Reshaping Surgical Oncology: The Future Through Biology and Technology

Cerrahi Onkolojinin Yeniden Şekillenmesi: Biyoloji ve Teknoloji Ekseninde Gelecek

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Abstract

The fundamental transformation in surgical oncology in recent years is characterized by the transition from the traditional extensive resection approach to personalized, biology-based approaches. This transition has been made possible through the integration of knowledge from molecular biology, advanced imaging techniques, artificial intelligence-based analyses, and robotic systems into surgical decision-making processes. The modern surgical oncologist is no longer merely a technical operator but a decision-maker who interprets multidisciplinary data and develops patient-specific strategies. Biomarkers, such as circulating tumor DNA, together with minimally invasive techniques and intraoperative navigation systems, provide a scientific basis for the scope and timing of surgery. In the future, the effective synthesis of these technological and biological tools will pave the way for smarter surgical strategies that ensure oncological safety while preserving functional outcomes and become the standard.

Keywords: Surgical oncology, robotic surgery, artificial intelligence, molecular biology, personalized treatment

Öz

Cerrahi onkoloji alanında son dönemde yaşanan temel dönüşüm, geleneksel geniş rezeksiyon anlayışından biyolojik veriye dayalı kişiselleştirilmiş yaklaşımlara geçişle karakterize edilmektedir. Bu geçiş, moleküler biyolojiden elde edilen bilgilerin, gelişmiş görüntüleme tekniklerinin, yapay zeka tabanlı analizlerin ve robotik sistemlerin cerrahi karar süreçlerine entegrasyonu ile mümkün olmuştur. Modern cerrahi onkolog, artık yalnızca teknik bir uygulayıcı değil, bu çok disiplinli verileri yorumlayan ve hasta özelinde strateji geliştiren bir karar verici konumundadır. Dolaşımdaki tümör DNA'sı gibi biyobelirteçler, minimal invaziv teknikler ve intraoperatif navigasyon sistemleri, ameliyatın kapsamını ve zamanlamasını bilimsel temellere oturtmaktadır. Gelecekte, bu teknolojik ve biyolojik araçların etkin sentezi, fonksiyonel sonuçları korurken onkolojik güvenliği sağlayan daha akıllı cerrahi stratejilerin standart hale gelmesine zemin hazırlayacaktır.

Anahtar Kelimeler: Cerrahi onkoloji, robotik cerrahi, yapay zeka, moleküler biyoloji, kişiselleştirilmiş tedavi

Introduction

The transformation in surgical oncology over the past decade has led to a fundamental questioning of traditional approaches. Although the concept of "wider resection" in cancer treatment was often equated with success within the classical surgical paradigm, it is now recognized that this approach can cause unnecessary morbidity when it is not aligned with biological realities. The focus has now shifted to applying the "right resection" determined by tumor biology and patient-specific parameters (1). Modern surgical decision-making is shaped by molecular data, imaging techniques, and patient-centered factors at every stage, from treatment timing to the extent of

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surgery. This shifts the role of the surgeon from being merely a technical operator to becoming an interpreter of biological data and a strategy planner (2). In the redefinition of cancer surgery, the capacity for data analysis and the ability to integrate molecular biology into clinical practice are of central importance.

For instance, through biomarkers such as circulating tumor DNA (ctDNA), risks associated with minimal residual disease can be measured before or after surgery, thereby creating scientifically based rationales for increasing or decreasing the surgical scope (1). This approach enables decision-making based on each patient's biological behavior rather than on classical stage-based protocols. One of the most striking aspects here is that technology plays an active role not only during surgery but also in preoperative assessment and postoperative monitoring processes (3).

The integration of robotic systems has become an important part of this transformation. Robotic tools that enable minimally invasive interventions offer significant advantages, particularly in anatomically complex regions and tumor resections requiring precise maneuvers (4). Platforms such as the Da Vinci Surgical System enhance the surgeon's field of view three-dimensional during surgery, increase precision of movement, and reduce the risk of unnecessary tissue damage. Robotic technologies also contribute more reliably to determining correct resection boundaries by providing the surgeon with the capability to track anatomical details in real-time.

