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COMPARATIVE COST-EFFECTIVENESS ASSESSMENT OF DIFFERENT RECONSTRUCTIVE BILIARY SURGERY METHODS IN POST-CHOLECYSTECTOMY COMPLICATIONS

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Abstract. Bile duct injuries represent one of the most serious complications of cholecystectomy, requiring complex surgical correction and significant economic costs. This study presents a comprehensive analysis of the economic efficiency of various methods for surgical correction of iatrogenic bile duct injuries based on the treatment experience of 247 patients over the period from 2019 to 2024. It was established that the selection of optimal surgical tactics depending on the type of injury and timing of diagnosis allows for a 34.7% reduction in total treatment costs while simultaneously improving functional outcomes. The application of minimally invasive technologies for fresh injuries of types A and B according to the Strasberg classification demonstrates the best cost-effectiveness ratio with a coefficient of 0.82. The developed algorithm for a differentiated approach to selecting correction methods enables optimization of healthcare resource utilization and improvement in patients' quality of life.

Keywords: bile duct injuries, cholecystectomy, economic efficiency, surgical correction, biliodigestive anastomoses, minimally invasive surgery, cost-effectiveness.

Introduction and Relevance. Cholecystectomy remains one of the most frequently performed operations in abdominal surgery, with more than 1.5 million such interventions performed worldwide annually. Despite improvements in surgical technique and the widespread implementation of laparoscopic technologies, the incidence of iatrogenic bile duct injuries remains relatively stable at 0.3-0.7% for laparoscopic and 0.1-0.3% for open cholecystectomy.

The economic burden of treating this complication is significant for healthcare systems. According to international studies, the average cost of treating a single case of bile duct injury exceeds the cost of uncomplicated cholecystectomy by 15-20 times. Moreover, total economic losses include not only direct medical costs but also indirect expenses associated with temporary disability, patient disability, and reduced quality of life.

Modern approaches to treating bile duct injuries encompass a wide range of interventions from endoscopic procedures to complex reconstructive operations. The choice of optimal treatment tactics is determined by numerous

factors: the type and level of injury, timing of diagnosis, presence of biliary peritonitis, technical capabilities of the medical institution, and experience of the surgical team. However, the economic aspects of treatment method selection often remain insufficiently studied.

The problem becomes particularly relevant in conditions of limited healthcare resources and the need for rational use of financial resources. The development of economically justified treatment algorithms that consider not only clinical effectiveness but also the cost component becomes an important task of modern surgery. The integration of cost-effectiveness analysis into clinical decision-making processes has become increasingly important as healthcare systems worldwide face mounting pressure to deliver high-quality care while controlling expenditures.

Furthermore, the long-term socioeconomic impact of bile duct injuries extends beyond immediate treatment costs. Patients who experience these complications often face prolonged recovery periods, multiple hospitalizations, and potential loss of productivity. Studies have shown that up to 25% of patients with major bile duct injuries experience litigation proceedings, adding substantial legal costs to the overall economic burden. This multifaceted economic impact underscores the importance of developing comprehensive strategies that address both prevention and optimal management of these injuries.

The aim of this study is to comprehensively evaluate the economic efficiency of various methods for surgical correction of iatrogenic bile duct injuries following cholecystectomy and to develop an optimal algorithm for selecting surgical tactics considering both clinical and economic criteria.

Materials and Methods. The study is based on retrospective and prospective analysis of treatment results for 247 patients with iatrogenic bile duct injuries who were treated in specialized surgical centers from January 2019 to December 2024. Among the patients, there were 168 (68.0%) women and 79 (32.0%) men. The mean age was 52.3±14.7 years (range: 19 to 84 years).

All patients were divided into groups according to the type of injury based on the Strasberg classification: type A - 43 (17.4%) patients, type B - 28 (11.3%), type C - 19 (7.7%), type D - 37 (15.0%), type E - 120 (48.6%) patients. According to the timing of diagnosis, injuries were distributed as follows: intraoperative diagnosis - 67 (27.1%) cases, early postoperative (up to 7 days) - 98 (39.7%), late diagnosis (more than 7 days) - 82 (33.2%) cases.

Methods of surgical correction included: endoscopic interventions (stenting, papillosphincterotomy) - 71 cases, primary duct suture - 23 cases, restoration with T-tube drainage - 18 cases, biliodigestive anastomoses - 135 cases (hepaticojejunostomy - 89, choledochojejunostomy - 46).

