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Advancing gastric cancer surgery: Oncological outcomes and novel approaches in laparoscopic D2 gastrectomy

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ABSTRACT

Introduction: Laparoscopic gastrectomy with D2 lymphadenectomy has become increasingly accepted in high-volume Eastern centers. However, concerns remain regarding the adequacy of nodal dissection and long-term oncological safety, particularly in advanced gastric cancer.

Materials and Methods: 246 Patients who underwent laparoscopic subtotal or total gastrectomy with D2 lymphadenectomy between 2012 and 2022 were analyzed. Demographic, perioperative, and pathological variables were collected. Outcomes included lymph node yield, complications, margin status, overall survival (OS), and disease-free survival (DFS). The impact of indocyanine green (ICG) fluorescence mapping and robotic assistance was evaluated.

Results: Of 246 patients, 162 (65.8%) underwent laparoscopic subtotal gastrectomy and 84 (34.2%) underwent total gastrectomy. The mean number of retrieved lymph nodes was 37.8±9.4, with 100% adequacy. The 30-day mortality was 1.6%, and major complications occurred in 12.6%, with anastomotic leakage in 3.6%. R0 resection was achieved in 94.3% of patients. At a median follow-up of 46 months, 5-year OS and DFS were 58.7% and 52.1%, respectively. In 72 patients with ICG-guided lymphadenectomy, nodal yield increased to 41.6, and robotic assistance (28 patients) was associated with lower morbidity and shorter hospital stay.

Conclusion: Laparoscopic gastrectomy with D2 lymphadenectomy is feasible, safe, and oncologically adequate in high-volume centers. Technical innovations such as ICG fluorescence mapping and robotic assistance enhance surgical precision and may further improve outcomes.

Keywords: D2 lymphadenectomy, gastric cancer, laparoscopic gastrectomy

Introduction

Gastric cancer remains one of the leading causes of cancer-related mortality worldwide, despite improvements in diagnosis and therapy.[1] Its incidence has declined in Western countries but continues to be highly prevalent in East Asia, especially in Japan, Korea, and China, where organized screening and advanced surgical techniques are routine.[2] Radical gastrectomy with D2 lymphadenectomy is considered the standard treatment for resectable gastric cancer, particularly for stage IB–III disease, and is endorsed by the Japanese Gastric Cancer Association (JGCA).[3] Historically, D2 dissection was associated with increased morbidity and mortality in Western trials, but refinements in perioperative management and technical expertise in Eastern centers have substantially improved its safety.[4]

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The introduction of laparoscopy into gastric cancer surgery marked a major step forward in the last two decades.[5] Large randomized controlled trials and meta-analyses from Korea and Japan demonstrated that laparoscopic distal gastrectomy provides equivalent oncological outcomes compared with open surgery, while offering benefits such as less blood loss, reduced pain, and faster recovery.[6,7] Initially, applying laparoscopy to advanced gastric cancer requiring D2 lymphadenectomy was controversial due to concerns regarding technical complexity and adequacy of nodal retrieval.[8] However, accumulating evidence has shown that laparoscopic D2 dissections consistently achieve sufficient lymph node yields, often exceeding 35 nodes, which meets international oncological standards.[9]

In recent years, laparoscopic total gastrectomy has also been validated, with long-term survival outcomes equivalent to open approaches.[10] These advances were made possible by growing surgical experience and the development of adjunctive technologies. Among them, indocyanine green (ICG) fluorescence imaging has emerged as a promising tool for real-time lymphatic mapping, enabling more precise and complete nodal dissection.[11] Prospective studies from Japan and Korea have shown that ICG-guided lymphadenectomy increases the number of retrieved lymph nodes and improves staging accuracy.[12] Another innovation is robotic-assisted gastrectomy, which provides enhanced dexterity, tremor filtration, and three-dimensional visualization.[13] Robotic systems have been associated with reduced blood loss, better ergonomics, and potentially fewer complications, though cost and accessibility remain limitations.[14]

Against this background, the present study aimed to evaluate the perioperative safety, oncological adequacy, and long-term outcomes of laparoscopic gastrectomy with D2 lymphadenectomy in a large consecutive series of 246 patients. We further analyzed the impact of technical innovations such as ICG-guided fluorescence mapping and robotic assistance on nodal retrieval, complications, and survival.

