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Unveiling the real benefits of robot-assisted surgery in gynaecology: from telesurgery to image-guided surgery and artificial intelligence

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ABSTRACT

Background: Several new robotic platforms are being commercialised, with different features in terms of types of consoles, numbers of arms, and targeting transabdominal or natural orifice approaches. The benefits of robotic surgery over laparoscopy have yet to be conclusively demonstrated in gynaecology, as several studies comparing perioperative and postoperative patient outcomes have reported no significant differences, leading to a lack of precise recommendations in surgical guidelines for both gynaecologic oncology and benign gynaecology. In addition, these outcomes must be balanced against the high costs of robotic surgery, in particular when considering building an infrastructure for safe telesurgery to democratise access to telementoring and remote interventions.

Objectives: Drawing from the expertise gained at the IRCAD Research and Training Center in Strasbourg, France, this article aims to provide an overview of the unveiled benefits of robotic-assisted surgery in gynaecology, investigating the role of digital surgery integration.

Methods: The objective of this narrative review is to provide an overview of the latest advancement in digital robotic-assisted surgery in gynaecology and illustrate the benefits of this approach related to the easiest integration with new technologies. To illustrate such evidence, PubMed, Google Scholar, and Scopus databases were searched.

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ABSTRACT

Main Outcome Measures: In the era of surgical innovation and digital surgery, the potential of robotic surgery becomes apparent through the capacity to integrate new technologies. Image-guided surgery techniques, including the analysis of preoperative and intraoperative images, 3D reconstructions and their use for virtual and augmented reality, and the availability of drop-in robotic ultrasound probes, can help to enhance the quality, efficacy and safety of surgical procedures.

Results: The integration of artificial intelligence, particularly computer vision analysis of surgical workflows, is put forward to further reduce complications, enhance safety, and improve operating room efficiency. Additionally, new large language models can assist during procedures by providing patient history and aiding in decision-making. The education and training of young surgeons will undergo radical transformations with robotic surgery, with telementoring and shared procedures in the side-by-side double-console setup.

Conclusions: Robotic systems play a fundamental role in the transition towards digital surgery, aiming to improve patient care through integration of such new technologies.

What is New? While the advantages of robotic surgery in terms of perioperative outcomes have yet to be demonstrated, the benefits of its easiest integration with new technologies are evident.

Keywords: Robotic-assisted surgery, image-guided surgery, artificial intelligence, telesurgery, training, minimally invasive surgery

Introduction

The integration of robotic surgery into clinical practice is becoming increasingly widespread and currently one robotic surgical procedure is performed every 16.8 seconds worldwide using the da Vinci system by Intuitive Surgical, the main actor among robotic companies in the last 25 years.[1] Given the increasing amount of robotics companies created annually, and the numerous new platforms with diverse features (multi-port, single port, flexible) under development and reaching market clearance, the current and expected growth rate is between 15-25%.[1,2] In oncologic gynaecology, only three randomised trials are present in the literature with small sample size.[3-5] A French multicentre trial the ROBO-GYN-1004 demonstrates no differences in terms of severe morbidity, conversion rate to open surgery and longer operating time for robotic surgery.[6] To date robotic surgery is indicated for obese patients with endometrial cancer[7] and in selected cases of ovarian cancer[8], while its adoption in cervical cancer surgery is still under investigation.[9-11] The robotic single-port approach is a feasible option in endometrial cancer comparable to the multiport procedure in terms of intraoperative and postoperative findings, and has an advantage in terms of shorter surgical times and aesthetic outcomes.[12-14] In benign gynaecologic surgery, robotic platforms are used in challenging cases of deep endometriosis or complex urogynaecological conditions[15] and as a possible option in reconstructive pelvic surgery.[16] A prospective multicentre randomised trial (LAROSE trial) enrolling 73 patients with suspicion of pelvic endometriosis, showed a similar OT between RAS and LPS (mean ± standard deviation, 107 ± 48 min vs. 102 ± 63 min) when adjusted to the stage of disease.[17]

Several studies have been published to compare robotic surgery with laparoscopy in terms of objective outcomes such as length of hospital stay, estimated blood loss, operative time, and postoperative pain.[11,18,19] However, significant differences have yet to be consistently demonstrated, and prospective clinical trials are still ongoing[10,17,20] without any guidelines recommending the robotic approach as the first choice. Additionally, and in contrast to other fields of abdominal surgery, in gynaecology a significant number of procedures, including hysterectomies and sacrocolpopexies, are carried out via the transvaginal route.[21] The number of reported robotic transvaginal procedures (R-vNOTES) is still low, but has been successfully demonstrated and compared with the traditional transvaginal approach. Robotic platforms designed to enhance transvaginal approaches, such as the Anovo™ Surgical System (Momentis Surgical, Israel) approved for benign disease, or a future inclusion of robotically steerable uterine manipulators into existing multi-arm systems, provide new opportunities for increased dexterity and instrument control in a restricted space.[21]

With rapid technological evolution and robust evidence supporting the benefits of minimally invasive surgery (MIS) over conventional laparotomy, the focus has shifted beyond telemanipulation of surgical instruments to exploring additional advantages offered by robotic systems.[19] In the research setting of clinical studies, the informatics interfaces of robotic platforms facilitate integration of emerging technologies. Combined with improved ergonomics for surgeons, these features are key to the potential benefits of these platforms.[22]

Modern surgical practices are evolving similarly to the transition from driving 1980s manual transmission cars with crank windows to using contemporary vehicles equipped with assisted driving/autopilot features, parking sensors, lane-keeping systems, and advanced safety mechanisms. These advancements have the potential to reduce patient risks and complications while also enhancing the quality of work for surgeons.

Drawing from the expertise gained at the IRCAD Research and Training Center in Strasbourg, France, where theoretical and hands-on robotic courses are conducted across various surgical disciplines in collaboration with robotic industrial partners, this article aims to provide an overview of the unveiled benefits of robotic surgery in gynaecology. This includes new approaches to education and training, communication between platforms and cutting-edge technologies in surgery, overcoming distances with telesurgery and telementoring, and the integration of image-guided surgery and artificial intelligence analyses into clinical practice (Figure 1).

