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PREDICTIVE MODELING AND ECONOMIC IMPACT OF SURGICAL TACTICS IN PERFORATION-ASSOCIATED PERITONITIS

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Abstract: Perforated duodenal ulcer with resulting peritonitis remains a critical issue in emergency surgery. We propose an optimized surgical strategy based on preoperative prediction of peritonitis severity for each patient. A total of 53 patients were divided into a main group (optimized approach) and a comparison group (standard treatment). The developed approach tailors the operative method to the extent of peritonitis – ranging from minimal emergency closure of the perforation with abdominal lavage in severe diffuse peritonitis to a more definitive surgical procedure in contained or moderate cases. A clinical and economic analysis was performed: the optimized-tactics group showed reduced mortality and postoperative complication rates, shorter hospital stays, and lower overall treatment costs compared to the comparison group. These results indicate that using a severity-guided surgical strategy improves patient outcomes and is cost-effective by reducing complications and avoiding repeated surgeries.

Keywords: perforated duodenal ulcer; peritonitis; surgical strategy; laparoscopy; cost-effectiveness.

ПРОГНОСТИЧЕСКАЯ МОДЕЛЬ И ЭКОНОМИЧЕСКАЯ ЭФФЕКТИВНОСТЬ РАЗЛИЧНЫХ МЕТОДОВ ХИРУРГИЧЕСКОГО ЛЕЧЕНИЯ ПРИ ПЕРФОРАТИВНОЙ ЯЗВЕ ДВЕНАДЦАТИПЕРСТНОЙ КИШКИ

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Резюме: Перфоративная язва двенадцатиперстной кишки, осложнённая перитонитом, остаётся серьёзной проблемой неотложной абдоминальной хирургии, связанной с высоким риском осложнений, летальности и экономических затрат. В данной работе проведён сравнительный анализ результатов лечения 53 пациентов, разделённых на две группы: основную (оптимизированная хирургическая тактика с учётом тяжести перитонита) и сравнительную (традиционное ведение). В основной группе использовалась стратификация риска на основе индекса

Маннгейма, шкалы SOFA и уровня лактата. У пациентов с высокой тяжестью проводилась ограниченная операция (ушивание + санация), при стабильном состоянии — лапароскопическое ушивание или радикальная операция. Полученные результаты продемонстрировали снижение летальности, частоты осложнений, продолжительности госпитализации и общих расходов на лечение в основной группе. Предложенный подход позволяет повысить клиническую и экономическую эффективность при лечении перфоративной язвы ДПК.

Ключевые слова: Перфоративная язва; двенадцатиперстная кишка; перитонит; хирургическая тактика; лапароскопия; индекс Маннгейма; прогноз; экономическая эффективность.

Relevance. Peptic ulcer perforation is a serious complication of peptic ulcer disease, demanding urgent surgical intervention. Although the overall incidence of perforated peptic ulcer has declined with widespread *Helicobacter pylori* treatment and proton-pump inhibitors, it remains a significant healthcare problem, accounting for roughly 5% of ulcer patients and carrying a high mortality rate (up to 20–30% in some series). Perforation of a duodenal ulcer leads to spillage of gastric/duodenal contents into the peritoneal cavity, causing diffuse peritonitis. This condition can rapidly progress to septic shock and multi-organ failure if not promptly and adequately managed. Key prognostic factors that markedly worsen outcomes include delayed presentation (>24 hours after perforation), hemodynamic shock on admission, advanced age (>60–70 years), and significant comorbid illness. These factors are often incorporated into risk stratification scores for perforation peritonitis, such as the Boey score (which allocates points for shock, comorbidities, and delay >24h) and the MPI. Indeed, patients presenting with any combination of shock, prolonged perforation, or organ dysfunction face much higher postoperative morbidity and mortality. In such high-risk cases, conventional one-size-fits-all surgical approaches may be suboptimal. This underscores the relevance of an optimized surgical strategy that considers the severity of peritonitis to guide management choices.

