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ROBOTICS AND ARTIFICIAL INTELLIGENCE (AI) IN GYNECOLOGIC SURGERY: PRACTICAL BENEFITS IN OVERT LAPAROSCOPY (NARRATIVE REVIEW 2021–2025)

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ABSTRACT

Introduction and Objectives: Gynecological surgery has undergone rapid development in recent years, from traditional laparoscopy to surgical robots increasingly supported by artificial intelligence. Robotic surgery is already standard in many gynecological oncology centers. However, there is considerable debate about its real advantages over laparoscopy, both from the perspective of patients, surgeons, and payers.

Brief Description of the State of Knowledge: The aim of the following narrative was to critically review the comparative practical benefits of both robotic surgery and laparoscopy in operative gynecology, with particular emphasis on clinical trial results, patient safety, operator ergonomics, learning curve, costs, and the role of artificial intelligence.

Methodology: A narrative literature review was conducted. PubMed/MEDLINE and Google Scholar were searched from 2021 to 2025 using English-language search terms such as: "robotic gynecologic surgery," "robot-assisted hysterectomy," "laparoscopic hysterectomy comparison," "endometrial cancer staging robotic," "deep infiltrating endometriosis robotic," "robotic sacrocolpopexy," "ergonomics surgeon laparoscopy," "learning curve robotic gynecology," "artificial intelligence gynecologic surgery," "cost analysis robotic hysterectomy," and "Poland robotic surgery NFZ financing."

KEYWORDS

Robotic Surgery, Laparoscopy, Gynecological Oncology, Artificial Intelligence, Treatment Costs, Surgical Ergonomics

CITATION

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Introduction:

Minimally invasive surgery has transformed gynecological surgery. Procedures such as hysterectomy, myomectomy, and pelvic floor reconstruction are now performed through small abdominal accesses, replacing large, conventional incisions. Laparoscopy was the first step in this revolution, but conventional laparoscopy has limited technical capabilities due to the stiffness of the instruments with limited articulation, the operator's positioning, the deep pelvis with narrow maneuvering space, and the assistant's susceptibility to hand tremor and fatigue [5, 12, 15, 18, 58].This limitation is particularly acute in patients with morbid obesity and a history of multiple surgeries [3, 10, 16, 21, 34, 43].Robotic systems introduce three fundamental changes: first, a 3D console with magnified surgical field and image stabilization improves the precision of dissection of nerves, vessels, and the ureter in the deep pelvis [3, 16, 25, 29, 30, 47].

Next, wrist-jointed instruments increase freedom of movement and facilitate suturing in difficult-to-access spaces, such as during anastomosis after bowel resection in deeply infiltrating endometriosis [16, 39, 41, 55].Another change is the robot's architecture, which relieves the operator's shoulders and spine from the platform, as the surgeon sits ergonomically, with their arms supported by the robot, maintaining tissue retraction and the camera. Interestingly, chronic neck, shoulder and spine pain is reported by over 70-80% of laparoscopic surgeons already in the middle of their professional career, which significantly accelerates burnout and early limitation of surgical practice [5, 12, 15, 18].

Studies published after 2021 have shown that the robotic console significantly reduces perceived musculoskeletal strain in surgeons, especially in the cervical spine. [5, 12, 15].

Parallel to the development of robotic surgery itself, we are witnessing another quality shift in the history of surgery in the form of the incorporation of artificial intelligence.

AI can now analyze images from an endoscopic camera in real time, recognize anatomical structures such as the ureter, iliac vessels, nerves, and the dissection plane, and provide guidance to the surgeon without the need to look away from the surgical field. [24, 25, 30, 35].

It helps develop surgeons' practical skills based on surgical recordings and detect technical errors. This technology is used to train young surgeons [7, 24, 25, 30, 35, 41].

One may ask whether robotic surgery actually offers benefits to the patient and the healthcare system that go beyond the effects of novelty, but when we compare it honestly with good advanced laparoscopy performed by an experienced team, clinical aspects must be taken into account, including blood loss, complications, hospitalization and recovery period, [34, 38, 40].

In Poland and Central and Eastern Europe, this economic dimension is particularly acute, as the purchase of a robotic surgical system costs PLN 10-15 million per hospital, which is often financed by EU or regional programs, and each individual procedure requires the use of disposable instrument sets worth several thousand euros [3,31,38, 40]. In Poland, between 2023 and 2025, the National Health Fund (NFZ) began to provide broader funding for robotic procedures in gynecological oncology, including endometrial and cervical cancer, but with prices reaching tens of thousands of zloty per case and with a growing total budget reaching hundreds of millions of zloty annually, leading to an increase in the number of surgical robots and surgical teams in the country [3,6,31,38,40].The aim of this narrative review is to summarize the latest reports and knowledge in the field of robotic surgery and laparoscopy used in surgical gynecology and what are the advantages and disadvantages of such treatment.[28,29,39,41].