Methods

The objective of this narrative review is to provide an overview of the latest advancement in digital robotic-assisted surgery in gynaecology and illustrate the benefits of this approach related to the easiest integration with new technologies. To illustrate such evidence, PubMed, Google Scholar, and Scopus databases were searched using the terms "artificial intelligence", "image-guided surgery", "digital surgery", "artificial intelligence" and "telesurgery" to retrieve relevant articles.

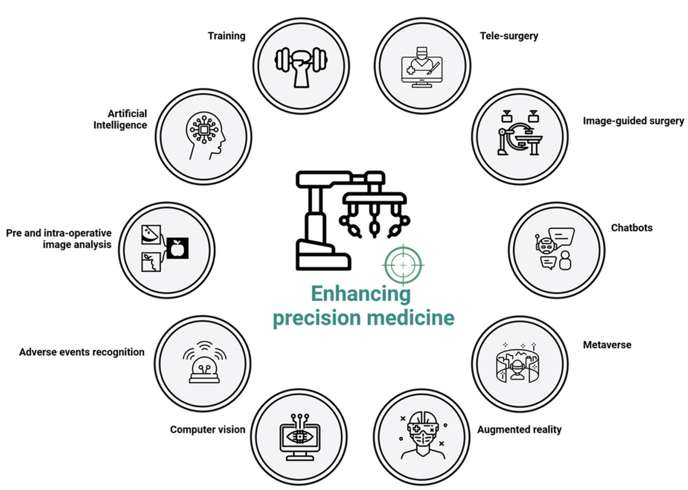

Figure 1. Potential benefits of robotic surgery: integration with new technologys.

Telesurgery

Telesurgery, which allows surgeons to operate on patients from remote locations, holds promise for transforming surgical practice and expanding the reach of healthcare services.[23] Since the advent of robotic surgery, the idea of performing operations over vast distances has captivated researchers and innovators.[24] In the latter part of the twentieth century, organisations such as NASA and the United States military invested heavily in developing technologies to facilitate remote surgical operations, thereby protecting surgeons from hazardous environments[24].

The potential of telesurgery to democratise access to advanced medical care is particularly significant in underserved rural areas of developed countries and in developing nations.[25] The World Health Organisation report states that 5 billion people lack access to surgery due to a paucity of trained workforce.[26] High-speed internet connections could make it possible for patients in remote or resource-limited settings to receive the same high-quality surgical care available in urban centres. Additionally, the ability to perform surgeries remotely transcends geographical barriers, enabling critical surgical interventions in otherwise inaccessible situations, such as during space missions or in disaster-stricken areas.[27,28] This was evident during the coronavirus disease-2019 pandemic, when telemedicine gained a pivotal role in *safe setting* patients' assessment.[29]

In regions facing a shortage of experienced surgeons, remote assistance can be especially beneficial. It allows expert surgeons to provide real-time guidance and support to less experienced practitioners, thereby enhancing both patient care and the outcomes of complex procedures, as well as the surgical training.[30]

Despite its transformative potential, the widespread adoption of telesurgery has encountered several obstacles since its introduction in the early 2000s.[31] Challenges such as limited access to reliable remote connections with low latency, the associated high costs, and the availability and medicolegal liability considerations for remote surgical practice across – and sometimes within – national borders, but also unclear liability and incentives for surgeons telementoring have hindered its implementation.[32] However, recent advancements in surgical robotics and telecommunication technologies are expanding the possibilities for telesurgery[25] and overcoming long-standing barriers, paving the way for remote surgical procedures to be integrated in clinical practice. This progress holds the potential to deliver high-quality surgical care to patients regardless of their location, potentially transforming global healthcare delivery.[30,32] Additionally, recent evidence shows that centralising care, particularly in gynaecologic oncology, improves patient outcomes. This underscores the benefits of telesurgery, which allows patients in peripheral hospitals to be operated on by expert surgeons.

Current Reports of Telerobotic Surgery

The early strides in telesurgery began in 1998 when Bauer et al.[33] documented a pioneering percutaneous urological procedure. In this case, a surgeon at the Johns Hopkins Hospital in Baltimore, USA, remotely controlled the positioning and advancement of a needle on a patient over 7,000 km away in Rome, Italy, using a PAKY (percutaneous access of the kidney) robot connected via a plain old telephone system line. The team achieved percutaneous access to the collecting system via two attempts in less than 20 minutes.[33] After this remote control of a single instrument, Marescaux et al.[31], achieved the first transatlantic robot-assisted laparoscopic cholecystectomy in 2001, known as "Operation Lindbergh", with remote control of a robotic system comprising a laparoscope and two instruments. This procedure connected the console of a ZEUS robotic system (Computer Motion Inc., California) with its bedside units over a high-speed terrestrial fibreoptic network (France Télécom/Equant) spanning a signal round-trip of 14,000 km, and the gallbladder dissection was completed in 54 minutes without complications.[31]

Advancements continued with Anvari et al.[34,35] who conducted 21 telerobotic laparoscopic operations between 2003 and 2005 between McMaster University in Hamilton, Ontario, and North Bay General Hospital in Northern Ontario, Canada, using the ZEUS TS micro joint system connected via an Internet Protocol Virtual Private Network. They experienced overall round-trip delays of 135 to 140 ms and no significant complications.[34,35] The team reported 22 total cases conducted on the same network, noting that an increased latency above 200 ms requires the surgeon to slow down to avoid overshooting.[34] Tian et al.[36] expanded the scope to stereotactic neurosurgery, performing 10 procedures between Beijing and Yan'an in late 2005 with the CAS-BH5 frameless robotic system.[36]

In 2019, Patel et al.[37] explored long-distance telerobotic surgery in cardiology by performing 5 tele-robotic-assisted percutaneous coronary artery interventions over 32 km using the CorPath GRX robotic system (Corindus Vascular Robotics, Waltham, MA, USA), with an observed delay of 53 ms and no complications. Later, Tian et al.[36] conducted 12 spinal surgeries using the TiRobot system connected to a 5G network (China Telecom and Huawei Technologies Co. Ltd.), with no network delays or adverse events. Acemoglu et al.[38] further advanced the field by performing a laser microsurgical procedure on a cadaver with a novel surgical robot connected to a 5G Radio Access Network, experiencing a maximum round-trip latency of 280 ms over 15 km.

