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Advances and Emerging Trends in Surgical Management of Gastric Cancer: A Contemporary Review

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Abstract: Gastric cancer remains one of the most significant global health burdens, representing the fifth most common malignancy and the third leading cause of cancer-related death worldwide. Despite gradual declines in incidence in several regions, it continues to be highly prevalent in East Asia, Eastern Europe, and parts of South America. Surgical resection remains the only potentially curative treatment, but the last two decades have witnessed transformative changes in surgical management, perioperative care, and integration with multimodal therapy. Conventional open gastrectomy has evolved toward minimally invasive laparoscopic and robotic approaches, while refinements in lymphadenectomy, function-preserving resections, and organ-sparing strategies aim to balance oncological radicality with improved postoperative quality of life. Furthermore, multimodal integration with perioperative chemotherapy, immunotherapy, and targeted therapy is reshaping surgical decision-making. Advances in perioperative care, such as Enhanced Recovery After Surgery (ERAS) protocols, combined with novel technologies including fluorescence-guided surgery, artificial intelligence, and 3D simulation, are further optimizing outcomes. This review provides a comprehensive synthesis of these advances, critically analyzing evidence from randomized controlled trials, cohort studies, and international guidelines. We emphasize ongoing controversies, global variations in practice, and future directions, arguing that surgical management of gastric cancer is moving toward a more individualized, minimally invasive, and precision-driven approach integrated within multimodal frameworks.

1. Introduction

Gastric cancer remains a critical global health challenge. According to GLOBOCAN 2020, approximately 1.09 million new cases and more than 769,000 deaths were reported worldwide, accounting for over 7.7% of all cancer deaths [1]. Geographic disparities are pronounced: East Asia, particularly Japan, Korea, and China, bear the highest incidence rates, while the disease burden in North America and Western Europe has gradually decreased due to dietary changes, widespread

refrigeration, and Helicobacter pylori eradication [2]. Nevertheless, gastric cancer continues to represent a leading cause of mortality, often diagnosed at advanced stages in low-resource settings.

Historically, surgical resection has been the cornerstone of curative therapy, with the earliest procedures pioneered by Theodor Billroth in the late 19th century. Since then, surgical management has undergone continuous refinements. The goal has remained consistent: achieving an R0 resection with adequate lymphadenectomy. Yet, the approach to achieving this goal has shifted dramatically. Open gastrectomy, once the universal standard, has been increasingly complemented by laparoscopic and robotic approaches. The refinement of lymphadenectomy, adoption of organ-sparing procedures, and integration with perioperative chemotherapy have further redefined the standard of care.

The rationale for reviewing advances in gastric cancer surgery lies in the rapid evolution of the field. Large-scale randomized controlled trials in Asia and Europe, advances in perioperative care such as ERAS protocols, and the emergence of novel technologies such as fluorescence-guided imaging and artificial intelligence have collectively transformed surgical oncology [3]. However, challenges remain, including disparities in practice across regions, uncertainties regarding the extent of lymphadenectomy, and the high costs of advanced technologies such as robotic surgery. This review synthesizes contemporary evidence, identifies unresolved controversies, and projects future directions, aiming to inform clinical practice and research priorities.

2. Historical Perspectives and Global Practice Variations

The surgical management of gastric cancer has historically varied across regions. In Japan and Korea, nationwide screening programs allow early detection, resulting in a higher proportion of patients eligible for curative resection. The Japanese Gastric Cancer Association (JGCA) established D2 lymphadenectomy as the standard, supported by retrospective and prospective data demonstrating survival benefits [4]. In contrast, Western countries initially favored less extensive D1 dissection due to concerns about perioperative morbidity and mortality.

The Dutch Gastric Cancer Group trial in the 1990s initially reported higher postoperative morbidity and mortality in the D2 group [5]. However, 15-year follow-up data revealed improved disease-specific survival and reduced locoregional recurrence in patients who underwent D2 dissection [6]. This finding shifted Western perspectives, leading to greater acceptance of D2 as the standard in high-volume centers. Similarly, the British MRC trial provided nuanced results that continue to inform guidelines.