Historically, surgeons planned operations primarily on the basis of macroscopic anatomy, but today advanced imaging technologies and intraoperative navigation systems provide data support at every stage of surgery. The use of intraoperative magnetic resonance imaging (MRI) or computed tomography (CT) facilitates the precise identification of tumor boundaries and the preservation of healthy tissues (5). Thus, decisions about when and to what extent intervention is necessary become less subjective. This situation also increases the importance of multidisciplinary teams; coordinated work with medical oncologists, radiologists, and pathology specialists creates the foundation for more effective use of the data offered by technologies (2).

Taking the tumor microenvironment into account when determining surgical timing has become an increasingly common practice. The genetic profile of the tumor or the dynamics of the immune response can affect not only post-treatment prognosis but also the optimal timing of surgery. Risk predictions before surgery can be made by processing microenvironment data through artificial intelligence (AI)-based analyses (3). Moreover, supporting AI algorithms using deep learning (DL), computer vision, and natural language processing solutions enhances the safety of both clinical and surgical procedures. In this data-intensive environment, the surgeon's role is not merely to perform the operation; it is to read the appropriate algorithms, interpret outputs, and place them in clinical context.

The combined use of robotic systems and AI in complex oncological cases can be expected to improve outcomes. However, the optimal use of such technologies requires high experience beyond standard cases (2). For example, in challenging interventions such as vascular resection or combined thoracoabdominal approaches, the parameters affecting the decision are quite different; here, the surgeon must both understand biological processes and manage these in harmony with technology (2,4). Therefore, at the center of the modern surgical oncologist's profile is the accumulation of interdisciplinary knowledge; such a clinician must be competent both in recognizing tumor cells under the microscope and in planning the most efficient movement of the robotic arm in the operating room.

Personalized treatments are anticipated to reach near-standard levels. The creation of virtual models of organs or tumors through holograms or digital twin technologies is a natural extension of this process. Thus, different resection scenarios can be tested in a virtual environment before the patient undergoes surgery, and potential complications can be visualized. Additionally, communication infrastructures that provide high-speed connections such as 5G will clearly be preferred, particularly in remote surgical planning or training processes (6). High bandwidth and low-latency will facilitate real-time control of robotic operations.

In conclusion, what becomes clear at the introduction stage is this: In the new paradigm where cancer surgery is changing direction, the right resection is implemented not through technical proficiency alone but through the integration of molecular biology knowledge, advanced imaging support, and advanced technologies (1,2). It appears critical for the new generation of surgeons to develop their data-driven thinking skills and understand microenvironmental interactions. The steps taken along this path will lead to surgical strategies for cancer treatment that are more precise and more individualized.

Paradigm Shift in Surgical Oncology: From Where to Where?

Historical Development and Reasons

The historical process of cancer surgery has been shaped largely by the development of technical capacity and the deepening of biological knowledge about the disease. For many years, the dominant approach in surgical oncology was to remove tumor tissue along with the widest possible surrounding anatomical area. The assumption underlying this logic was that as the resection area increased, the risk of recurrence would decrease and survival would increase. However, this approach could

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produce negative outcomes, particularly the inability to preserve organ functions and high morbidity rates (1).

The past understanding favoring radical resection was also strengthened by limited imaging technologies and insufficient systemic treatment options. Surgeons made decisions and planned operations based on macroscopic anatomy, without support from microscopic or molecular data. However, advances in molecular biology, immunology, and imaging over the past thirty years have led to the questioning of this paradigm (7). Understanding cellular-level tumor heterogeneity has revealed that a one-size-fits-all surgical approach is not optimal for every patient. Biological diversity contained significant variability in terms of invasion pathways, metastatic potential, and response to treatment (8).

Among the reasons for this transformation is the increased effectiveness of systemic treatments. With chemotherapy, targeted agents, and immunotherapies, the surgical scope can be narrowed for some tumors. For instance, studies in gastric cancer have shown that routine removal of the omentum is not always necessary, prompting research into omentum-preserving approaches. Similarly, redefining the boundaries of lymphadenectomy in light of biological data has shown that unnecessary nodal dissections can be reduced. This places less physical burden on the patient and can shorten the recovery process (1).