From March to October 2021, the Micro Hand S robotic system was adopted to perform robot-assisted laparoscopic radical nephrectomies on 29 patients across eight hospitals, demonstrating the potential of 5G technology and surgical robots for treating renal tumours with a median distance of 187 km and a round-trip delay of 26 ms.[39] In 2022, the Hinotori Surgical Robot System, developed by Medicaroid Inc., was successfully used to perform telesurgical gastrectomies, establishing a basis for short-distance telesurgical procedures using high-speed optic-fibre communication.[40] To date no telesurgical cases have been reported on gynaecology globally.

Robotic Platforms for Pelvic Surgery Designed for Telesurgery

In recent years, several new robotic surgical systems have entered the marketplace, promising to reduce surgical costs and increase the accessibility of robotic procedures. Many of these platforms come equipped with built-in capabilities for remote connections, leveraging advancements in telecommunication and cellular networks from 1G to 6G (Table 1).[41,42] This progress has enabled the development of fully digital and connected systems, crucial for the practice of telesurgery. The time lag between a surgeon's actions and the robot's response remains a critical issue, as significant delays can compromise precision and safety during surgery.[43] An experimental study using the dV-Trainer simulator concluded that latencies under 200 ms are ideal for telesurgery, with up to 300 ms still being acceptable. Higher latencies require compensatory mechanisms to maintain performance.[44] Among the new systems, the Hinotori Surgical Robot System from Medicaroid Inc. stands out. Hinotori features a multi-port setup with an immersive console and manoeuvrable surgeon cockpit. Initially approved for urology in Japan in 2020, its use has expanded to gynaecology and general surgery in 2022. Medicaroid Europe is now pursuing CE marking compliance, aiming to introduce Hinotori to the European market.[42] Another significant player is the Edge Medical Telesurgery System from Shenzen Edge Medical Company. The Multiport 1000 and Single Port SP1000 platforms, approved for various surgeries including gynaecology, come with high-performance communication modules and low-latency control systems designed for remote operations.[42] The KangDuo Surgical Robot System, developed in China, offers a versatile setup with multiple arm configurations and compatibility with various endoscopes and accessory equipment. It integrates advanced features like fluorescence imaging and augmented reality (AR) surgical navigation. The system supports multiple consoles, enhancing the safety and flexibility of telesurgery by allowing local surgeons to manage cases if technical difficulties arise.[42] MicroPort MedBot Robotic Systems, also from China, include the Toumai laparoscopic surgical system. Compatible with 5G networks and capable of dual-console operation, the Toumai system has successfully performed ultra-long-distance surgeries, demonstrating the feasibility and reliability of telesurgery across vast distances. These advancements underscore the potential of new robotic platforms to revolutionise telesurgery, enhancing the performance of telecommunication and bringing high surgical quality worldwide (Table 1).[42]

Ethical Issue in Telerobotic Surgery

Maintaining the integrity of the surgeon-patient relationship in telesurgery is complex due to varying levels of remote involvement, from verbal guidance to full control of procedures, raising concerns about dehumanisation and patient objectification.[30] Patient vulnerability is significant, requiring full disclosure of local surgeons' skill limitations and the necessity of remote experts, with risks of overstating capabilities for financial gain. Telesurgery introduces physical and emotional distance between the surgeon and patient, which can reduce trust and connection. The lack of in-person interactions may undermine patients' confidence and make the relationship feel transactional, as surgeons have limited ability to convey empathy and emotional support. Communication may suffer due to technical issues and the absence of face-to-face discussions, potentially leading to misunderstandings and diminished trust.[37] Additionally, telesurgery often involves multiple surgeons across different locations, which can disrupt continuity of care, making it difficult for patients to experience a consistent and personalised treatment journey. Clear communication about remote involvement and a novel approach to informed consent are essential, along with a defined accountability chain for errors.[45] Informed consent requires thoroughly informing patients about the procedure, including its remote nature, reasons for choosing telesurgery over local surgery, and potential risks and complications. Patients may worry about the ability of the on-site surgeon to handle emergencies, so contingency plans must be clearly outlined. The process also defines the responsibilities of both the remote and local surgical teams, as well as any technical parties involved. Virtual consultations can help patients ask questions, voice concerns, and build trust with both teams.[46] Balancing medical appropriateness with cost effectiveness and improved access to advanced surgical care is crucial, despite the unclear financial responsibility

Table 1. Summary of robotic platforms for pelvic surgery equipped with built-in capabilities for remote connections.[42]

Model	Characteristics	Application	Connection	Average delay	Maximum distance
Hinotori Medicaroid, Japan	Single boom, multiport	Animal, lab cadaver	Dedicated network, 5G, guaranteed-type line	-	-
MPI000 Edge Medical System, China	Single boom, multiport	Human	Dedicated line, China Telecom	<200 ms	3000 km
SP 1000 Kangduo Robotics, China	Single boom, single port	Human	5G, wired networks	-	3000 km
Toumai Micropprt, Medbot, China	Immersive console, multiport	Human	5G, dedicated network, Internet	24-41 ms at 200 km; 52 ms at 1,000-2,000 km; up to 159 ms at 5,000 km	5000 km

for tele-surgical infrastructure. Moreover, nations may lack the necessary social and legal infrastructure to support telesurgery, facing international governance challenges.[30]

Image-guided Robotic Surgery

The next major advancements in minimally invasive precision surgery lie in the development of specialised software which facilitates the creation of 3D models from preoperative and intraoperative imaging.[47] Image-guided surgery is central to ongoing improvements in robotic surgery, offering much more than just sensors, actuators, and telemanipulation.[48] Enhanced visualisation and critical guidance for complex procedures are achieved through integrated imaging technologies.[49]

Computer-assisted intraoperative data collection, information processing, and decision support systems hold significant promise. Technologies such as virtual reality (VR), AR are becoming increasingly prevalent in daily life and are gradually being incorporated into MIS.[50,51] Advanced imaging systems can significantly enhance a surgeon's vision beyond natural capabilities, overcoming current limitations in tactile feedback and force sensing. This allows surgeons to visualise tissue consistency and resistance during manipulation.[52]

Recent research has been propelled by the successes of deep learning in automatic image analysis and interpretation. AR systems have already been reported to identify sentinel lymph nodes in endometrial cancer[53] and to intraoperatively assess bowel infiltration by endometriosis.[54] One challenge in AR is achieving precise registration in enhanced views, especially with soft tissues which continuously undergoes modifications due to respiratory movements, intraperitoneal insufflation, or surgical manipulation. The retroperitoneum is comparatively stable, making accurate overlays easier than with other intra-abdominal organs.[55,56]