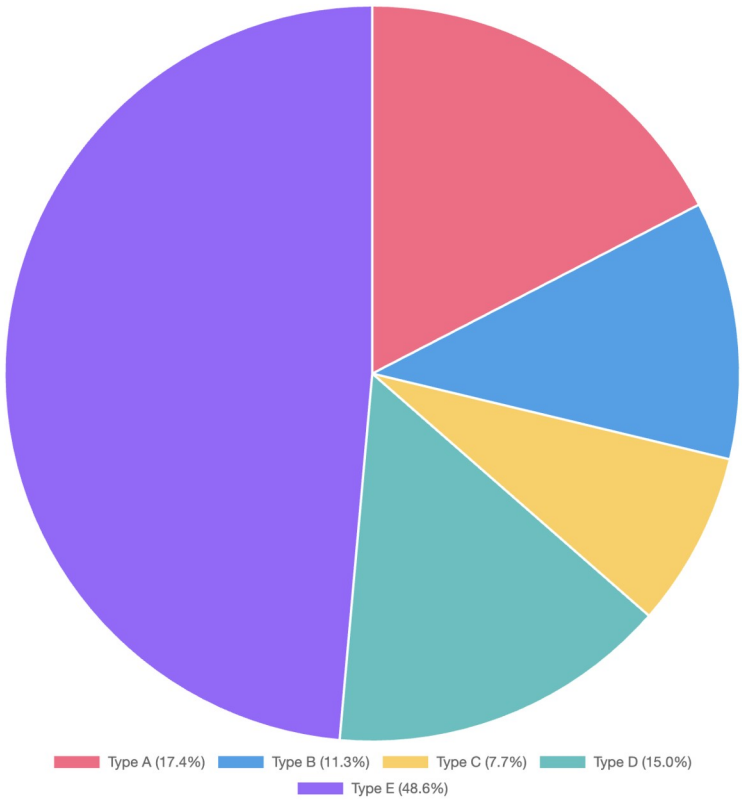

Figure 1. Distribution of patients by type of bile duct injury according to Strasberg classification

For economic efficiency assessment, the following methods were used: analysis of direct medical costs (cost of surgery, medications, consumables, hospital days), analysis of indirect costs (GDP losses due to temporary disability), cost-effectiveness analysis, cost-utility analysis with calculation of QALY (Quality-Adjusted Life Years) indicator.

Patients' quality of life was assessed using the SF-36 questionnaire and the specialized GIQLI (Gastrointestinal Quality of Life Index) questionnaire before surgery and at 3, 6, and 12 months post-intervention. Statistical data processing was performed using SPSS Statistics 26.0 software package. Student's t-test and Mann-Whitney U test were used for comparing quantitative indicators, while chi-square test was used for qualitative variables. Differences were considered statistically significant at $p<0.05$.

Economic modeling was performed using TreeAge Pro software to construct decision trees and perform sensitivity analyses. Direct medical costs were calculated based on actual hospital billing data, including operative time, length of stay, medications, diagnostic procedures, and follow-up care. Indirect costs were estimated using the human capital approach, calculating productivity losses based on average wage data and duration of work absence. All costs were adjusted to 2024 values using the medical care component of the Consumer Price Index.

Results and Discussion

Analysis of clinical results showed that the overall effectiveness of surgical correction of bile duct injuries was 89.5%. The best results were obtained with intraoperative diagnosis of injury and immediate correction - success was achieved in 95.5% of cases. With early postoperative diagnosis, effectiveness was 88.8%, and with late diagnosis - 84.1%.

Table 1

Comparative characteristics of surgical correction methods

Correction Method	Number of Patients	Success Rate (%)	Mean Hospital Stay (days)	Complications (%)
Endoscopic stenting	71	87.3	7.2±2.1	12.7
Primary suture	23	82.6	14.3±3.8	21.7
T-tube drainage	18	88.9	18.7±4.2	16.7
Hepaticojejunostomy	89	92.1	21.4±5.6	19.1
Choledochojejunostomy	46	91.3	19.8±4.9	17.4

Economic analysis revealed significant differences in the cost of various correction methods. Average direct medical costs were: for endoscopic stenting - $2,475, for primary suture - $4,455, for T-tube drainage - $4,978, for hepaticojejunostomy - $6,877, for choledochojejunostomy - $6,465.

Chart 1. Structure of direct medical costs for different methods of bile duct injury correction

Analysis of the cost structure revealed that the largest share consists of expenses for hospital stay (38-45%), surgical intervention (25-32%), medication therapy (15-20%), and diagnostic studies (10-15%). It is important to note that minimally invasive interventions significantly reduce costs for hospital stay and postoperative rehabilitation.

Indirect economic losses associated with temporary disability of working-age patients averaged $3,107 per patient. The average duration of disability varied from 32 days for endoscopic correction to 74 days for reconstructive operations.