Materials and Methods

This retrospective cohort study was conducted at a tertiary referral center between January 2012 and December 2022. A total of 246 patients who underwent laparoscopic gastrectomy with D2 lymphadenectomy for histologically confirmed gastric adenocarcinoma were included. The study was approved by the institutional ethics committee, and informed consent was obtained from all patients.

Patient Selection

Inclusion criteria were:

Age ≥18 years,

Diagnosis of gastric adenocarcinoma confirmed by preoperative endoscopic biopsy,

No evidence of unresectable or metastatic disease at the time of surgery (except limited peritoneal implants amenable to resection in selected stage IV cases),

Completion of a laparoscopic subtotal or total gastrectomy with curative intent and standard D2 lymphadenectomy.

Exclusion criteria were:

Emergency surgery for bleeding or perforation,

Palliative bypass procedures without resection,

Patients with incomplete clinical or pathological data.

Preoperative Evaluation

All patients underwent standard staging work-up, including upper gastrointestinal endoscopy, computed tomography (CT) of the chest and abdomen, and in selected cases, positron emission tomography (PET-CT). Staging laparoscopy was performed when peritoneal dissemination was suspected. Preoperative comorbidities were documented and classified according to the American Society of Anesthesiologists (ASA) physical status score and Eastern Cooperative Oncology Group (ECOG) performance status. The ASA physical status classification and ECOG performance status were recorded according to standard definitions. The extent of gastrectomy and lymphadenectomy was defined in accordance with the Japanese Gastric Cancer Association (JGCA) guidelines.

Surgical Technique

All procedures were performed laparoscopically by experienced surgical teams specialized in minimally invasive gastric surgery. Subtotal gastrectomy was performed in 162 patients (65.8%), and total gastrectomy in 84 patients (34.2%). Standard D2 lymphadenectomy was carried out in accordance with the Japanese Gastric Cancer Association (JGCA) guidelines, including systematic dissection of perigastric and extraperigastric nodal stations (No. 1–12). Reconstruction was achieved using either a linear stapled or hand-sewn technique for gastrojejunostomy or esophagojejunostomy.

In the last 72 patients, indocyanine green (ICG)-guided fluorescence imaging was utilized for intraoperative lymphatic mapping to enhance nodal retrieval. Additionally, 28 patients (11.4%) underwent robotic-assisted laparoscopy, integrated into the treatment protocol during the later study period.

Neoadjuvant chemotherapy was administered in patients with clinically stage II or higher disease according to the institutional multidisciplinary board recommendation, typically using a platinum–fluoropyrimidine–based doublet regimen. Adjuvant chemotherapy was considered for pathologic stage II–III disease, following current international guidelines

Data Collection

Demographic characteristics (age, sex, body mass index [BMI]), ASA and ECOG scores, tumor location, histological subtype, operative details (operation time, blood loss, conversion rate), pathological findings (tumor stage, T and N classification, number of retrieved and metastatic lymph nodes, resection margin status), and perioperative complications were recorded. Postoperative complications were graded according to the Clavien–Dindo classification, and anastomotic leakage, intraabdominal abscess, bleeding, and pulmonary complications were analyzed separately.

Outcome Measures

The primary outcomes were the number of lymph nodes retrieved, the radicality of resection (R0/R1), and postoperative morbidity and mortality. Secondary outcomes included disease-free survival (DFS) and overall survival (OS), calculated from the date of surgery to recurrence, death, or last follow-up. Survival analyses were performed using the Kaplan–Meier method. Recurrence was evaluated using a combination of clinical assessment, tumor marker monitoring, and imaging studies (contrast-enhanced CT or PET-CT). The diagnosis of recurrence was confirmed based on radiologic and/or clinical findings consistent with disease progression

Statistical Analysis

All data were analyzed using IBM SPSS Statistics version 28.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean±standard deviation (SD) or median (range), and categorical variables as frequencies and percentages. The chi-square or Fisher's exact test was used for categorical variables, and the Student's t-test or Mann–Whitney U test for continuous variables, as appropriate. Survival outcomes were compared using the log-rank test, and multivariate analyses were performed with the Cox proportional hazards model. A p-value <0.05 was considered statistically significant.

Ethical Approval

This study was approved by the Ethics Committee of Erzurum City Hospital (No: 2025/03-159, Date: 11/03/2025). All procedures were conducted in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments.

Results

A total of 246 patients who underwent laparoscopic gastrectomy with D2 lymphadenectomy were analyzed. The median follow-up period was 46 months (range, 12–118 months).