Hybrid operating rooms, equipped with integrated intraoperative imaging systems like computed tomography, magnetic resonance imaging, ultrasonography, and fluoroscopy, offer additional support during surgeries in advanced settings.[57] Ideally, *in vivo* 3D tissue analysis would guide surgical procedures in real time. Some robotic platforms come equipped with integrated software that can display images in a dual view within the console (such as da Vinci's TilePro™), facilitating integration with image-guided surgery tools.[58]

Beyond 3D macroscopic guidance, there is an increasing need for real-time intraoperative tissue analysis, especially to tailor the extent of resection in oncological surgeries.[59] Various intraoperative optical imaging techniques are currently being evaluated to complement or enhance extemporaneous histopathological analysis.[52,60] For *in vivo* tissue, 3D high-resolution ultrasound is a major advancement in intraoperative analysis, supporting decisions such as the necessity of resection in cases like lymph node metastasis.[61] Intraoperative ultrasound application, through drop-in probes connected by flexible cables which can be easily manoeuvred with robotic graspers, is being increasingly adopted across different robotic platforms due to their adaptability. Robotic probes with frequencies of 7-13 MHz can be inserted through 10-12 mm trocars, and their flexibility and manoeuvrability, surpassing the rotational capability of robotic instruments, allow them to reach anatomical locations otherwise inaccessible with traditional laparoscopic ultrasound probes.[62] A recent systematic review highlighted the applications of ultrasound-guided robotic procedures in surgery, particularly emphasising its potential in gynaecologic oncology.[52]

Fluorescence imaging, using fluorescent tracers, enables visualisation beyond the visible surface, allowing for the evaluation of organ perfusion, the definition of specific segments within organs, and highlighting critical anatomical structures essential for various procedures.[63] Its integration into robotic systems like the da Vinci Firefly® enhances its utility. Advances in computer-assisted signal analysis and artificial intelligence algorithms are poised to provide additional insights and intraoperative guidance.[64] Combining fluorescence image-guided surgery with 3D VR/AR models offers enhanced intraoperative support.[65] Quantitative fluorescence imaging and artificial intelligence-driven analysis of fluorescence signal dynamics support perfusion assessment and tissue classification, promoting the broader adoption of fluorescence image-guided surgery.[66]

The next steps aim to introduce experimental techniques in robotic surgery, which enable intraoperative microscopic visualisation, ideally detecting low-volume metastasis and improving the sensitivity of frozen sections in gynaecologic oncology.[62] This includes the introduction of high-frequency (up to 70 MHz) and ultra-high-frequency (up to 100 MHz) ultrasound probes as drop-in for robotic surgery, which can achieve resolutions of 30 μm.[67] Additionally, integrating full-field optical coherence tomography (FF-OCT) offers an immediate *ex vivo* imaging system which does not require dedicated sample preparation and has a quick learning curve with tissue section analysis similar to traditional histopathology.[60,68] This innovative technique can be useful for real-time assessment of lymph nodal status, especially in cervical cancer, where the presence of metastatic nodes guides the intraoperative decision making.[69] For resected specimens, whole-slide imaging can digitally reconstruct a 3D volume, preventing missed lesions due to skipped depth slides.[70] In the era of digital surgery, robotic platforms can serve as computer interfaces capable of integrating multiple modalities of real-time image data analysis.

Integration of Artificial Intelligence in Robotic Surgery

The digital interface of robotic platforms facilitates communication with artificial intelligence systems more effectively than it is possible with other types of MIS, such as endoscopy or laparoscopy.

Surgical Workflow Analysis

Surgery workflow analysis relies on artificial intelligence models to automatically monitor and assess the progression of surgical procedures.[71] This field has undergone significant evolution over the past decade, with advanced algorithms now integrated into the software of robotic platforms like Medtronic's Surgery, Johnson & Johnson's C-SATS, and Intuitive Surgical's Orpheus.[72] A primary objective of surgery workflow analysis is the automatic identification of the major steps or phases during an operation. This task is fundamental in surgical artificial intelligence and heavily relies on deep learning techniques applied to high-quality, annotated surgical video data. These systems not only recognise current steps, but also measure the time spent in each step, which may be an indicator of difficulties and potential complications.[73] Prolonged durations in certain steps can trigger alerts, predicting complication risks or notifying senior surgeons of resident difficulties. Deviations from standardised workflows can be flagged, ensuring adherence to best practices.[74] Additionally, performance analytics derived from workflow analysis provides insights into surgical proficiency. The time taken to complete surgical steps serves as a benchmark for assessing technical competency, enabling the evaluation of learning curves and peer performance comparisons. Moreover, recognising when a procedure is nearing completion can enhance operating room efficiency.[75] Automated notifications can alert wards to prepare for the next patient and prompt cleaning staff, thereby reducing turnaround times and hospital costs.[76] As artificial intelligence continues to advance, the integration of comprehensive workflow analysis into surgical practice promises to refine procedural standards, enhance training, and optimise efficiency.[77]

Human errors significantly contribute to surgical complications and negative outcomes. Many studies use deep learning to automatically validate safety procedures visually.[78] For instance, laparoscopic cholecystectomy can lead to bile duct injuries, occurring in about 3 out of every 1,000 surgeries. To mitigate these risks, the Critical View of Safety (CVS) was devised in 1995 to ensure correct identification of the cystic duct and cystic artery, and it's now being automatically assessed by artificial intelligence.[79,80] Researchers have recently used deep learning to verify adherence to the CVS, acting as a warning system. Systems to automatically identify safe and unsafe areas during surgery, using instrument tracking to establish a safety alert system, are under development.[57,79,81] The Rome-Strasbourg gynaecologic oncology team is conducting computer vision studies aimed at reducing complications and enhancing surgical safety for sentinel node dissection in uterine cancers (LYSE study).