Peritonitis severity can be quantified using prognostic scoring systems. The Mannheim Peritonitis Index (MPI) is a validated tool that assigns weighted points for adverse factors (e.g. organ failure, malignancy, time >24h, diffuse peritonitis) and stratifies patients into risk categories. High MPI scores (e.g. ≥ 26 –29) strongly correlate with increased mortality. Likewise, the Sequential Organ Failure Assessment (SOFA) score gauges the degree of organ dysfunction (cardiovascular, renal, respiratory, etc.), and rising SOFA indicates evolving sepsis and poorer prognosis. An initial serum lactate level is another critical indicator – hyperlactatemia reflects tissue hypoperfusion and systemic shock; for instance, lactate >4 mmol/L on admission suggests severe sepsis and is associated with greater mortality. These metrics not only predict outcomes but

can also guide therapy: for example, resuscitation goals in sepsis include normalizing lactate and achieving adequate urine output and blood pressure. By assessing MPI, SOFA, and lactate, the surgical team can judge how “sick” a patient is on presentation. Integrating these prognostic tools into decision-making may allow a tailored surgical approach – from minimally invasive repair in stable cases to damage-control surgery in fulminant peritonitis.

The objective of this study was to assess the impact of an optimized surgical management strategy for perforated duodenal ulcer, tailored according to peritonitis severity prognosis, on clinical outcomes and economic efficiency, in comparison to the standard surgical treatment.

Materials and Methods. We conducted a single-center prospective cohort study at a tertiary academic hospital. The study period spanned 24 months, during which all patients presenting with acute perforated duodenal ulcer and generalized peritonitis were evaluated for inclusion. The diagnosis of perforated ulcer was confirmed by imaging (free air under diaphragm on X-ray or CT scan) and intraoperative findings. Ethical approval was obtained from the institutional review board, and informed consent was obtained from all patients or next-of-kin in emergencies.

A total of 53 adult patients (age ≥ 18) with perforation of a duodenal ulcer resulting in secondary peritonitis were included. Patients with perforated gastric ulcers, traumatic perforations, or ulcer perforation with a well-contained abscess (localized peritonitis) were excluded to maintain a homogeneous cohort. All included patients had evidence of diffuse peritoneal contamination (free gas and fluid on imaging, diffuse peritonitis on exam). The majority (81%) were male, reflecting the typical male predominance in PUD perforation. Mean patient age was 48.6 ± 16.2 years, and 30% had at least one major comorbidity (e.g. cardiovascular disease or diabetes). At presentation, 8 patients (15%) were in septic shock (systolic BP < 90 mmHg requiring vasopressors), and 10 (19%) had a delay > 24 hours from symptom onset to admission – factors evenly distributed between groups.

Upon admission, severity of peritonitis was quantified for each patient using MPI, SOFA, and initial lactate. The MPI was calculated from clinical and intraoperative data (factors: age > 50 , organ failure, malignancy, origin of sepsis, extension of peritonitis, time > 24 h, etc.), yielding scores ranging 12–41 in our cohort (mean ~ 26 in both groups). Patients were categorized as low risk (MPI ≤ 20), intermediate (21–29), or high risk (≥ 30) – 32% of patients were high-risk by MPI. The SOFA score was computed based on admission vitals and labs; mean SOFA was 4.7 ± 2.1 , with 6 patients having SOFA ≥ 8 (suggesting significant organ dysfunction). Blood lactate was measured from arterial blood gas; mean lactate was 3.4 ± 2.0 mmol/L, with 11 patients (21%) > 4 mmol/L (consistent with septic shock). We also noted the Boey score for each patient (three risk factors: shock, comorbidity, perforation > 24 h); 7 patients (13%) had Boey score 3. Importantly, there were no statistically significant differences in

these baseline severity indicators between the two study groups (Table 1). This ensured a fair comparison, as both groups had similar proportions of high-risk and low-risk cases.

Study Groups: Patients were non-randomly allocated into two management arms based on date of presentation (odd vs even days) to avoid selection bias:

Main Group (Optimized Tactics, n = 28): This group was managed with an algorithm that tailored surgical tactics to the predicted severity of peritonitis. Key components of the optimized strategy were:

Aggressive initial resuscitation following sepsis guidelines, with attention to endpoints like mean arterial pressure ≥ 65 mmHg, urine output ≥ 0.5 mL/kg/h, and lactate clearance. Patients in shock received prompt fluid boluses, broad-spectrum antibiotics, and vasopressors as needed prior to surgery (without undue delay).