China, with its high incidence of gastric cancer, has gradually integrated international evidence into national practice, adopting D2 dissection as the standard for resectable disease while simultaneously exploring minimally invasive techniques [7]. Latin America and parts of Africa, however, face significant barriers to implementing D2 surgery, including limited surgical training and infrastructural challenges. These disparities highlight the importance of tailoring surgical strategies to local healthcare capacities.

Current guidelines reflect this global variation. The JGCA and Korean Gastric Cancer Association strongly recommend D2 dissection, while the National Comprehensive Cancer Network (NCCN) and the European Society for Medical Oncology (ESMO) adopt a more selective stance, recommending D2 dissection only in high-volume centers with experienced surgeons. This ongoing divergence underscores the tension between oncologic radicality and patient safety in surgical decision-making.

3. Conventional Surgical Approaches

Conventional open gastrectomy remains a cornerstone of gastric cancer surgery, particularly for

locally advanced disease. The primary procedures include total gastrectomy, distal (subtotal) gastrectomy, and proximal gastrectomy, with the choice guided by tumor location, stage, and margin considerations. The overriding principle is to achieve an R0 resection, defined as complete tumor removal with negative microscopic margins.

Total gastrectomy is generally indicated for proximal tumors or diffuse-type gastric cancer, where ensuring an adequate proximal margin requires removal of the entire stomach. Subtotal gastrectomy, most commonly distal gastrectomy, is the operation of choice for cancers of the antrum and pyloric regions, with data from randomized controlled trials indicating similar oncologic outcomes to total gastrectomy in appropriately selected cases [8]. Proximal gastrectomy has been explored for early-stage proximal tumors to preserve gastric function, though it carries risks of reflux and nutritional deficiencies unless reconstruction is optimized.

Lymphadenectomy is integral to conventional surgery. The extent is categorized into D1 (perigastric nodes), D1+ (including limited second-tier stations), and D2 (including celiac, splenic, and hepatoduodenal nodes) [9]. Japanese and Korean data consistently support D2 dissection as the standard for stage IB–III disease, providing improved survival with acceptable morbidity when performed in experienced centers [10]. Western trials initially questioned this approach, but long-term follow-up and advances in perioperative care have shifted consensus toward D2 as the global standard in high-volume institutions.

Historically, D3 dissection involving para-aortic nodes was investigated, but randomized trials such as JCOG9501 failed to show a survival benefit, and thus D3 has not been adopted as a standard [11]. Another important aspect of conventional surgery is the controversy over splenectomy and distal pancreatectomy. While these procedures were once routinely performed as part of D2, they are now avoided unless directly invaded by the tumor due to their association with increased morbidity and mortality [12].

Perioperative outcomes of conventional open surgery have improved dramatically over the last few decades. Mortality rates, which exceeded 10% in Western centers during the 1980s, have fallen to less than 2% in high-volume Asian centers today. This progress reflects advances in anesthesia, surgical technique, and postoperative critical care. Nevertheless, open surgery remains associated with longer recovery, more postoperative pain, and delayed return to normal function compared to minimally invasive approaches.

4. Minimally Invasive Gastrectomy

The introduction of minimally invasive surgery (MIS) has revolutionized gastric cancer management. Laparoscopic gastrectomy, first performed in the early 1990s, has matured into an established option for early gastric cancer and, increasingly, for locally advanced disease [13].

Randomized controlled trials have provided robust evidence. The KLASS-01 trial from Korea demonstrated non-inferiority of laparoscopic distal gastrectomy compared to open surgery for early gastric cancer in terms of long-term survival, while also showing advantages in postoperative recovery and reduced blood loss [14]. Similarly, the JCOG0912 trial in Japan confirmed oncologic safety for laparoscopic distal gastrectomy in early-stage disease [15]. For advanced gastric cancer, the KLASS-02 and CLASS-01 trials further validated laparoscopic approaches in expert hands, reporting comparable survival outcomes and improved short-term recovery metrics [16].

Robotic gastrectomy, enabled by platforms such as the da Vinci Surgical System, has expanded the scope of MIS. Advantages include three-dimensional visualization, tremor filtration, and greater dexterity with articulated instruments. Studies suggest that robotic surgery reduces intraoperative blood loss, improves precision in D2 lymphadenectomy, and may shorten the learning curve for complex procedures [17]. However, randomized evidence directly comparing robotic to

laparoscopic surgery remains limited. High costs and longer operative times continue to be barriers to widespread adoption, though ongoing RCTs are expected to clarify its role.