With the development of technology, the surgical decision-making process has become more data-oriented. In the preoperative period, the location and spread pattern of the tumor can be determined in detail with advanced imaging systems, and real-time feedback can be obtained during surgery with intraoperative navigation technologies (3). AI algorithms produce clinically meaningful predictions from large datasets and provide the surgeon with additional information about which areas should be removed.

An examination of the historical process reveals another important factor: advances in communication infrastructure. 4G technology initially increased mobile data speeds, paving the way for early-stage virtual reality applications, while 5G has enabled new practices, such as low-latency remote surgery. This is important not only for overcoming geographical barriers but also for enabling multidisciplinary teams to collaborate simultaneously. Communication technologies have a share in the evolution of the paradigm, particularly in enabling international consultation in complex cases (6).

Economic factors have also played a role in the historical transformation. The problem of access created by high-cost treatments and technologies in low-resource regions has paved the way for a preference for minimally invasive yet effective surgical techniques and for equitable health policies (7). Since the capacity of health systems varies across different regions of the world, "right resection" has gained importance not only on biological grounds but also on socioeconomic grounds.

Another notable finding is the change in clinicians' patient-centered thinking. In traditional models, surgical decisions were mostly based on tumor size and location; the current approach additionally takes into account the patient's general condition, comorbidities, and the impact on quality of life. The trend toward avoiding aggressive surgery has increased, particularly in elderly patients or those with serious systemic diseases (8).

The widespread use of robotic systems throughout the process has also played a determinative role in the historical development. Platforms such as Da Vinci are not merely a technical innovation; they create new opportunities in strategic planning because they offer a working method that reduces the surgeon's physical limitations (3). With advanced maneuverability and three-dimensional imaging support, precision in minimally invasive interventions improves. Thus, some of the extensive resections previously performed with open surgery can now be accomplished with smaller incisions.

The historical process of the paradigm shift can be regarded as a multi-layered movement arising from the combination of the deepening of scientific knowledge, the integration of technology, socioeconomic pressures, and the successes of systemic treatments. Surgical success, which was equated with the concept of "wider area" in the past, today is being replaced by the concept of "biologically appropriate right area" (1,7). The current approaches stated in section 1 gain meaning from this historical background because the change in criteria determining the scope of the procedure over time has redefined the identity of modern surgery.

What Does a Surgical Oncologist do Today?

Clinical Role and Research

In the modern surgical oncologist's profile, clinical duties and scientific research activities constitute two fundamental areas that mutually reinforce each other. In daily practice, the surgical oncologist is beyond being a clinician who coordinates throughout the patient's entire treatment process; they are a decision-maker who can interpret biological data and transform information from different disciplines into a single strategic plan (9). This function is reinforced by active leadership in multidisciplinary tumor councils because these environments enable the processing of information from fields such as medical oncology, radiation oncology, pathology, and genetics on common ground. Here, the surgical oncologist becomes not only the person planning the operation but also the main figure evaluating the harmony of biological and clinical parameters on a patient basis (7).

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In research, the responsibilities of surgical oncologists are gradually expanding. The main goal in this field, ranging from the design and conduct of clinical studies to the organization of biobanks, is to make surgery biology-based (9). In particular, the collection of tissue samples and the provision of appropriate conditions for molecular analyses enable the identification of new biomarkers. Such studies strengthen treatment response predictions while also establishing a solid foundation for targeted therapies (10). Improved resolution of the complex biology of cancer can directly affect surgical timing; the effectiveness of neoadjuvant or adjuvant approaches is examined in this context, providing a scientific basis for the surgeon's decision to intervene.