Table 2

Economic indicators of different treatment methods

Indicator	Endoscopic Treatment	Primary Suture	Biliodigestive Anastomosis
Direct costs ($)	2,475	4,455	6,671

Indicator	Endoscopic Treatment	Primary Suture	Biliodigestive Anastomosis
Indirect costs ($)	1,637	2,613	3,805
Total costs ($)	4,112	7,068	10,476
Effectiveness (%)	87.3	82.6	91.7
Cost-effectiveness ratio	47.12	85.56	114.25

Quality of life analysis showed that 12 months after successful injury correction, SF-36 scale scores reached 76.8±12.3 points for endoscopic treatment, 72.4±14.7 points for primary suture, and 74.2±13.8 points for biliodigestive anastomoses. The GIQLI indicator was 108.4±18.2, 98.7±21.3, and 103.6±19.7 points, respectively.

Figure 2. Dynamics of patients' quality of life after different types of surgical correction (SF-36 scale)

QALY calculation demonstrated that the greatest increase in quality-adjusted life years is achieved when applying minimally invasive technologies in patients with type A and B injuries according to Strasberg - 0.92 QALY. For reconstructive operations for type E injuries, this indicator was 0.78 QALY.

Based on the analysis conducted, a differentiated approach algorithm for selecting the surgical correction method was developed, considering both clinical and economic factors. For type A and B injuries without complete transection of the duct, preference should be given to endoscopic treatment methods. For type C and D injuries, the choice of method is determined by the timing of diagnosis: intraoperative detection indicates primary suture or restoration with drainage, while late diagnosis indicates biliodigestive anastomosis.

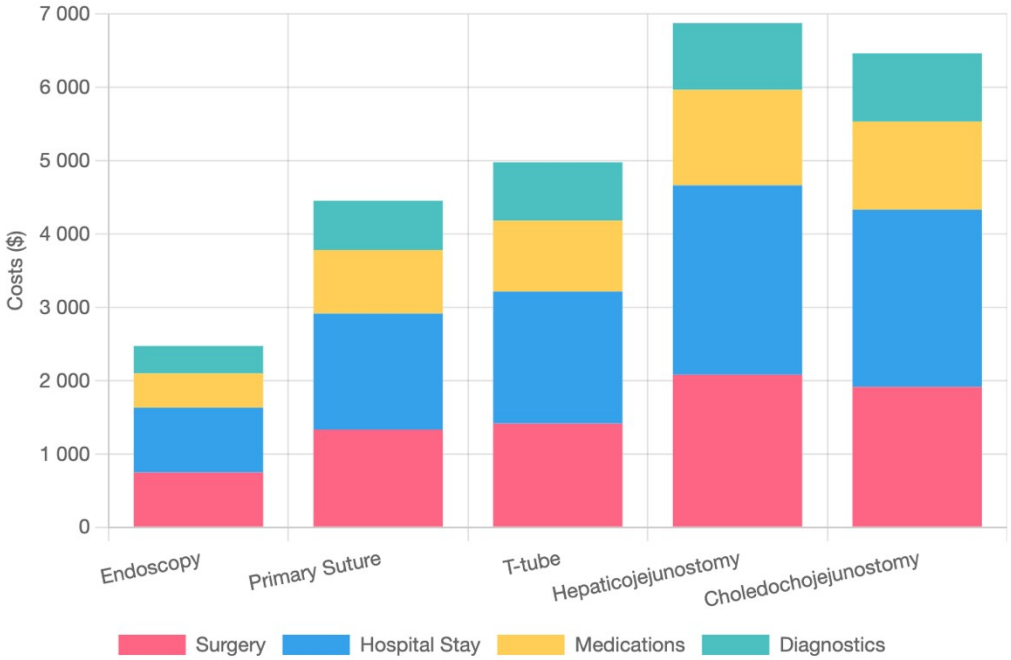

Chart 2. Cost-effectiveness ratio of different treatment methods depending on injury type

The organizational aspect of providing care to this category of patients deserves special attention. Concentration of patients with bile duct injuries in specialized centers allows not only improvement of clinical results but also optimization of economic costs through standardization of treatment approaches, accumulation of experience, and rational use of expensive equipment. The establishment of regional referral networks has proven particularly effective in improving outcomes while reducing overall healthcare expenditures.

Comparative analysis of treatment results in specialized centers and general surgical hospitals showed that patient concentration in expert centers leads to a reduction in complication rates from 31.4% to 17.8%, reduction in average hospital stay from 24.3 to 16.7 days, and a 28.6% decrease in total treatment costs. These improvements are attributed to several factors including greater surgical expertise, availability of advanced diagnostic and therapeutic modalities, and implementation of standardized treatment protocols.