ChatBots

Robotic consoles are also well-suited for easy communication with new large language models capable of providing computational outputs based on specific inputs.[82] Studies assessing the validity of these systems' responses are ongoing, with prospects of surgeons engaging with these machines in decision-making during complex procedures.[83] Decision-making in the operating room requires a collaborative team effort, and today, artificial intelligence is increasingly aiding in this process. Surgery is just one step in the entire continuum of patient care, and the concept of having a chatbot powered by deep learning systems which can provide precise patient information is emerging as a valuable tool. Such a chatbot can deliver real-time intraoperative information as well as comprehensive details about the patient's medical history, including anamnesis, comorbidities, and consultations with other specialists. This integration of chatbots into the surgical workflow may enhance the ability to make informed decisions, ultimately improving patient outcomes.[82]

Education and Training in Robotic Surgery

Robotic platforms are fundamentally reshaping the landscape of training for both residents and young surgeons.[84] Unlike traditional open or laparoscopic surgeries, the integration of virtual simulators with consoles akin to those used in real patient scenarios presents undeniable advantages for education.[85] Through these platforms, learners can engage in immersive experiences which closely mimic actual surgical procedures, allowing for hands-on practice without harming patients. Furthermore, VR systems equipped with progressively complex tasks enable learners to undergo training in a gradual manner, progressively advancing through objectives of increasing difficulty.[86]

One notable feature offered by several companies is the dual-console mode, which provides a unique opportunity for experienced surgeons to mentor and guide younger colleagues in real time. This collaborative approach not only fosters skill development but also promotes knowledge sharing and professional growth within the surgical team.[87]

As the demand for specialised training in robotic surgery continues to rise, various scientific societies are taking steps to establish their own training curriculum programs such as Gynaecological Endoscopic Surgical Education and Assessment (GESEA) robotics program endorsed by the European Society for Gynaecological Endoscopy (ESGE) or the Robotic courses provided by the European Network of Young Gynae Oncologist (ENYGO) and European Society of Gynaecologic Oncology (ESGO).[88] This initiative is particularly significant given that not all residency programs currently offer dedicated paths. However, with the proliferation of robotic platforms in the market and ongoing development efforts, the challenge lies in ensuring that training courses expose learners to a diverse range of platforms.[89]

In response to this challenge, dedicated training centres represent essential hubs for providing comprehensive instruction across various robotic platforms. These centres serve as focal points for collaboration between industry experts, academic institutions, and healthcare organisations, facilitating the exchange of knowledge and best practices in robotic surgery training.[72]

The integration of robotic platforms into surgical training represents a paradigm shift in medical education. By leveraging virtual simulators, VR systems, and collaborative learning opportunities, these platforms empower aspiring surgeons to acquire the skills and expertise needed to excel in the rapidly evolving field of robotic surgery.[85]

Study Limitations

The high costs associated with robotic surgical systems create a significant barrier, as these technologies require substantial initial investments, ongoing maintenance, and specialised training, all of which impose financial strain on healthcare providers and patients.[72] The expense of robotic systems often necessitates advanced operating rooms and specialised staff, limiting their availability in less affluent areas and contributing to disparities in access.[27] Additionally, the infrastructure required for robotic surgery, such as reliable telecommunication networks for telesurgery, is not universally available, which further restricts its application in resource-limited settings. These factors highlight the complexity of adopting robotic surgery on a larger scale, emphasising the need for a balanced view that considers both the significant potential and the notable challenges.[84]

Future Direction

Robotic surgery serves as a bridge between laparoscopy and digital surgery, thanks to its seamless integration with digital interfaces. Image-guided surgery, enhanced by deep learning applications, opens up unprecedented intraoperative diagnostic possibilities. Future studies should explore more the use of FF-OCT, photoacoustic imaging, HFUS, and drop-in robotic probes in the assessment of cancer/no cancer tissue status in gynaecological oncology.[90] Computer vision could further could aid in enhancing the assessment of quality and effectiveness in robotic procedures through image analysis. In the near future, telesurgery is expected to help overcome physical boundaries, paving the way for the democratisation of healthcare access.

Conclusion

The adoption of robotic platforms is increasing across all surgical fields. Retrospective studies and meta-analyses have not yet demonstrated significant benefits over standard laparoscopy in gynaecology. While prospective studies are ongoing and scientific evidences still lacking, the real advantages of robotic surgery are likely to be found in its superior integration with new technologies. Future prospective studies should focus on the potential for integrating robotic platforms with artificial intelligence systems, image-guided surgery, and overcoming physical limitations through telerobotic surgery.