Patient Characteristics

Of the patients, 158 (64.2%) were male and 88 (35.8%) were female, with a mean age of 61.4±10.8 years (range, 33–82 years). The mean body mass index (BMI) was 24.5±3.2 kg/m². According to the ASA classification, 54 patients (22.0%) were ASA I, 113 (46.0%) ASA II, 94 (38.2%) ASA III, and 20 (8.1%) ASA IV. ECOG performance status was 0 in 54 patients (22.0%), 1 in 118 (48.0%), 2 in 62 (25.2%), and 3 in 12 (4.9%). The majority of patients (72.4%) had at least one comorbidity, most frequently hypertension and diabetes mellitus (Table 1).

Table 1. Patient Characteristics

Variable	Value
Total patients	246
Male	158 (64.2%)
Female	88 (35.8%)
Mean age (years)	61.4±10.8
Mean BMI (kg/m²)	24.5±3.2
ASA I/II/III/IV	54/113/94/20
ECOG 0/1/2/3	54/118/62/12

Tumor Characteristics

Tumor localization was in the antrum/corpus in 134 cases (54.4%), proximal stomach/cardia in 76 (30.9%), and diffuse or whole-stomach involvement in 36 (14.6%). Histologically, intestinal-type adenocarcinoma was predominant (158 patients, 64.2%), followed by diffuse type (74 patients, 30.1%) and mixed type (14 patients, 5.7%).

Pathological staging according to the AJCC 8th edition revealed stage I disease in 46 patients (18.7%), stage II in 82 (33.3%), stage III in 98 (39.8%), and stage IV in 20 patients (8.1%). Most stage IV patients had limited peritoneal implants or positive cytology, and all underwent resection with curative intent.

Operative Outcomes

A total of 162 patients (65.8%) underwent laparoscopic subtotal gastrectomy and 84 patients (34.2%) laparoscopic total gastrectomy. The mean operative time was 242±48 minutes (range, 180–370 min), significantly longer in total gastrectomy cases ($p<0.05$). The mean estimated blood loss was 178±65 ml, also higher in total gastrectomy ($p<0.05$).

Conversion to open surgery was required in 14 patients (5.6%), primarily due to uncontrolled bleeding (n=6), dense adhesions (n=5), or technical difficulty in advanced tumors (n=3) (Table 2).

Lymph Node Dissection

A complete D2 lymphadenectomy was achieved in all cases. The mean number of retrieved lymph nodes was 37.8±9.4 (range, 28–62), and adequate nodal harvest (>15 nodes) was 100%. The mean number of metastatic lymph nodes was 4.2±3.6.

In the subgroup of 72 patients who underwent ICG-guided fluorescence lymphatic mapping, the mean number of retrieved nodes increased to 41.6±8.7, which was statistically higher compared with the conventional group ($p=0.021$). Furthermore, the nodal upstaging rate (detection of additional positive nodes) was slightly higher in the ICG group ($p=0.07$).

Postoperative Morbidity and Mortality

The 30-day postoperative mortality was 1.6% (n=4). Major postoperative complications (Clavien–Dindo ≥ III) occurred in 31 patients (12.6%). The most frequent severe complication was anastomotic leakage (n=9, 3.6%), followed by intraabdominal abscess (7, 2.8%), pulmonary complications (6, 2.4%), postoperative bleeding (5, 2.0%), and other causes (4, 1.6%) (Table 3, Fig. 1).

The mean hospital stay was 9.4±3.2 days (range, 6–24 days). Patients with major complications had significantly longer hospital stays ($p<0.001$). Reoperation was required in 8 patients (3.2%), mainly for leakage or bleeding.

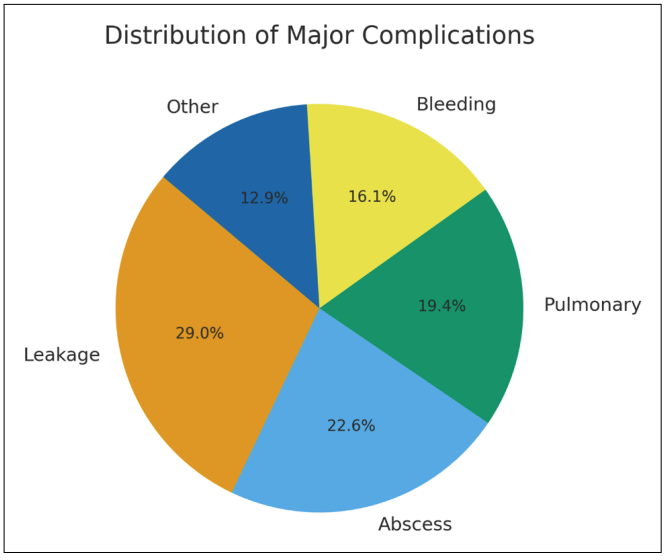

Figure 1. Distribution of Major Postoperative Complications.

