15]. Furthermore, clinical decision-making based on AI algorithms raises questions about medical responsibility, particularly in the case of error, as automated systems can influence critical decisions without direct human intervention [15].

3.4. Telework in Healthcare: Flexibility and Risks

Telemedicine and telework have gained ground in healthcare due to technological advancements. Healthcare professionals can work remotely, monitoring patients through advanced sensors and digital platforms, facilitating medical care at a distance [9,10]. It may be easier to envision telework in laboratories but telework can also be applied to surgery.

3.4.1. Telework in the Laboratory

Digital technologies have allowed many healthcare professionals, including cytotechnologists and pathologists, to work remotely. The ability to analyze images and issue diagnoses from any location has created new telework opportunities in healthcare [9]. Telework in healthcare offers greater flexibility and facilitates international collaboration, as professionals can share and analyze digital samples from different locations [9]. It also allows laboratories to process more samples in less time, improving operational efficiency [9]. However, telework also poses certain risks, such as the depersonalization of medical care and the potential loss of direct control over the work environment [9]. Additionally, not all professionals have equal access to technological tools, which can create inequalities in diagnostic quality [9].

3.4.2. Telework in Surgery

Telesurgery, or remote surgery, is a technology that allows a surgeon to control a surgical robot from a distance, operating on patients located in different geographical areas. An iconic example of this was the Lindbergh Operation in 2001, in which a surgeon in New York performed a gallbladder surgery on a patient in France using the ZEUS robotic surgical system. This operation demonstrated the feasibility of performing surgical procedures over long distances, thanks to real-time data transmission via high-speed networks [16].

Currently, advances in 5G networks have significantly improved latency, a crucial factor in telesurgery. The low latency offered by 5G ensures that the surgeon's commands are transmitted to the robot with minimal delay, which is essential for maintaining surgical precision. However, technical challenges remain, such as the need for robust infrastructure and the ability to compensate for any delay in sensory and haptic feedback [17].

3.5. Professional Training and Barriers to Implementation

The rapid adoption of new technologies has created a gap between the traditional skills of healthcare personnel and the new digital skills required to manage robotic systems and AI. This lack of training is one of the main obstacles to the full adoption of these technologies in hospitals [7,8].

To bridge this gap, it is essential to develop continuous training programs that enable doctors, nurses, and cytotechnologists to adapt to the new technological demands [7,8]. Furthermore, collaboration with educational institutions is crucial to ensure that new healthcare professionals are prepared to use these tools from the beginning of their careers [8]. In this regard, there are publications that explain various teaching methodologies aimed at facilitating the acquisition of knowledge on new technologies in clinical practice. Collaboration between educational and clinical institutions is crucial in these cases [18]. These training programs should be accompanied by efficient monitoring and evaluation methods. Both equipment and procedures must be checked. In this regard, various authors propose Best Practices. The use of these Best Practices seeks to ensure that the training programs are useful and appropriate to the clinical practice environment [19].

3.6. Future: The Promising Neuralink Project and Its Challenges

Brain-machine interfaces hold promise for the restoration of sensory and motor function and the treatment of neurological disorders, but clinical brain-machine interfaces have not yet been widely adopted, in part, because modest channel counts have limited their potential. Neuralink seeks to develop a brain-computer interface with thousands of channels to help patients with neurological disorders such as paralysis and degenerative diseases [20]. This study details how Neuralink's flexible microchips could improve quality of life by restoring motor and sensory function, although they face technological challenges, such as long-term compatibility with brain tissue and surgical risks. In addition to their medical applications, Neuralink poses significant ethical challenges, such as the potential to alter human identity and autonomy. Other challenges include concerns about brain data privacy and the potential risks of manipulation [21].

Table 1. Summary of the results from the cited studies.

Technology	Advantages	Disadvantages	References
Robotic Surgery	Greater precision, less invasiveness, better visualization	High cost, learning curve, staff resistance	[2–7,12,16,17,19]
AI in Cytology	Automation, higher accuracy, error reduction	High initial costs, dependence on data quality	[8,9,11,13–15,18]

4. Discussion and Conclusions

The advancement of new technologies in healthcare, such as robotic surgery and artificial intelligence applied to cytology, is redefining clinical practice. These innovations are improving the precision and efficiency of surgical and diagnostic procedures, enabling healthcare professionals to make more informed decisions and personalize treatments based on specific patient data [6,10,15].

However, the implementation of these technologies also presents significant challenges. Initial costs, resistance to change from professionals, the need for specialized training, and ethical dilemmas related to the use of big data and medical responsibility are issues that must be addressed to ensure successful integration [7–9].

In the future, the success of these technologies will depend on their proper implementation and the ability of healthcare professionals—doctors, nurses, and specialist technicians—to adapt to an increasingly digitized clinical environment.

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