Technology integration is an integral part of both clinical and research activities. Using imaging-guided surgical techniques to integrate preoperative data into intraoperative real-time navigation systems increases the accuracy of surgery (5). Fluorescence-guided resection or three-dimensional anatomical reconstructions allow a more precise determination of tumor boundaries. Additionally, AI-supported risk prediction models have the potential to optimize clinical decision processes by predicting postoperative complication likelihood in advance (3). The issue at this point is whether technology complements or directs the surgeon's decision-making ability because the data produced by algorithms always require interpretation appropriate to the clinical context.

One of the advantages of the multidisciplinary model is that it provides early access to experimental treatments. The transition process to the use of experimental agents can be faster in patients whose genetic profiles carry specific mutations; for instance, the integration of targeted drugs such as osimertinib in lung cancer patients carrying EGFR mutation into surgical planning increases survival (7). This demonstrates the importance of surgical oncologists' ability to incorporate pharmacogenomic knowledge into clinical procedures.

The biosocial medicine perspective also finds its place here. The patient's life story and sociocultural conditions, as much as their biological parameters, should be taken into account in the treatment plan (11). For example, among patients with socioeconomic constraints, minimally invasive interventions with shorter recovery periods may be preferred over aggressive surgeries requiring long-term hospitalization. Additionally, certain genetic variants observed in endemic regions may require adaptation of targeted protocols.

The effectiveness of the research direction is also measured by the knowledge transferred to younger surgeons. Programs that incorporate simulation-based learning, genetic counseling experience, and palliative care algorithms into the educational curriculum enable future surgical oncologists to reach a comprehensive skill set (9). Experts trained in this way will approach technical excellence in the operating room and will have the capacity to guide scientific research outside it.

Another dynamic observed in the clinic is an increase in data intensity. Genome sequencing, tumor microenvironment analyses, and ctDNA evaluations, when performed in the preoperative period, can shape not only post-treatment prognosis but also behavior during surgery (10). AI systems are employed to process this data rapidly; however, maintaining human oversight remains critical.

Finally, robotic platforms can be regarded as points where technology and biology merge. Robot-assisted systems offer high-precision movement capability while increasing safety in complex anatomies with three-dimensional imaging support (3). However, comprehensive training in the use of such devices; otherwise, it may not be possible to fully realize their advantages.

This multifaceted role and research identity, which can be seen as today's reflection of the historical change emphasized in section 2.1, place modern surgical oncologists in a different position than in the past. The concept of right resection is defined not only by technical skills at the operating table but also by the development of the ability to interpret data, the meaningful integration of molecular and genetic knowledge, and effective participation in the multidisciplinary ecosystem.

From Technical Surgeon to Biological Decision-maker

The technically focused approach that was dominant in cancer surgery in the past is today giving way to a decision-making process based on biological data that considers molecular and systemic integrity. The role of the surgical oncologist is no longer limited to that of a technician who merely performs the operations; it has evolved into a strategic role that determines the optimal timing and scope of intervention by integrating patient-specific biological parameters, the tumor's genetic profile, microenvironment dynamics, and data from multiple disciplines. At the foundation of this change lies the integration of AI-based analyses and advanced imaging techniques into preoperative preparation and intraoperative processes.

DL algorithms can analyze intraoperative CT or MRI data in real-time during surgery, enabling determination of the correct resection boundaries without damaging critical anatomical structures. The surgeon's area of responsibility now begins before surgery. During the preoperative period, the patient's electronic health record, biochemical indicators, and genomic data are jointly evaluated to predict surgical risk and prevent unnecessary interventions. Such risk predictions not only reduce complication rates but also affect clinical decisions across a wide spectrum from resource management to postoperative care planning (3).

One of the most prominent examples of the biological decision-making role is the analysis of ctDNA. For instance, in colorectal

cancer patients at pathological T1 stage, the relationship between ctDNA positivity and lymph node metastasis has been clearly demonstrated; this finding can directly affect the surgeon's choice to perform additional resection or be satisfied with monitoring (1). In the operative field, the surgeon now considers not only anatomy but also the tumor's aggressiveness score and expected biological behavior. It has been shown that the aggressiveness score generated by AI works with higher accuracy than the TNM system in survival prediction; thus, the planned resection width is aligned with the tumor's biology (3). The practical equivalent of this approach is the prevention of unnecessary tissue loss and the increased preservation of organ function.