Key findings:

Robotics are particularly beneficial in obese patients, patients at high anesthetic risk, and in pelvic surgery, where they significantly facilitate dissection in difficult-to-access spaces, reduce the rate of conversion to laparotomy, and allow for a minimally invasive approach [3,21,29,34,47].Oncologically (endometrial cancer, cervical cancer), survival outcomes after robotic surgery are lower than after laparoscopy, with similar sentinel lymph node safety [29,47,53].

A surgical robot significantly reduces the physical burden on the operator, reducing the strain on the musculoskeletal system typical of laparoscopy, which significantly impacts the operator's long-term performance [5,12,15,18,58].

Unfortunately, a significant factor negatively impacting robotic surgery is the direct costs, such as disposable equipment and platform depreciation. Although some of this difference is offset by shorter recovery times, lower rates of complications, conversions, and shorter hospital stays in high-risk groups [38,40].

In clinical practice and the training of young surgeons, a new breakthrough is emerging in the form of AI integration, including automatic recognition of critical structures, intelligent camera guidance, and automatic video analysis as a training tool.

Results:

In summary, the robot is not a one-to-one replacement for laparoscopy in simple cases. Its domain is technically challenging cases that require multi-planar pelvic dissection and suturing in a confined space, particularly in obese patients and in advanced endometriosis when pelvic floor statics need to be restored [39,43,47,55].

Perioperative results:

The most important perioperative factors include operative time, blood loss, complications, propensity for conversion, and length of hospital stay.Large comparative analyses and meta-analyses of hysterectomy and myomectomy have observed a consistent pattern in procedure duration for robotic procedures, which is typically longer than for laparoscopic procedures, particularly in the early phase of robotic program implementation, primarily due to robot preparation time and greater involvement of the medical team[29, 33, 34, 43, 44].

In randomized and large cohorts, differences can reach up to several dozen minutes [10, 22, 29, 53].

Kivekäs's (2025) study of radical hysterectomies found that the average duration of the surgeries was approximately 139 minutes, compared to 170 minutes for laparoscopy. However, this was a highly specialized cohort with a mature robotic program and optimized logistics [29]. In other centers, the opposite is observed, as the robot can be slower than the laparoscopic method, but this difference decreases after several dozen cases [2, 3, 29, 37].

In the case of blood loss and the need for transfusion, these are among the strengths of robotic surgery, as the differences are not always dramatic, as laparoscopy is also a minimally invasive procedure. Many studies on hysterectomy and myomectomy have noted average blood loss and a less frequent need for conversion to laparotomy in the surgical robotic group, especially in patients with a high BMI [34, 43, 47]. In the group of patients with endometrial cancer treated minimally invasively, their 3-year recurrence-free and overall survival were very high (>93%) and there were no significant differences between the laparoscopic and robotic methods, and the tendency to convert to laparotomy was practically not observed [53].

Reducing the tendency to convert to laparotomy is crucial. In obese patients with a BMI >35 kg/m², the robot minimizes the risk of situations where minimally invasive surgery is not possible due to stabilization of the surgical field with additional arms in retraction and greater freedom of movement of the instruments in the limited space of the pelvis [3, 21, 29, 34, 47].

This significantly translates into fewer large abdominal incisions, reduced postoperative pain, and faster recovery. The length of hospital stay in robotic surgery depends on the course of the surgery, but is generally assumed to be 1 to 3 days [16, 21, 29, 34, 43, 47].

In classical pelvic floor reconstruction, the length of stay after laparoscopic and robotic surgery was similar, and the rate of symptomatic recurrence after several dozen months of follow-up remained low and did not differ significantly between groups (2-4%) [39]. In summary, the robot typically prolongs the surgical time, especially at the beginning of the learning curve, and increases the cost of the instruments. However, it reduces the risk of conversion to laparoscopy and allows for maintaining a minimally invasive approach even in technically extremely difficult cases, which would mostly be performed via laparotomy or a long laparoscopic procedure [2, 3, 43, 47, 53, 55].