Risk-based surgical approach: For patients stratified as low-to-moderate risk (e.g. MPI < 30 , no refractory shock), emergency laparoscopy was the preferred approach. Experienced surgeons performed laparoscopic repair of the duodenal perforation with an omental patch (Graham patch) when feasible. A 4-port technique was used, and a thorough peritoneal lavage with warm saline was done laparoscopically. If laparoscopy revealed large perforations (> 10 – 15 mm) or unfavorable conditions (friable tissue, extensive contamination), a decision to convert to open surgery was made early. High-risk patients (MPI ≥ 30 , or exhibiting hemodynamic instability despite resuscitation) underwent damage-control surgery via open laparotomy: a quick surgery consisting of simple closure of the perforation (usually with an omental patch) and extensive lavage, with temporary abdominal closure if required. For instance, in 3 of the sickest patients, an open abdomen with vacuum-assisted closure was employed, planning for a second-look operation.

Planned re-interventions for severe cases: In the optimized group, if peritonitis was purulent/feculent and MPI high, a planned second-look laparotomy at ~ 24 – 36 hours was scheduled (in 5 patients) to reassess and re-lavage the abdomen. This proactive strategy aimed to mitigate the risk of missed sepsis or anastomotic failure in very ill patients, rather than waiting for clinical deterioration.

Postoperative critical care was likewise guided by severity scores – high-risk patients were managed in ICU with goal-directed therapy (e.g. ventilatory support, renal support as needed). Daily SOFA and lactate were trended; failure of lactate to clear or SOFA to improve would trigger aggressive investigation (e.g. CT for abscess) or intervention.

Comparison Group (Standard Tactics, n = 25): This group received the conventional surgical management for perforated duodenal ulcer, representing the historical standard. All patients in this arm underwent urgent open surgery (laparotomy) through an upper midline incision. The perforation on the duodenum was sutured primarily and reinforced with a Graham omental patch

in every case, followed by thorough peritoneal lavage and closed abdomen. No formal risk stratification protocol was applied to alter the surgical plan – even patients with severe physiology were managed with the same one-stage procedure, at the surgeons' discretion. There were no planned second-look operations in this group; reoperations were only done if clinically indicated by deterioration. Postoperatively, these patients received routine care: ICU admission was based on clinical judgment (generally for shock or ventilation needs), and no specific protocol for serial lactate or scoring was mandated (though these were recorded for study purposes).

Both groups received similar adjunct treatments: all patients were started on broad-spectrum antibiotics covering gut flora (typically a carbapenem or piperacillin-tazobactam plus antifungal if *Candida* was suspected) as per hospital sepsis protocol. Proton pump inhibitors were given intravenously. If *Helicobacter pylori* was confirmed by biopsy or urease test (done intraoperatively in 42 patients), appropriate eradication therapy was prescribed after recovery. Nutritional support was provided via enteral feeding as early as tolerated.

Table 1

Baseline Characteristics of Patients in Optimized vs Standard Groups

Characteristic	Optimized (n=28)	Standard (n=25)	<i>p</i> -value
Age, years (mean ± SD)	49.2 ± 17.0	48.0 ± 15.5	0.80
Male sex, % (n)	78.6% (22)	80.0% (20)	0.89
Comorbidity (≥1), % (n)	32% (9)	28% (7)	0.75
Time from perforation to surgery	10.4 ± 5.8 hours	11.0 ± 6.1 hours	0.74
Shock on admission (% of patients)	17.9% (5)	12.0% (3)	0.71
MPI score (mean ± SD)	26.5 ± 6.1	25.8 ± 5.4	0.67
MPI ≥ 26 ("high risk"), % (n)	35.7% (10)	32.0% (8)	0.77
SOFA score (mean ± SD)	4.9 ± 2.3	4.6 ± 2.0	0.65
Lactate on admission (mmol/L)	3.5 ± 2.1	3.3 ± 1.9	0.78
Boey score 0/1/2/3 (n)	6/14/6/2	5/13/6/1	0.88†
Pre-op serum albumin (g/L)	33.1 ± 5.0	34.0 ± 4.6	0.47
Size of ulcer perforation (mm)	6.8 ± 3.1	7.4 ± 3.7	0.53
Laparoscopic approach attempted	57% (16/28)	16% (4/25)	0.002

This table confirms that any outcome differences are likely attributable to the management strategy rather than initial disparities. Both groups had comparable risk profiles – for instance, approximately one-third in each had MPI in the high-risk range. The Optimized group did have a much higher usage of laparoscopy (16 patients vs only 4 patients in Standard), reflecting the protocol's emphasis on minimally invasive surgery for suitable cases.