Emerging MIS techniques include reduced-port and single-incision laparoscopic surgery (SILS) [18]. These approaches aim to further reduce surgical trauma and improve cosmetic outcomes. However, technical challenges such as instrument crowding and limited working space restrict their use to highly selected cases in specialized centers. Long-term oncological equivalence has yet to be proven.

Overall, MIS is now established as the preferred approach for early gastric cancer and an increasingly accepted option for advanced cases in experienced centers. Its adoption, however, remains variable globally, depending on surgeon expertise, infrastructure, and healthcare system resources.

5. Function-preserving and Organ-sparing Techniques

Beyond the pursuit of oncologic radicality, there is growing emphasis on preserving function and quality of life. Function-preserving surgical techniques have been increasingly adopted for early-stage disease detected through screening in East Asia.

Pylorus-preserving gastrectomy (PPG) is a representative example. Indicated for early-stage tumors located in the middle third of the stomach, PPG preserves pyloric function, thereby reducing the incidence of dumping syndrome and bile reflux [19]. Long-term data from randomized trials and large retrospective series in Korea and Japan have shown equivalent oncological safety compared to distal gastrectomy, with superior nutritional and functional outcomes.

Proximal gastrectomy with reconstruction has been developed for early upper-third gastric cancers. The key challenge is reflux esophagitis, which is common after simple esophagogastrostomy. Alternative reconstructions, such as double-tract or jejunal interposition, significantly reduce reflux while preserving function [20]. Recent studies demonstrate acceptable oncologic outcomes and improved postoperative quality of life, though technical demands are higher.

Sentinel node navigation surgery represents another major advance. By using tracers such as indocyanine green (ICG) or radioisotopes, surgeons can identify sentinel nodes intraoperatively. Negative sentinel nodes allow for limited gastric resection, avoiding radical gastrectomy in selected early cancers. Trials such as SENORITA in Korea and JCOG0302 in Japan have demonstrated feasibility and safety, though widespread adoption awaits further standardization and confirmation of long-term oncological equivalence [21].

These function-preserving techniques underscore a paradigm shift in gastric cancer surgery: the goal is no longer simply survival, but survival with preserved function and quality of life.

6. Integration with Multimodal Therapy

Surgical management of gastric cancer increasingly takes place within a multimodal framework. Integration of systemic therapy has proven critical to improving outcomes.

Perioperative chemotherapy has become standard in many regions. The landmark MAGIC trial demonstrated that perioperative epirubicin-cisplatin-fluorouracil (ECF) chemotherapy improved survival compared to surgery alone in Western patients. More recently, the FLOT4 trial established the docetaxel-based FLOT regimen as superior to ECF, with higher pathological response rates and improved overall survival [22]. As a result, perioperative FLOT is now considered the gold standard in Europe.

In Asia, neoadjuvant chemotherapy has been increasingly integrated for locally advanced disease. Trials such as JCOG0501 explored S-1 and cisplatin regimens, while ongoing trials continue to

refine protocols [23]. The overall goal is to downstage tumors, improve resectability, and eradicate micrometastases.

Targeted therapies and immunotherapies are reshaping the landscape. HER2-positive gastric cancers benefit from trastuzumab-based regimens, while PD-1 inhibitors such as nivolumab and pembrolizumab are demonstrating survival benefits in advanced and perioperative settings. The CheckMate-649 trial showed significant survival improvements with nivolumab plus chemotherapy, paving the way for immunotherapy integration [24].

Cytoreductive surgery with hyperthermic intraperitoneal chemotherapy (HIPEC) is being investigated for patients with limited peritoneal disease. Although controversial, selected studies suggest potential survival benefits in highly selected patients, though widespread application awaits results from ongoing RCTs such as PERISCOPE II.

The integration of systemic therapies requires close multidisciplinary coordination, with surgical decisions increasingly influenced by systemic treatment response and molecular tumor profiles.