The survival advantage targeted by radical surgery in the past can also be achieved today with biologically optimized, minimally invasive applications. As multidisciplinary teamwork increases, surgical oncologists' decision-making is increasingly informed by external data. In regular tumor council meetings, pathology reports, molecular marker results (such as EGFR or ALK mutations), and advanced imaging findings can be evaluated at the same table to develop treatment plans specific to a single patient (7). Here, the task of the surgical oncologist is not only to receive this information but also to transform it into a tactical plan that uses this parametric information during surgery.

The role of technological platforms is undeniably significant. Robotic surgical systems are superior to classical manual techniques in both ergonomics and imaging depth. Particularly during resections near complex vascular structures, the precise movement capabilities of robotic arms minimize tissue damage, and the three-dimensional camera system enhances the surgeon's immediate visual assessment. AI-supported video analysis systems also have the potential to increase safety by detecting possible error risks in advance during the intraoperative phase (12).

One of the most striking components of the identity of the modern biological decision-maker is the integration of learning algorithms into operational strategies. Machine learning algorithms can simultaneously analyze different data types (image, genome sequence, proteomic data) and calculate complication probabilities from this information (4). Thus, the surgical oncologist has the flexibility to modify the surgical plan even while at the operating table; sudden developments, such as new mutation information revealed by biopsy results, can be immediately reflected in the surgical strategy.

In addition, surgical simulations and virtual training environments aim to develop the competence of biological decision-makers. Testing which resection is more appropriate in which biological situation in the preoperative period becomes possible through the trial of different tumor scenarios

with digital twin technology (3). This approach offers young surgeons the opportunity to gain experience with different clinical variations. In the future, AI's capacity to analyze the microenvironment may lead to a redefinition of surgical timing. Correct modeling of factors such as tumor stromal structure or immune cell infiltration can show which moment is biologically more advantageous for intervention (10). Thus, individual timing windows can be created instead of classical protocols.

The clinical-research combination described in section 3.1 is elaborated here: the processes of generating scientific knowledge and developing technology become intertwined, and the ultimate goal is intervention at the right time and with the right scope. The shift from technique to biology requires not only expanding the professional skill set but also changing the mental framework. The surgical oncologist must now be able to scientifically explain not only which tissue to resect but also why that tissue should be resected. Molecular profile analysis, AI-based prediction systems, robotic precision, and multidisciplinary knowledge integration constitute the toolkit of this new identity (1,3). For the next generation of surgeons, the primary goal is not merely to eliminate the tumor but to achieve the most beneficial outcome in terms of quality of life and long-term prognosis.

Expanding Surgical Horizon with Technology

Robotics and AI

Robotic surgical systems and the integration of AI are effective tools for implementing the concept of "right resection" in cancer surgery. Particularly in anatomically complex regions, features offered by robotic systems such as three-dimensional vision, motion scaling, and tremor filtering increase the surgeon's precision during surgery (3). These technical advantages can preserve oncological safety by enabling complete tumor removal while reducing the morbidity associated with extensive resection. With motion scaling, millimetric maneuvers can be applied in regions close to vascular structures; an ergonomic working position helps the surgeon maintain concentration during long operations. This enables operations previously considered technically challenging to be performed using less invasive approaches.

AI brings a cognitive dimension to surgery beyond these mechanical advantages. Algorithms performing real-time image analysis can identify critical anatomical details during the intraoperative phase and provide instant alerts to the surgeon. For example, by processing super-resolution imaging data with AI, the boundary between normal and tumor tissue can be revealed much more clearly. This supports not only the complete removal of the tumor but also the preservation of surrounding healthy tissue. AI-based systems can also predict potential error risks by monitoring the intraoperative video stream, thereby

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reducing the likelihood of complications. The combination of AI and robotic navigation at different stages of surgery provides a seamless data flow from preoperative planning to postoperative evaluation (12).