Oncological results

Data from 2021-2025 show that in low- and intermediate-risk endometrial cancer and in selected cases of cervical cancer, robotic hysterectomy with mesenteric or paraaortic lymphadenectomy or lymph node mapping (SLN) results in relapse-free survival and overall survival comparable to laparoscopy [3, 16, 21, 29, 47, 53].

In a large group of patients with endometrial cancer treated minimally invasively, 3-year relapse-free survival and survival were very high, as much as >93%, and did not differ significantly between the laparoscopic and robotic approaches [53]. Importantly, in these analyses, sentinel lymph node biopsy with indocyanine green (ICG) staining was most commonly used, which significantly limits the scope of systemic lymphadenectomy, thus reducing the risk of lower limb lymphedema and pelvic lymphatic cyst formation [29, 47, 53].

The role of the robot lies not so much in its greater radicality, but primarily in facilitating precise dissection of delicate lymphatic and neural structures while maintaining 3D-quality visualization. In obese patients with a BMI of 35-40 kg/m² or more, the ability to maintain minimally invasive access, rather than proceeding to laparotomy, translates into less surgical trauma and potentially faster access to adjuvant treatment [3, 21, 29, 34, 47]. A similar trend has been observed in radical oncological hysterectomies for cervical cancer in centers with extensive experience in robotic surgery. They report low rates of urogynecological complications, including ureteral damage and vesicovaginal fistulas, short hospital stays, and maintenance of safe margins while minimizing bleeding [34, 47, 53].

There is ongoing debate as to whether the results from highly specialized centers can be directly transferred to hospitals with lower capacity.

Ergonomics, operator safety, and team durability

Ergonomically, laparoscopic procedures are challenging because surgeons stand for long periods in a forced position with torso rotation and static neck and shoulder tension, with strong wrist flexion. A series of surveys and observational studies conducted among gynecologists after 2021 showed a 70-90% incidence of neck, shoulder, lumbar, and upper limb pain, even among highly active specialists, not only at the end of their careers [15, 18, 19].

In some analyses, more than half of the surgeons stated that pain hindered their clinical practice, and some considered limiting the implementation of complex laparoscopic procedures due to musculoskeletal strain [5, 12, 15, 18]. Robotic surgery radically changes this dynamic, as the surgeon sits at a console with forearm support, a neutral wrist position, and a relieved cervical spine. The robotic arms take over tissue retraction and stabilize the camera, eliminating prolonged camera holding or forced shoulder positioning by the assistant.From a systemic perspective, this is fundamental, as reduced operator workload translates to a longer operating career and a reduced risk of sick leave. This also includes more stable referral teams and the ability to concentrate complex cases in specialized centers [5, 12, 15, 18, 58].

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Learning Curve, Training, and the Role of AI

Early robotic experiments were often criticized as a technology exclusive to surgical stars, requiring a lengthy learning curve. However, data from 2021-2025 show that this learning curve is flattening thanks to standardized training programs and AI [35, 37, 41].

Case series analysis shows that clinical outcomes such as complications, propensity to conversion, and blood loss are becoming reproducible [2, 3, 28, 29, 37].

Robotic surgery training is shifting the paradigm from master to student to a hybrid model, where simulators, analysis of surgical video recordings, and automatic motion quality metrics are mandatory. AI automatically saves and cuts video recordings at various stages, such as during broad ligament dissection, ureter dissection, or uterine vessel ligation. It also measures the economy of tool movements and suggests improvements in the ergonomics of the needle grip, tissue traction, and hand coordination. [7, 24, 25, 30,35, 41].

AI also supports real-time learning, for example, by highlighting critical structures in the surgical field, such as the ureter and autonomic nerves, and by warning the operator about dangerous tool proximity [24, 25, 30, 35].Experimental studies have already demonstrated automatic real-time segmentation of the ureter and the overlay of spatial information in augmented reality (AR) mode during robotic hysterectomy or lymphadenectomy [24, 25, 30, 35].

From a training quality perspective, it is crucial that the robot provides several people with a stable, enlarged view of the surgical field, not just the operator and the assistant responsible for the camera. This facilitates step-by-step learning and standardizes technical standards across the team [30, 35, 41].

Costs and Financing

Unfortunately, cost is the most frequently cited argument against the widespread use of robotics in surgical gynecology, as the cost of purchasing a surgical robot of the Da Vinci class for a hospital is several million zlotys. In one Polish clinical center, the cost of purchasing the system, including the video equipment and instrumentation, was approximately 10.4 million zlotys, part of which was covered by EU funds and regional health programs [31].