7. Perioperative Care and Enhanced Recovery

Advances in perioperative care have dramatically improved surgical outcomes. Enhanced Recovery After Surgery (ERAS) protocols, originally developed for colorectal surgery, are now widely applied in gastric cancer surgery [25]. ERAS emphasizes multimodal strategies to reduce surgical stress, including preoperative counseling, early mobilization, multimodal analgesia, avoidance of routine drains and nasogastric tubes, and early oral feeding [26].

Large cohort studies and meta-analyses have demonstrated that ERAS reduces hospital stay by 2–3 days, lowers complication rates, and improves patient satisfaction without increasing readmission rates. Implementation requires a multidisciplinary team involving surgeons, anesthesiologists, nutritionists, and nursing staff [27].

Nutrition plays a particularly important role in gastric cancer surgery. Prehabilitation programs focusing on nutritional support, exercise, and psychological preparation are increasingly being adopted. Postoperatively, early initiation of enteral feeding is encouraged, as it is associated with improved recovery and reduced infection risk.

The use of digital health technologies is also emerging in perioperative care. Telemedicine, wearable sensors, and mobile apps facilitate real-time monitoring, early detection of complications, and better continuity of care after discharge.

8. Emerging Technologies and Future Directions

Novel technologies are increasingly influencing gastric cancer surgery, aiming to enhance precision, safety, and outcomes.

Fluorescence-guided surgery using indocyanine green (ICG) has become a powerful intraoperative tool [28]. It enables real-time visualization of lymphatic drainage and vascular perfusion, enhancing lymph node retrieval and reducing anastomotic leak risk. Meta-analyses show that ICG use increases the number of harvested lymph nodes without compromising safety.

Artificial intelligence (AI) and augmented reality (AR) are poised to transform surgical practice. AI-based image analysis supports preoperative planning by predicting lymph node metastasis and tumor margins [29]. Intraoperatively, AI can assist in navigation, margin assessment, and real-time decision-making. AR, integrating imaging data into the surgical field, may provide surgeons with digital overlays of tumor boundaries and vascular anatomy.

Three-dimensional printing and virtual surgical simulation offer personalized preoperative planning. Patient-specific anatomical models facilitate rehearsal of complex procedures, enhance surgical training, and improve patient education.

The concept of precision surgery is emerging, integrating molecular profiling and radiogenomics into decision-making. Tumor biology may increasingly dictate surgical extent and strategy, paving the way for personalized surgery. As genomic and imaging technologies advance, surgery will be tailored not only to the anatomical but also the biological characteristics of the disease.

9. Challenges and Controversies

Despite remarkable advances, several controversies persist in gastric cancer surgery. The appropriate extent of lymphadenectomy remains debated, particularly in Western populations with higher comorbidity rates. While D2 is considered standard in Asia, concerns remain about morbidity in less experienced centers.

The role of minimally invasive surgery in advanced disease is evolving, but questions remain about long-term oncological equivalence and generalizability beyond high-volume centers. Robotic surgery, while promising, is hampered by high costs, limited availability, and lack of definitive randomized evidence demonstrating superiority over laparoscopy.

Function-preserving techniques raise concerns about oncological safety in larger tumors or those with higher risk of lymph node metastasis. Sentinel node navigation surgery, though promising, faces challenges in standardization, reproducibility, and ensuring accuracy across centers.

The integration of immunotherapy into perioperative settings raises new challenges regarding optimal timing, surgical safety, and long-term outcomes. Moreover, disparities in access to advanced surgical technologies persist globally, raising issues of equity and healthcare justice.

10. Conclusion

The surgical management of gastric cancer has entered a transformative era. Traditional open gastrectomy with D2 lymphadenectomy remains the foundation of curative therapy, but minimally invasive approaches, function-preserving procedures, and integration with systemic therapies are rapidly redefining standards of care. Advances in perioperative care and novel technologies such as fluorescence imaging, robotics, and artificial intelligence herald the arrival of precision surgery.

Future progress will depend on international collaboration, rigorous randomized controlled trials, and global efforts to reduce disparities in access to high-quality surgical care. The ultimate goal remains unchanged: to maximize oncologic efficacy while preserving function and quality of life. The next decade is likely to see a paradigm shift toward individualized, minimally invasive, and biologically tailored surgical strategies integrated within multidisciplinary frameworks, ensuring that patients worldwide benefit from the ongoing evolution of gastric cancer surgery.

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