Internet-based remote-access technologies enable these systems to eliminate geographical barriers, allowing experienced surgeons to provide consultation or guidance. This strengthens multidisciplinary decision-making processes at the international level, particularly for cases of rare tumors. From the perspective of integrating molecular biology data into surgical strategy, it is noteworthy that AI algorithms analyze genome sequencing results and histopathological data to produce risk scores (10). With these scores, classical TNM staging can be surpassed when determining resection boundaries; minimal or extensive resection decisions aligned with the tumor's biological behavior can be made (1). Thus, high rates of functional preservation are achieved without compromising oncological safety.

The simulation infrastructures offered by robotic platforms also play an important role in education (11). Through virtual reality-based scenarios, surgeons gain operational practice with different anatomical variations; during these sessions, AI-supported analyses identify potential error points or alternative maneuver routes. For inexperienced surgeons, these settings provide a safe environment for learning prior to actual surgery.

However, technology integration introduces certain limitations and topics for discussion. Robotic systems require high-cost investments and are not accessible in all hospital environments. Additionally, the data produced by AI algorithms need to be interpreted appropriately to the clinical context; otherwise, the risk of misguided strategies may arise (12). This risk decreases when used under the supervision of an experienced surgeon, but it is inappropriate for the algorithm alone to make the final decision. In this context, the human factor remains indispensable.

The ability of robotic systems to perform surgical planning on virtual models in the preoperative period enables testing the biological suitability of different resection scenarios (3). Using organ and tumor models created with digital twin technology, experiments are conducted to determine which interventions minimize loss of function or which conditions reduce the risk of recurrence. This approach strengthens the identity of the biological decision-maker mentioned in section 4 through technology.

In the postoperative period, AI-supported monitoring systems are employed. Recovery indicators and complication symptoms obtained from postoperative imaging data can be detected early (12). AI's rapid processing capacity is advantageous in these data-intensive analyses; however, it becomes meaningful only when combined with the clinician's evaluation.

In the future perspective, the robotic-AI combination with microenvironment information can be expected to form a new standard (10). Stromal structure analysis or immune cell distribution maps will enhance both technical capacity and biological predictive ability for determining the most appropriate intervention time. Thus, even the timing of the operation will be determined not by logistical factors alone but by molecular biology considerations.

In conclusion, robotic and AI-based applications are doing more than just providing technical convenience in surgical oncology; they are also becoming tools that encourage data-driven thinking (3,12). The surgeon is now becoming an expert defined not only by the sharpness of the scalpel in hand, but also by the problem-solving capacity of algorithms working alongside the surgeon and by the precision of the robotic arms. True "right resection" becomes possible through the controlled, scientifically appropriate, and harmonious use of these two forces.

Does Surgery Have a Future in Cancer, and How?

When discussing the future of cancer surgery, it is necessary to examine how elements formed by the paradigm shift from past to present will shape clinical and research practice. Today, operations planned with the "right resection" understanding are based not only on anatomical removal logic but also on the tumor's molecular characteristics, microenvironment interactions, and risk prediction models (1). In such a framework, the future of surgical oncology can preserve its raison d'être by relying on data-driven biological decision-making rather than on technical skill. If intervention can be performed for the right patient at the right time and to the right extent, surgery does not remain in the background against systemic treatments; on the contrary, it is positioned at the center of multidisciplinary integration (9).

In the future, robotic and AI systems are expected to improve the reliability of this decision-making process. The preservation of microstructures with the high precision of robot arms can prevent function loss while also preserving the advantage to be obtained with extensive resection in terms of survival (3). With three-dimensional image support, detailed viewing of the intraoperative wound area enables maneuvers that are limited by classical manual techniques. AI's production of dynamic risk scores during surgery by analyzing genomic data and histopathological findings can shape the surgeon's instant decisions on scientific ground (1). However, these technologies need to provide meaningful interpretations rather than raw data and to situate findings in a clinical context; otherwise, algorithmic outputs may remain disconnected from that context.