Of course, it should be noted that this also includes the costs of disposable instruments and service. A 2024/2025 analysis by a gynecological oncology center estimated the cost of robotic instrumentation alone at €1,800 per procedure, with the average cost per hospital day at €600 [3]. In pelvic floor reconstructive surgery and single-port hysterectomy, a comparison of a single laparoscopic and robotic procedure showed that the total cost of the robotic procedure, including equipment and personnel, was several times higher: approximately $7,200 for robotic surgery and approximately $1,100 for laparoscopy [22].

Regarding private patients who are not covered by the reimbursement system, in 2022 the cost of robotic gynecological surgery in Poland, including hysterectomy with reconstruction, was estimated at approximately PLN 40,000-45,000, meaning that commercial access to robotics was, and often still is, an elite niche [38].However, the public system has begun to overcome this barrier. Financing for surgical robotic procedures in gynecologic oncology has been included in the unlimited funding stream in Poland since 2023-2025, with rates for a single procedure reaching tens of thousands of zlotys, starting at approximately 30,000 zlotys per clinical case. The National Health Fund and regional health programs have spent several hundred million zlotys annually on robotic procedures across all specialties, which has translated into an increase in the number of active robotic systems in the country and a broadening of clinical indications, particularly in endometrial cancer [6, 31, 38, 40].

Economically, the picture is ambiguous. In terms of direct costs, the robot is more expensive than laparoscopy in simple, routine cases, such as an uncomplicated hysterectomy in a slim patient without multiple adhesions. However, in high-risk groups, such as morbidly obese patients, patients with significant metabolic and cardiac disease burden, patients requiring complex pelvic floor reconstruction, or multi-organ resection of deeply infiltrating endometriosis, the robot reduces the conversion rate to laparotomy, shortens recovery, and potentially lowers the costs of complications and reoperations. This, from the perspective of the hospital and the payer, may bring the total cost of the treatment episode closer to laparoscopy, and over time, make it more cost-effective than laparotomy.[3, 21,47]

Discussion:

The results of a review of scientific papers from 2021-2025 suggest asking the question "surgery robot or laparoscopy?" This question cannot be answered in a binary manner, as it all depends on the clinical case, including which patients benefit from a robot and justify the additional cost and time [29, 34,47, 53, 55].

First, the use of robotic surgery will certainly be indicated in the high-risk population of patients with morbid obesity and comorbidities, which currently constitute a large proportion of endometrial cancer patients. For these patients, laparoscopy can be technically challenging, and laparotomy is associated with significant surgical trauma and a higher risk of wound infection, respiratory complications, and prolonged recovery. In this group of patients, the robot allows for full minimally invasive oncological dialysis with acceptable blood loss and a low rate of conversion to laparotomy [3, 21, 29, 34, 47, 53]. This significantly translates into faster mobilization, a reduced risk of thromboembolic complications, and a shorter return to function. Economically, even if the cost of disposable instruments is high, the potential costs of complications following laparotomy and prolonged hospitalization can be even higher [3, 21, 31, 34, 38, 40, 47]. Anatomically challenging cases, such as surgical procedures for advanced, deeply infiltrating endometriosis, repeat pelvic surgeries, or pelvic floor reconstruction with simultaneous hysterectomy and sacrocolpopexy, make the robot significantly easier to dissect and suture in the deep pelvis and reduce operator fatigue [16, 39, 41, 43, 55]. In clinical practice, this means that cases that in many centers would by definition be referred to laparotomy because they would be too demanding for laparoscopic surgeons can be performed minimally invasively with a shorter hospital stay. Patients experience less postoperative pain, a much quicker return to activity, and often a better cosmetic outcome [16, 22, 39, 43, 55].

Oncological results:

In early-stage endometrial cancer, the robot does not worsen overall survival or recurrence-free survival compared to laparoscopy [29, 47, 53]. In practice, this means that the robot is oncologically safe, provided the procedure is performed correctly and in accordance with staging principles. Thanks to robotic surgery in gynecology, more patients struggling with obesity, adhesions, or advanced age can qualify for minimally invasive treatment, which was previously unavailable to them [3, 21, 29, 34, 47, 53].