Results and Discussion. All 53 patients underwent successful surgical repair of the duodenal perforation. In the Optimized group, 16 of 28 patients (57%) were managed laparoscopically at initial surgery. Of these, 2 required conversion to open laparotomy due to technical difficulties (dense adhesions in one case, large perforation ~20 mm in another). For the 12 patients in the Optimized arm who had primary open surgery, 7 were planned open approaches due to high risk (shock or MPI >29), and 5 were conversions as noted. Additionally, 5 patients (18%) in this group underwent a planned second-look laparotomy ~24 hours post-initial surgery: in 3 cases to wash out residual contamination and ensure no missed visceral injury, and in 2 cases to perform a delayed definitive closure after an initial damage-control packing. In contrast, the Standard group had 4 patients (16%) initially attempted laparoscopically – 3 of those were converted to open due to poor visibility and friable ulcer edges. Thus effectively *only 1 patient* in the Standard arm had a completely laparoscopic repair, whereas the rest (96%) had open surgery with a one-stage procedure. No planned second-look operations were scheduled in the Standard protocol; however, 3 patients (12%) required an unplanned reoperation in the early postoperative period (discussed below).

Postoperatively, all patients were managed in ICU if they met sepsis criteria or had significant comorbidities; this included 10 patients from the Optimized group and 9 from the Standard group ($p=0.79$). The mean duration of ICU stay, however, differed: Optimized patients spent a shorter time in ICU on average (2.8 ± 1.5 days) vs Standard (4.1 ± 2.3 days, $p=0.04$), likely owing to faster physiological stabilization. In the Optimized group, intensive monitoring and proactive interventions (guided by lactate and SOFA trends) were credited with preventing further decline – for example, lactate normalized to <2 mmol/L within 12 hours in 80% of Optimized patients who had initial hyperlactatemia, as aggressive source control and resuscitation took effect.

The optimized, severity-driven strategy was associated with a lower postoperative mortality compared to standard management. In-hospital (30-day) mortality was 7.1% (2 of 28 patients) in the Optimized group, versus 20.0% (5 of 25 patients) in the Standard group. Although this ~3-fold reduction in mortality did not reach statistical significance given the sample size ($p = 0.17$, Fisher's test), it is clinically meaningful. Both deaths in the Optimized group were in elderly, high-MPI patients who presented in refractory septic shock – one died from multi-organ failure on post-op day 5 despite intensive care, and the other from fulminant myocardial infarction unrelated to surgical issues. In the Standard group, the five deaths were primarily due to uncontrolled sepsis: two patients died of abdominal septic shock with organ failure (one had an unrecognized anastomotic leak; one had diffuse persisting peritonitis), two succumbed to aspiration pneumonia and ARDS, and one to myocardial infarction. It is notable that no patient in the Optimized group died of ongoing abdominal sepsis or a surgical complication, whereas at least two deaths in the

Standard group might have been preventable with earlier intervention (both had intra-abdominal abscesses at autopsy). The trend suggests improved survival with the tailored approach, aligning with literature that appropriate early intervention improves PPU outcomes. For context, reported mortality in perforated ulcer ranges widely from ~1.3% in young low-risk patients up to 30% in the elderly. Our Standard group's 20% mortality is on the higher end (reflecting some delayed presentations), while the Optimized group's 7.1% is closer to expected for a general PPU population. This reduction echoes findings by Tulinsky *et al.*, who observed laparoscopic management was associated with a lower mortality (13.6%) than open (41.4%) in their series, although selection bias meant sicker patients underwent open surgery. In our study, by employing damage control in those very sick patients, we may have narrowed the mortality gap.

Overall, these results demonstrate that optimizing the surgical tactic based on severity led to improved postoperative outcomes. By intervening in a staged manner for the sickest patients, the Optimized strategy possibly averted the cascade of uncontrolled sepsis that can lead to multiple complications. The conventional one-size approach left some high-risk patients inadequately treated initially, resulting in higher reoperation and infection rates. Our findings are consistent with previous studies emphasizing early appropriate source control: e.g., each hour of surgical delay increases mortality by 2.4%. In our Standard group, a subset of patients likely remained contaminated after the initial surgery (perhaps due to edematous tissues or insufficient lavage), whereas the Optimized plan to re-lavage and not close tightly in certain cases prevented that scenario. Moreover, the increased use of laparoscopy in the Optimized group clearly improved certain outcomes (wound infections, pain, recovery time), in line with existing evidence. A recent meta-analysis by Zhou *et al.* noted laparoscopic repair of PPU was associated with fewer overall complications and especially fewer wound infections, albeit with similar leak rates to open. Our data mirror those findings – we observed a 50% reduction in total complications and ~70% reduction in wound infections with the more laparoscopic-intensive approach.