Footnotes

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References

1. Couffinhal DJ, Johanet PH, Cormerais Q. Robotic-assisted surgery for soft tissue in France: national overview, regional disparities and real- life impact. A medico-administrative database analysis. J Robot Surg. 2022;4;18:332.
2. Surgical Robots Market Share & Trends Growth Report, 2032, n.d. Global Market Insights Inc. Last Accessed Date: 11.14.2023. Available from: https://www.gminsights.com/industry-analysis/surgical-robots-market
3. Luo C, Liu M, Li X. Efficacy and safety outcomes of robotic radical hysterectomy in Chinese older women with cervical cancer compared with laparoscopic radical hysterectomy. BMC Womens Health. 2018;18:61.
4. Mäenpää MM, Nieminen K, Tomás EI, Laurila M, Luukkaala TH, Mäenpää JU. Robotic-assisted vs traditional laparoscopic surgery for endometrial cancer: a randomized controlled trial. Am J Obstet Gynecol. 2016;215:588.
5. Silva E Silva A, de Carvalho JPM, Anton C, Fernandes RP, Baracat EC, Carvalho JP. Introduction of robotic surgery for endometrial cancer into a Brazilian cancer service: a randomized trial evaluating perioperative clinical outcomes and costs. Clinics. 2018;73:522.
6. Narducci F, Bogart E, Hebert T, Gauthier T, Collinet P, Classe JM, et al. Severe perioperative morbidity after robot-assisted versus conventional laparoscopy in gynecologic oncology: results of the randomized ROBOGYN-1004 trial. Gynecol Oncol. 2020;158:382-9.
7. Corrado G, Vizza E, Perrone AM. Comparison between laparoscopic and robotic surgery in elderly patients with endometrial cancer: a retrospective multicentric Study. Front Oncol. 2021;11;724-886.
8. Gallotta V, Certelli C, Oliva R, Rosati A, Federico A, Loverro M, et al. Robotic surgery in ovarian cancer. Best Pract Res Clin Obstet Gynaecol. 2023;90:102391.
9. Bixel KL, Leitao MM, Chase DM et al. ROCC/GOG-3043: a randomized non-inferiority trial of robotic versus open radical hysterectomy for early-stage cervical cancer. Journal of Clinical Oncology. 2022;16:5605.
10. Falconer H, Palsdottir K, Stalberg K, Dahm-Kähler P, Ottander U, Lundin ES, et al. Robot-assisted approach to cervical cancer (RACC): an international multi-center, open-label randomized controlled trial. Int J Gynecol Cancer. 2019;29:1072-6.
11. Gallotta V, Conte C, Federico A, Vizzielli G, Gueli Alletti S, Tortorella L, et al. Robotic versus laparoscopic radical hysterectomy in early cervical cancer: a case matched control study. Eur J Surg Oncol. 2018;44:754-9.
12. Corrado G, Mereu L, Bogliolo S, Cela V, Freschi L, Carlin R, et al. Robotic single site staging in endometrial cancer: a multi-institution study. Eur J Surg Oncol. 2016;42:1506-11.
13. Mereu L, Berlanda V, Surico D, Barbara G, Riccardo P, Arsenio S, et al. Evaluation of quality of life, body image and surgical outcomes of robotic total laparoscopic hysterectomy and sentinel lymph node mapping in low-risk endometrial cancer patients - A Robotic Gyne Club study. Acta Obstet Gynecol Scand. 2020;99:1238-45.
14. Mereu L, Carri G, Khalifa H. Robotic single port total laparoscopic hysterectomy for endometrial cancer patients. Gynecol Oncol. 2012;127:644.
15. Pavone M, Seeliger B, Alesi MV, Goglia M, Marescaux J, Scambia G, et al. Initial experience of robotically assisted endometriosis surgery with a novel robotic system: first case series in a tertiary care center. Updates Surg. 2024c;76:271-7.
16. Simoncini T, Panattoni A, Aktas M, Ampe J, Betschart C, Bloemendaal ALA, et al. Robot-assisted pelvic floor reconstructive surgery: an international Delphi study of expert users. Surg Endosc. 2023;37:5215-25.
17. Soto E, Luu TH, Liu X, Magrina JF, Wasson MN, Einarsson JI, et al. Laparoscopy vs. robotic surgery for endometriosis (larose): a multicenter, randomized, controlled trial. Fertil Steril. 2017;107:996-1002.
18. Bizzarri N, Restaino S, Gueli Alletti S, Monterossi G, Gioè A, La Fera E, et al. Sentinel lymph node detection in endometrial cancer with indocyanine green: laparoscopic versus robotic approach. Facts Views Vis Obgyn. 2021;13:15-25.
19. Pavone M, Baroni A, Campolo F. Robotic assisted versus laparoscopic surgery for deep endometriosis: a meta-analysis of current evidence. J Robotic Surg. 2024a;18:212.
20. Dinoi G, Tarantino V, Bizzarri N, Perrone E, Capasso I, Giannarelli D, et al. Robotic-assisted versus conventional laparoscopic surgery in the management of obese patients with early endometrial cancer in the sentinel lymph node era: a randomized controlled study (RObese). Int J Gynecol Cancer. 2024;34:773-6.
21. Pavone M, Lecointre L, Seeliger B, Oliva R, Akladios C, Querleu D, et al. The vaginal route for minimally invasive surgery: a practical guide for general surgeons. Minim Invasive Ther Allied Technol. 2025;34:78-87.
22. Wong SW, Crowe P. Visualisation ergonomics and robotic surgery. J Robot Surg. 2023;17:1873-8.
23. Barba P, Stramiello J, Funk EK, Richter F, Yip MC, Orosco RK. Remote telesurgery in humans: a systematic review. Surg Endosc. 2022;36:2771-7.
24. Raison N, Khan MS, Challacombe B. Telemedicine in surgery: what are the opportunities and hurdles to realising the potential? Curr Urol Rep. 2015;16:43.
25. Choi PJ, Oskouian R, Tubbs RS. Telesurgery: past, present, and future. Cureus. 2018;10:2716.
26. Liu L, Johnson HL, Cousens S, Perin J, Scott S, Lawn JE, et al. Global, regional, and national causes of child mortality: an updated systematic analysis for 2010 with time trends since 2000. Lancet. 2012;379;2151-61.
27. Bansal E, Kunaprayoon S, Zhang LP. Opportunities for global health diplomacy in transnational robotic telesurgery. AMA J Ethics. 2023;25:624-36.
28. Haidegger T, Sándor J, Benyó Z. Surgery in space: the future of robotic telesurgery. Surg Endosc. 2011;25:681-90.

29. Nickel F, Cizmic A, Chand M. Telestration and augmented reality in minimally invasive surgery: an invaluable tool in the age of COVID-19 for remote proctoring and telementoring. JAMA Surg. 2022;157:169-70.

30. Frenkel CH. Telesurgery's evolution during the robotic surgery renaissance and a systematic review of its ethical considerations. Surg Innov. 2023;30:595-600.

31. Marescaux J, Smith MK, Fölscher D, Jamali F, Malassagne B, Leroy J. Telerobotic laparoscopic cholecystectomy: initial clinical experience with 25 patients. Ann Surg. 2001;234:1-7.

32. Seeliger B, Marescaux J. Robot-assisted laparoscopic telesurgery -from inception to future perspectives. Show-Chwan Med J. 2023;22:454-9.

33. Bauer J, Lee BR, Stoianovici D, Bishoff JT, Micali S, Micali F, et al. Remote percutaneous renal access using a new automated telesurgical robotic system. Telemed J E Health. 2001;7:341-6.

34. Anvari M. Remote telepresence surgery: the Canadian experience. Surg Endosc. 2007;21:537-41.

35. Anvari M, McKinley C, Stein H. Establishment of the world's first telerobotic remote surgical service. Ann Surg. 2005;241:460-4.

36. Tian W, Fan M, Zeng C, Liu Y, He D, Zhang Q. Telerobotic spinal surgery based on 5g network: the first 12 cases. Neurospine. 2020;17:114-20.

37. Patel TM, Shah SC, Pancholy SB. Long distance tele-robotic-assisted percutaneous coronary intervention: a report of first-in-human experience. eClinicalMedicine. 2019;14:53-8.

38. Acemoglu A, Peretti G, Trimarchi M, Hysenbelli J, Krieglstein J, Geraldes A, et al. Operating from a distance: robotic vocal cord 5G telesurgery on a cadaver. Ann Intern Med. 2020;173:940-41.