Table 2. Operative Outcomes

Variable	Value
Subtotal gastrectomy	162 (65.8%)
Total gastrectomy	84 (34.2%)
Mean operative time (min)	242±48
Mean blood loss (ml)	178±65
Conversion to open surgery	14 (5.6%)

Table 3. Postoperative Complications

Complication	n (%)
Anastomotic leakage	9 (3.6)
Intraabdominal abscess	7 (2.8)
Pulmonary complication	6 (2.4)
Bleeding	5 (2.0)
Other	4 (1.6)
Total major morbidity	31 (12.6)
30-day mortality	4 (1.6)

Pathological and Margin Status

R0 resection was achieved in 232 patients (94.3%), whereas R1 margins were observed in 14 patients (5.7%), mostly in those with T4b or stage IV tumors. The rate of R0 resection was significantly lower in advanced-stage disease (p=0.003).

Oncological Outcomes

The median follow-up was 46 months. The 3-year overall survival (OS) rate was 71.2%, and the 5-year OS was 58.7%. The 3-year disease-free survival (DFS) rate was 66.4%, and the 5-year DFS was 52.1% (Fig. 2).

When analyzed by stage, 5-year OS was 92.3% for stage I, 71.8% for stage II, 44.9% for stage III, and 22.1% for stage IV (p<0.001, log-rank test) (Fig. 3). Patients with ICG-guided lymphadenectomy demonstrated a non-significant trend toward improved DFS at 3 years (p=0.09).

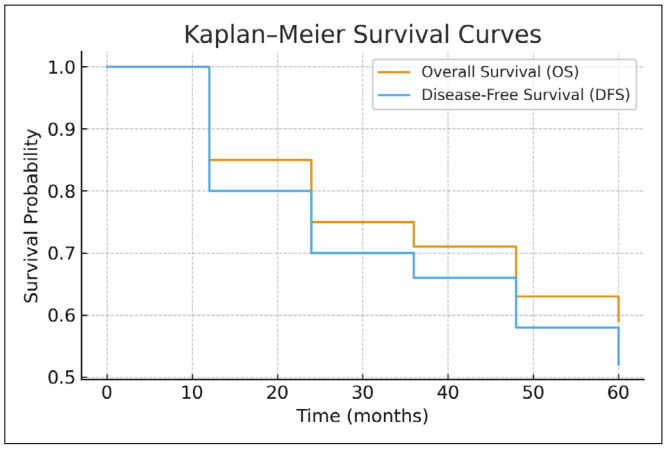

Figure 2. Kaplan–Meier Survival Analysis for Overall and Disease-Free Survival.

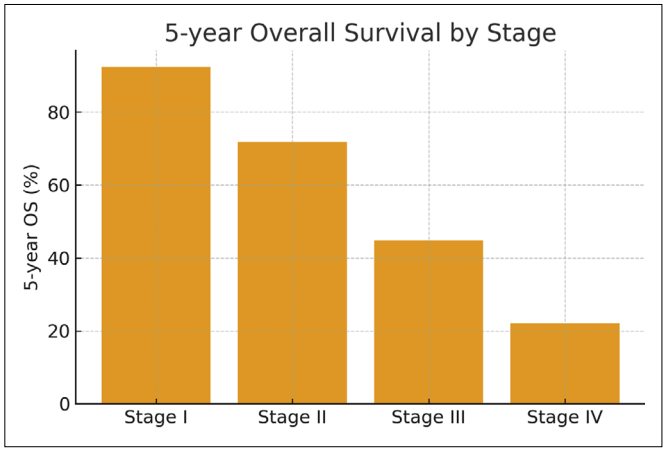

Figure 3. Five-Year Overall Survival Rates According to Pathological Stage.

Subgroup analysis revealed that patients undergoing robotic-assisted laparoscopy (n=28) had a lower rate of major complications (7.1% vs 13.4%, p=0.12) and a shorter median hospital stay (7 vs 10 days, p=0.04) compared with conventional laparoscopy.