All surviving patients were followed up for at least 1 year (median follow-up 18 months). Ulcer recurrence (defined as a new peptic ulcer on endoscopy) was low in both groups, as most patients received H. pylori eradication and acid suppression. There were 2 cases of ulcer recurrence in the Standard group (8% incidence) and 1 case in the Optimized group (3.6%). The one Optimized patient with recurrence was a young man non-adherent to PPI and H. pylori therapy who developed a symptomatic ulcer at 9 months (treated medically). In the Standard group, one recurrence was the patient who re-perforated at 1 month (surgically managed at that time), and the other was an asymptomatic ulcer found on routine endoscopy at 6 months in a patient with persistent H. pylori infection (successfully treated then). No significant difference in

recurrence rates was observed ($p=0.61$). This suggests that the surgical tactic (laparoscopic vs open, etc.) did not markedly affect long-term ulcer healing, as expected; rather, eradication of *H. pylori* and avoidance of NSAIDs are key to preventing recurrence in both cohorts. Both groups had similar medical follow-up, and nearly all patients were confirmed *H. pylori*-negative after therapy. Thus, the optimized approach did not compromise ulcer disease control – if anything, the single re-perforation in the Standard group hints that perhaps more rigorous follow-up could be beneficial there. Notably, one might worry that leaving an open abdomen or doing damage-control (as in a few Optimized cases) could increase risk of fistula or complications later; we did not observe any long-term fistula formation or ventral hernias within the follow-up, although two patients with open abdomen required minor skin grafts for granulation tissue (healed well).

Economic Analysis: One of the central aims of this study was to evaluate cost-effectiveness of the optimized surgical strategy. We found that tailoring the surgical approach not only improved clinical outcomes, but also reduced healthcare costs. The average total hospital treatment cost per patient was $\$5,960 \pm 1,340$ in the Optimized group vs $\$8,120 \pm 2,050$ in the Standard group, a difference of approximately $\$2,160$ (27% reduction, $p = 0.01$).

Conclusions

1. Optimizing surgical tactics for perforated duodenal ulcer by incorporating peritonitis severity prognostic criteria leads to superior clinical outcomes and is economically advantageous. In this study, a tailored management protocol – involving early risk stratification (using MPI, SOFA, lactate), selective use of laparoscopic repair for stable patients, and damage-control or staged surgery for those with severe peritonitis – significantly reduced postoperative complications (especially septic complications and wound infections), shortened hospital stay, and yielded a trend toward lower mortality compared to the traditional one-size-fits-all approach. Importantly, these clinical benefits were achieved alongside a reduction in treatment costs, primarily due to fewer resource-intensive complications and shorter recovery times.

2. Our findings support a paradigm in which surgical decision-making for perforated ulcer is guided by severity assessment: low-risk patients should undergo minimally invasive definitive repair for a faster recovery, while high-risk patients benefit from an initial abbreviated surgery and aggressive postoperative critical care, with planned re-interventions if necessary. This tailored approach ensures that each patient receives the intensity of treatment appropriate for their condition – neither under-treating the sick nor over-treating the stable. By doing so, we optimize patient outcomes while also utilizing healthcare resources more efficiently.

3. In practical terms, we recommend that all centers managing perforated peptic ulcers adopt the routine use of risk stratification scores (MPI

or similar) upon patient presentation, and have protocols in place for laparoscopic management and for damage-control surgery in the appropriate scenarios. With increasing evidence, including from this study, that such strategies improve survival and reduce morbidity in perforation peritonitis, they represent an evidence-based advancement in care. As surgeons and healthcare systems strive for better quality and value, an approach that saves lives *and* money is a clear win-win. Future multicenter studies and randomized trials should further validate these findings, but the consistency of our results with existing literature gives confidence that optimizing surgical tactics based on peritonitis severity is indeed both clinically and economically prudent.

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