39. Li J, Yang X, Chu G, Feng W, Ding X, Yin X, et al. Application of improved robot-assisted laparoscopic telesurgery with 5G technology in urology. Eur Urol. 2023;83:41-4.

40. Nakauchi M, Suda K, Nakamura K, Tanaka T, Shibasaki S, Inaba K, et al. Establishment of a new practical telesurgical platform using the hinotoriTM Surgical Robot System: a preclinical study. Langenbecks Arch Surg. 2022;407:3783-91.

41. Gamal A, Moschovas MC, Jaber AR, Saikali S, Perera R, Headley C, et al. Clinical applications of robotic surgery platforms: a comprehensive review. J Robot Surg. 2024;18:29.

42. Rocco B, Moschovas MC, Saikali S, Gaia G, Patel V, Sighinolfi MC. Insights from telesurgery expert conference on recent clinical experience and current status of remote surgery. J Robotic Surg. 2024;18:240.

43. Evans CR, Medina MG, Dwyer AM. Telemedicine and telerobotics: from science fiction to reality. Updates Surg. 2018;70:357-62.

44. Song Z, Li S, Luo M, Li H, Zhong H, Wei S. Assessing the role of robotic surgery versus laparoscopic surgery in patients with a diagnosis of endometriosis: a meta-analysis. Medicine. 2023;102:33104.

45. van Wynsberghe A, Gastmans C. Telesurgery: an ethical appraisal. J Med Ethics. 2008;34:e22.

46. Patel V, Saikali S, Moschovas MC, Patel E, Satava R, Dasgupta P, et al. Technical and ethical considerations in telesurgery. J Robotic Surg. 2024;18:40.

47. Fedorov A, Beichel R, Kalpathy-Cramer J, Finet J, Fillion-Robin JC, Pujol S, et al. 3D Slicer as an image computing platform for the quantitative imaging network. Magn Reson Imaging. 2012;30:1323-41.

48. Mascagni P, Longo F, Barberio M, Seeliger B, Agnus V, Saccomandi P, et al. New intraoperative imaging technologies: innovating the surgeon's eye toward surgical precision. J Surg Oncol. 2018;118:265-82.

49. Checcucci E, Verri P, Amparore D, Cacciamani GE, Rivas JG, Autorino R, et al. The future of robotic surgery in urology: from augmented reality to the advent of metaverse. Ther Adv Urol. 2023;15:17562872231151853.

50. Giannone F, Felli E, Cherkaoui Z, Mascagni P, Pessaux P. Augmented reality and image-guided robotic liver surgery. Cancers. 2021;13:6268.

51. Pessaux P, Diana M, Soler L, Piardi T, Mutter D, Marescaux J. Towards cybernetic surgery: robotic and augmented reality-assisted liver segmentectomy. Langenbecks Arch Surg. 2015;400:381-5.

52. Pavone M, Seeliger B, Teodorico E, Goglia M, Taliento C, Bizzarri N, et al. Ultrasound-guided robotic surgical procedures: a systematic review. Surg Endosc. 2024d;38:2359-70.

53. Lecointre L, Verde J, Goffin L, Venkatasamy A, Seeliger B, Lodi M, et al. Robotically assisted augmented reality system for identification of targeted lymph nodes in laparoscopic gynecological surgery: a first step toward the identification of sentinel node. Surg Endosc. 2022;36:9224-33.

54. Martel C, Arnalsteen C, Lecointre L, Lapointe M, Roy C, Faller E, et al. Feasibility and clinical value of virtual reality for deep infiltrating pelvic endometriosis: a case report. J Gynecol Obstet Hum Reprod. 2023;52:102500.

55. Manzie T, MacDougall H, Cheng K, Venchiarutti R, Fox R, Sharman A, et al. Virtual reality digital surgical planning for jaw reconstruction: a usability study. ANZ J J Surg. 2023;93:1341-7.

56. Marescaux J, Seeliger B. Robotic surgery: a time of change. Updates Surg. 2023;75:793-94.

57. Mascagni P, Padoy N. OR black box and surgical control tower: Recording and streaming data and analytics to improve surgical care. J Visc Surg. 2021;158:18-25.

58. Bartoş A, Iancu I, Ciobanu L, Badea R, Spârchez Z, Bartoş DM. Intraoperative ultrasound in liver and pancreatic surgery. Med Ultrason. 2020;23;319-28.

59. Sena G, Paglione D, Gallo G, Goglia M, Osso M, Nardo B. Surgical Resection of a recurrent hepatocellular carcinoma with portal vein thrombosis: is it a good treatment option? a case report and systematic review of the literature. J Clin Med. 2022;11:5287.

60. Pavone M, Spiridon IA, Lecointre L, Seeliger B, Scambia G, Venkatasamy A ,et al. Full-field optical coherence tomography imaging for intraoperative microscopic extemporaneous lymph node assessment. Int J Gynecol Cancer. 2023;33:1985-7.

61. Agustí N, Viveros-Carreño D, Mora-Soto N, Ramírez PT, Rauh-Hain A, Wu CF, et al. Diagnostic accuracy of sentinel lymph node frozen section analysis in patients with early-stage cervical cancer: a systematic review and meta-analysis. Gynecol Oncol. 2023;177:157-64.

62. Guerra F, Amore Bonapasta S, Annecchiarico M, Bongiolatti S, Coratti A. Robot-integrated intraoperative ultrasound: initial experience with hepatic malignancies. Minim Invasive Ther Allied Technol. 2015;24:345-49.

63. Loverro M, Bizzarri N, Capomacchia FM, Watrowski R, Querleu D, Gioè A, et al. Indocyanine green fluorescence applied to gynecologic oncology: beyond sentinel lymph node. Int J Surg. 2024;10:3641-53.

64. Barberio M, Al-Taher M, Forgione A, Hoskere Ashoka A, Felli E, Agnus V, et al. A novel method for near-infrared fluorescence imaging of the urethra during perineal and transanal surgery: demonstration in a cadaveric model. Colorectal Dis. 2020;22:1749-53.

65. De Simone B, Abu-Zidan FM, Saeidi S, Deeken G, Biffl WL, Moore EE, et al. ICG Fluorescence Guided Emergency Surgery Survey Consortium, Catena, F., 2024. Knowledge, attitudes and practices of using Indocyanine Green (ICG) fluorescence in emergency surgery: an international web-based survey in the ARtificial Intelligence in Emergency and trauma Surgery (ARIES)-WSES project. Updates Surg. 2024;76:1969-81.