Discussion

This study of 246 patients demonstrated that laparoscopic gastrectomy with D2 lymphadenectomy is both feasible and oncologically safe when performed in a high-volume Eastern center. The mean number of retrieved lymph nodes was 37.8, which exceeds the international benchmark of 15 nodes and is comparable to outcomes from Korean and Japanese multicenter trials.[6,9] Adequate nodal clearance is a critical determinant of staging accuracy and long-term prognosis, and our results confirm that laparoscopic approaches can meet oncological standards.

Perioperative outcomes were favorable. The conversion rate to open surgery was 5.6%, which is consistent with recent Eastern series reporting rates of 3–8%.[7,9] Major complications occurred in 12.6% of patients, with anastomotic leakage in 3.6%, intraabdominal abscess in 2.8%, pulmonary complications in 2.4%, and postoperative bleeding in 2.0%. These outcomes closely mirror complication rates reported in large-scale Korean and Japanese studies.[10,12] The 30-day mortality of 1.6% is also within the acceptable range for gastric cancer surgery and demonstrates the safety of laparoscopic D2 procedures in experienced hands.[15,16]

Long-term outcomes were encouraging. The five-year overall survival rate was 58.7%, and the five-year disease-free survival rate was 52.1%. When stratified by stage, survival reached over 90% for stage I, about 72% for stage II, 45% for stage III, and 22% for stage IV, which is consistent with published Eastern cohorts.[5,10,17] These results demonstrate that laparoscopic D2 gastrectomy does not compromise long-term oncological efficacy compared with open surgery.

An important finding in our study was the benefit of ICG fluorescence mapping. In the subgroup of 72 patients who underwent fluorescence-guided lymphadenectomy, the mean nodal yield increased significantly to 41.6. This result aligns with reports from Japanese and Korean groups, which demonstrated that ICG facilitates identification of lymphatic channels and improves lymph node harvest.[18,19] Although our study was not powered to assess survival differences, a trend toward improved disease-free

survival was observed in the ICG group, suggesting that enhanced nodal clearance may translate into oncological benefits, a finding that has also been noted in other Eastern prospective trials.[20]

Robotic-assisted surgery was performed in 28 patients and was associated with fewer major complications and shorter hospital stays compared with conventional laparoscopy. Although the differences did not reach statistical significance, the trend is consistent with recent multicenter Korean analyses showing that robotic gastrectomy reduces intraoperative blood loss and may lower anastomotic leakage rates.[21,22] Nonetheless, the cost-effectiveness of robotic approaches remains uncertain, and their availability is limited to specialized centers.[23]

Our results emphasize the importance of surgical expertise, institutional experience, and multidisciplinary care in achieving favorable outcomes with laparoscopic D2 gastrectomy. The learning curve for total gastrectomy and advanced D2 dissections is steep, but with adequate case volume and training, outcomes comparable to open surgery can be achieved.[7,24] These findings are highly relevant for global practice, as Western adoption of minimally invasive D2 gastrectomy has been slower, partly due to lower gastric cancer incidence and differences in surgical training.[2,25]

The strengths of our study include its relatively large sample size, standardized surgical technique, and comprehensive follow-up, which provide robust long-term data. Furthermore, the integration of fluorescence and robotic innovations offers valuable insights into the future of gastric cancer surgery. However, certain limitations should be acknowledged. The retrospective design introduces the possibility of selection bias, and the absence of a contemporaneous open surgery control group limits direct comparison. Additionally, while survival outcomes were promising, larger randomized trials are needed to validate the oncological equivalence of laparoscopic D2 gastrectomy across diverse patient populations.[8,21]

Conclusion

In conclusion, laparoscopic gastrectomy with D2 lymphadenectomy is a safe and effective treatment for gastric cancer in high-volume centers. Adequate lymph node yields, acceptable complication rates, and favorable survival outcomes support its role as a standard surgical option. Technical innovations such as ICG fluorescence mapping and robotic assistance further enhance surgical precision and may improve patient outcomes. Future multicenter prospective studies are necessary to confirm these findings and establish cost-effective strategies for integrating new technologies into routine practice.

Disclosures

Ethics Committee Approval: This study was approved by the Ethics Committee of Erzurum City Hospital (No: 2025/03-159, Date: 11/03/2025).

Peer-review: Externally peer-reviewed.

Conflict of Interest: None declared.

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