In terms of ergonomics, gynecological surgeons are at high risk of chronic musculoskeletal disorders and physical burnout. The limited availability of experienced operators using the robot, thanks to the sitting position at the console and the elimination of static, forced body positions, reduces pain and fatigue after long procedures [5, 12, 15, 18, 19].If we look at the scale of the healthcare system, this has a very positive impact, as we are dealing with fewer sick leave days, longer operational capacity, and the gradual development of reference centers with a high caseload, which significantly improves logistics and stabilizes results [2, 3, 28, 29, 37]. For young surgeons, laparoscopy of complex cases, such as complete excision of the rectovaginal septum in endometriosis or complete pelvic lymphadenectomy, can be a nearly insurmountable barrier without years of experience at a reference center. In robotic surgery, especially when supported by AI, the learning process is modular, standardized, and documented in video. AI divides the procedure into steps and evaluates movements, allowing the operator to better perceive anatomical structures and implement corrections [7, 24, 25, 30, 35, 41]. This method can significantly increase access to high-quality training, instead of perpetuating a situation where only a few centers have the know-how. AI in the operating room is also beginning to assist in real time, not just postoperatively. For example, it recognizes the ureter, iliac vessels, lymph nodes, and safe dissection planes, reducing the risk of damage to potentially critical structures [24, 25, 30, 35]. In terms of costs, in surgical procedures such as myomectomy in a patient with moderate myoma, laparoscopy remains cheaper and faster than using a robot, and postoperative results are excellent [10, 16, 43, 55].In such situations, the public healthcare system has no strong economic justification for subsidizing robotic surgery. However, in high-risk patients, such as those with morbid obesity, multiple comorbidities, or advanced endometriosis, the robot has the potential to reduce complications and the number of emergency laparotomies, which from the point of view of the hospital and the payer may translate into savings such as fewer post-laparotomy wound infections or faster recovery [3, 21, 22, 40, 47].Such methods have begun to be implemented in Poland. The National Health Fund (NFZ) funds robotics primarily where there are clinical and organizational benefits, primarily in gynecologic oncology, and not for every lower-risk procedure [6, 31, 38, 40]. Most data comes from highly specialized centers, usually academic, with experienced robotics staff. Some analyses are retrospective and focused on the most challenging cases, but in other centers, the relationship was reversed. There are no large randomized trials comparing robotic surgery and laparoscopy in the same group of patients with high metabolic and anesthetic risk. However, randomized trials are already underway in obese patients with endometrial cancer, which are expected to provide hard oncological data regarding quality of life and cost estimates [3, 29, 34, 47, 53].It can be said that slim patients with small uteri and no significant adhesions can be considered for laparoscopy, and the laparoscopic method remains the gold standard due to the procedure's duration and cost [10, 16, 22, 43, 55]. In the case of an obese patient with comorbidities, numerous adhesions, and requiring a complex pelvic lymphadenectomy, or deep endometriosis involving the ureter and intestine, in a very limited operating space, the robot can significantly improve the safety of the procedure and reduce the risk of conversion to laparotomy. In oncology, this advantage may translate into faster implementation of adjuvant treatment without delays associated with wound healing [34, 39, 41, 47, 53].

Conclusions:

Robotic surgery in gynecology is no longer a technological curiosity. Data from 2021-2025 show that in complex clinical cases, such as patients with morbid obesity, advanced deep infiltrating endometriosis, or the need for extensive pelvic floor reconstruction, the robot significantly increases the chances of maintaining a minimally invasive approach and maintains oncological safety with high survival rates.In high-risk populations, such as simple benign hysterectomy in slim patients, laparoscopy remains a faster and less expensive treatment method, and patient outcomes are equally good. In these cases, the robot does not provide a proportional return on investment [10, 16, 22, 43, 55]. Robot ergonomics and AI support could become a key systemic advantage, as the robot reduces musculoskeletal strain on the operator and can extend the careers of specialized teams. AI accelerates training and standardizes the quality of the technique, and introduces intraoperative decision support in critical structure recognition and intelligent camera guidance, which can significantly reduce the risk of complications[24, 25, 30, 35, 41, 58]. Economically, the robot is significantly more expensive to purchase and operate, but potentially cost-effective in high-risk patients, for whom avoiding laparotomy and shortening recovery generates indirect savings. In Poland, public funding has begun to cover such oncological cases, accelerating access to the technology, although procedures with purely benign indications remain unfunded[22, 31, 34, 38, 40, 47].Further research into robotic surgery and laparoscopy certainly requires large randomized trials in obese populations and high-risk cancer patients, with endpoints in terms of quality of life, costs, and recovery time.Long-term evaluation of the impact of robot ergonomics on the occupational health of operators. Safety and legal liability before using AI for intraoperative dissection of critical anatomical structures. Public financing models that reward not only the cost of a given procedure but also fewer complications.

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