66. Esposito A, Schlachter S, Schierle GS, Elder AD, Diaspro A, Wouters FS, et al. Quantitative fluorescence microscopy techniques. Methods Mol Biol. 2009;586:117-42.

67. Walk EL, McLaughlin SL, Weed SA. High-frequency ultrasound imaging of mouse cervical lymph nodes. J Vis Exp. 2018;52718.

68. Dalimier E, Salomon D. Full-field optical coherence tomography: a new technology for 3D high-resolution skin imaging. Dermatology. 2022;224:84-92.

69. Cibula D, Dostalek L, Hillemanns P, Scambia G, Jarkovsky J, Persson J, et al. Completion of radical hysterectomy does not improve survival of patients with cervical cancer and intraoperatively detected lymph node involvement: ABRAX international retrospective cohort study. Eur J Cancer. 2021;143:88-100.

70. Assayag O. Large field, high resolution full-field optical coherence tomography: a pre-clinical study of human breast tissue and cancer assessment. Technol Cancer Res Treat. 2014;13:455-68.

71. Mascagni P, Fiorillo C, Urade T, Emre T, Yu T, Wakabayashi T, et al. Formalizing video documentation of the Critical View of Safety in laparoscopic cholecystectomy: a step towards artificial intelligence assistance to improve surgical safety. Surg Endosc. 2020;34:2709-14.

72. Boal M, Di Girasole CG, Tesfai F, Morrison TEM, Higgs S, Ahmad J, et al. Evaluation status of current and emerging minimally invasive robotic surgical platforms. Surg Endosc. 2024;38:554-85.

73. Mascagni P, Alapatt D, Urade T, Vardazaryan A, Mutter D, Marescaux J, et al. A computer vision platform to automatically locate critical events in surgical videos: documenting safety in laparoscopic cholecystectomy. Ann Surg. 2021;274:93-5.

74. Ward TM, Mascagni P, Ban Y, Rosman G, Padoy N, Meireles O, et al. Computer vision in surgery. Surgery. 2021;169:1253-6.

75. Rossitto C, Gueli Alletti S, Romano F, Fiore A, Coretti S, Oradei M, et al. Use of robot-specific resources and operating room times: the case of Telelap Alf-X robotic hysterectomy. Int J Med Robot. 2016;12:613-9.

76. Kitaguchi D, Watanabe Y, Madani A, Hashimoto DA, Meireles OR, Takeshita N, et al. Artificial intelligence for computer vision in surgery: a call for developing reporting guidelines. Ann Surg. 2022;275:609-11.

77. Kitaguchi D, Takeshita N, Matsuzaki H, Takano H, Owada Y, Enomoto T, et al. Real-time automatic surgical phase recognition in laparoscopic sigmoidectomy using the convolutional neural network-based deep learning approach. Surg Endosc. 2020;34:4924-31.

78. Madani A, Liu Y, Pryor A, Altieri M, Hashimoto DA, Feldman L. SAGES surgical data science task force: enhancing surgical innovation, education and quality improvement through data science. Surg Endosc. 2024;38:3489-93.

79. Mascagni P, Vardazaryan A, Alapatt D, Urade T, Emre T, Fiorillo C, et al. Artificial intelligence for surgical safety: automatic assessment of the critical view of safety in laparoscopic cholecystectomy using deep learning. Ann Surg. 2022;275:955-61.

80. Strasberg SM, Hertl M, Soper NJ. An analysis of the problem of biliary injury during laparoscopic cholecystectomy. J Am Coll Surg. 1995;180:101-25.

81. Madani A, Namazi B, Altieri MS, Hashimoto DA, Rivera AM, Pucher PH, et al. Artificial intelligence for intraoperative guidance: using semantic segmentation to identify surgical anatomy during laparoscopic cholecystectomy. Ann Surg. 2022;276:363-9.

82. Goglia M, Pace M, Yusef M, Gallo G, Pavone M, Petrucciani N, et al. Artificial intelligence and ChatGPT in abdominopelvic surgery: a systematic review of applications and impact. In Vivo. 2024;38:1009-15.

83. Gilson A, Safranek CW, Huang T, Socrates V, Chi L, Taylor RA, et al. How does ChatGPT perform on the United States medical licensing examination (USMLE)? The implications of large language models for medical education and knowledge assessment. JMIR Med Educ. 2023;9:45312.

84. Seeliger B, Pavone M, Schröder W, Krüger CM, Bruns CJ, Scambia G, et al. Skill progress during a dedicated societal robotic surgery training curriculum including several robotic surgery platforms. Surg Endosc. 2024;38:5405-12.

85. Chen R, Rodrigues Armijo P, Krause C; SAGES Robotic Task Force; Siu KC, Oleynikov D. A comprehensive review of robotic surgery curriculum and training for residents, fellows, and postgraduate surgical education. Surg Endosc. 2020;34:361-7.

86. Simmonds C, Brentnall M, Lenihan J. Evaluation of a novel universal robotic surgery virtual reality simulation proficiency index that will allow comparisons of users across any virtual reality simulation curriculum. Surg Endosc. 2021;35:5867-75.

87. Collà Ruvolo C, Afonina M, Balestrazzi E, Paciotti M, Piro A, Piramide F, et al. A comparative analysis of the HUGOTM robot-assisted surgery system and the Da Vinci® Xi surgical system for robot-assisted sacrocolpopexy for pelvic organ prolapse treatment. Int J Med Robot. 2023;2587.

88. Campo R, Wattiez A, Tanos V, Di Spiezio Sardo A, Grimbizis G, Wallwiener D, et al. Gynaecological endoscopic surgical education and assessment. a diploma programme in gynaecological endoscopic surgery. Eur J Obstet Gynecol Reprod Biol. 2016;199:183-6.

89. Cardoso SA, Suyambu J, Iqbal J, Cortes Jaimes DC, Amin A, Sikto JT, et al. Exploring the role of simulation training in improving surgical skills among residents: a narrative review. Cureus. 2023;15:30-5.

90. Giménez M, Gallix B, Costamagna G, Vauthey JN, Moche M, Wakabayashi G, et al. Definitions of computer-assisted surgery and intervention, image-guided surgery and intervention, hybrid operating room, and guidance systems: Strasbourg International Consensus Study. Ann Surg Open. 2020;1:21.