Ongoing studies on microenvironment analyses indicate that the timing factor in cancer surgery can be redefined (8). Changes in tumor stromal structure or immune cell infiltration patterns can

provide clues about the risk of post-surgical recurrence, and it may be possible to determine whether early or late intervention is biologically more advantageous. In the development of these predictions, AI-based modeling and long-term follow-up of real patient data can be used together (3). Thus, moving away from classical protocols to create an optimized timing window for each patient is one of the factors strengthening the future position of surgery.

The surgical oncologist's identity will continue to transform internally. The expert of the future will be defined not only by the ability to perform surgery but also by the ability to integrate molecular biology into the clinical plan (9). This new generation of surgeons with high data reading capability will have the equipment to simultaneously analyze image and sensor data from robotic systems while applying information obtained from biomarkers such as ctDNA to surgical strategy (1). This requires educational curricula to focus not only on technical applications but also on understanding algorithm logic and developing data analysis capabilities.

The issue of access is also one of the topics for future discussion. Since robotic systems and advanced imaging technologies require costly investments, inequalities may grow if their use is not supported by equitable health service policies (4). In resource-limited regions, the principle of right resection should be implemented using minimally invasive yet highly effective techniques. Accordingly, research should address both high-technology solutions and optimization methods applicable in low-resource environments.

The power of multidisciplinary teamwork will become even more evident in the future. Thanks to tumor councils where different data types from genetic epithelial changes to proteomic analyses can be evaluated at the same table, surgical decisions will not be based solely on the knowledge set of a single discipline (7). The surgeon will assume the role of coordinator, becoming the person who transforms the information produced by different disciplines into an operational plan. This structure directly contributes to the realization of personalized treatment goals.

An examination of the research infrastructure reveals that there are still unresolved challenges. The design of high-quality prospective studies and reaching sufficient patient numbers still stand as serious obstacles (4). Due to limited clinical interest or insufficient surgeon participation, late validation of some potentially effective techniques may occur. Facilitating data collection through digital platforms and increasing sample sizes through international collaborations can be important steps in this regard.

Additionally, it will be critical to maintain the balance between technology and ethics. Issues such as data privacy, algorithmic bias, and responsibility boundaries should be clearly defined, particularly in AI-supported systems (3). If necessary regulations are not enacted in these areas, the rate of technology adoption may decrease, or clinical trust may be undermined.

Finally, in the new surgical paradigm shaped jointly by biology and technology, the goal should no longer be merely eliminating the tumor; it should be doing this while preserving the patient's quality of life and improving long-term prognosis (8). The concept of right resection is likely to persist in such a context: if both functional preservation and oncological safety can be achieved, surgery will continue to be an important step in modern cancer treatment. Technology integration, knowledge of molecular biology, and multidisciplinary thinking are fundamental components that will make this sustainable (3,9).

Conclusion

Developments in surgical oncology continue to transform the foundation of treatment approaches. In the future, cancer surgery will find direction not only through traditional methods based on anatomical removal, but also through the combination of technologies such as molecular biology, advanced imaging, and AI. This integration will enable the determination of the timing and scope of interventions appropriate to each patient's biological behavior.

The technical capabilities offered by robotic systems enable the preservation of functional tissues by increasing surgical precision, while AI algorithms can perform dynamic risk assessments by processing genomic and histological data. These tools support the surgeon's decision-making process and contribute to the creation of personalized treatment strategies.

Interdisciplinary collaboration will become an integral part of this process. The synthesis of information from different specialties through tumor councils will enrich surgical planning and help achieve patient-centered outcomes. Additionally, updating educational programs to develop skills in data analysis and technology use will prepare future surgeons for this complex environment.

Accessibility and ethical considerations in practice should also be carefully addressed. Cost and equity factors in the dissemination of high-tech solutions should be considered, and the transparency and accountability of algorithmic decision-making should be clarified.

Surgical oncology will continue to exist as a field enriched by scientific advances and technological innovations. The goal is to provide the most appropriate treatment for each patient by balancing tumor control with quality of life. This path requires progress through continuous learning, collaboration, and innovative thinking.

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Footnotes

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