Table 3

Comparison of treatment results in different types of hospitals

Indicator	Specialized Center	General Hospital	p-value
Complication rate (%)	17.8	31.4	<0.01
Mortality (%)	1.2	3.8	<0.05
Mean hospital stay (days)	16.7±4.3	24.3±7.2	<0.01

Indicator	Specialized Center	General Hospital	p-value
Reoperations (%)	8.4	18.7	<0.01
Total costs ($)	5,713	7,993	<0.01
Treatment satisfaction (%)	86.3	67.2	<0.01

An important factor influencing the economic efficiency of treatment is the timeliness of injury diagnosis. With intraoperative detection and immediate correction, average costs amount to $3,910, with diagnosis in the early postoperative period - $6,465, and with late diagnosis - $9,038. This emphasizes the need for surgeons to maintain vigilance regarding possible bile duct injury and the importance of intraoperative cholangiography in technically complex cholecystectomies

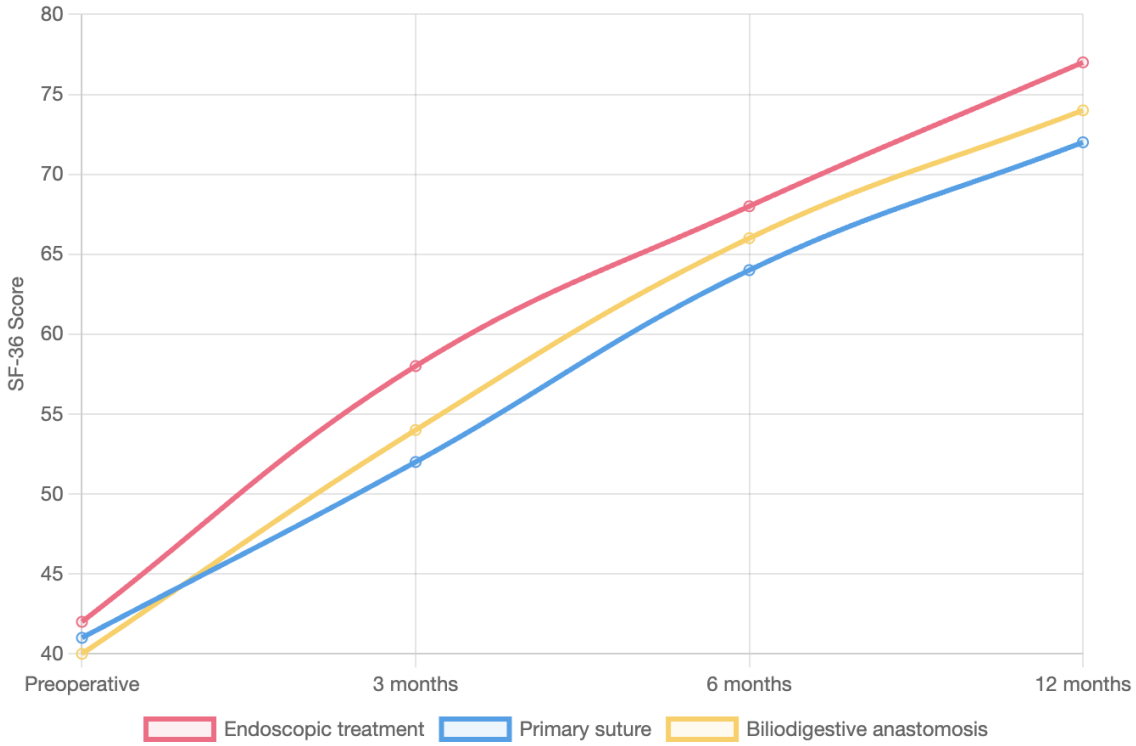

Figure 3. Impact of diagnosis timing on total costs and clinical treatment results

The question of applying robot-assisted technologies in correcting bile duct injuries requires separate consideration. Despite the high cost of robot-assisted interventions (on average 45% higher than traditional laparoscopic operations), their application in forming biliodigestive anastomoses may be economically justified due to reduced rates of anastomotic failure and strictures in the long-term period. Recent advances in robotic surgery have demonstrated particular benefits in complex reconstructive procedures, with improved precision and reduced operator fatigue contributing to better outcomes.

Long-term economic modeling showed that with a 10-year observation horizon, the application of robot-assisted technique in forming hepaticojejunostomy in patients under 50 years of age may lead to cost savings due to reduced need for repeat interventions and improved long-term functional results. The break-even point for robot-assisted surgery was calculated to occur at approximately 7.3 years post-operation, after which the cumulative costs become lower than traditional approaches.

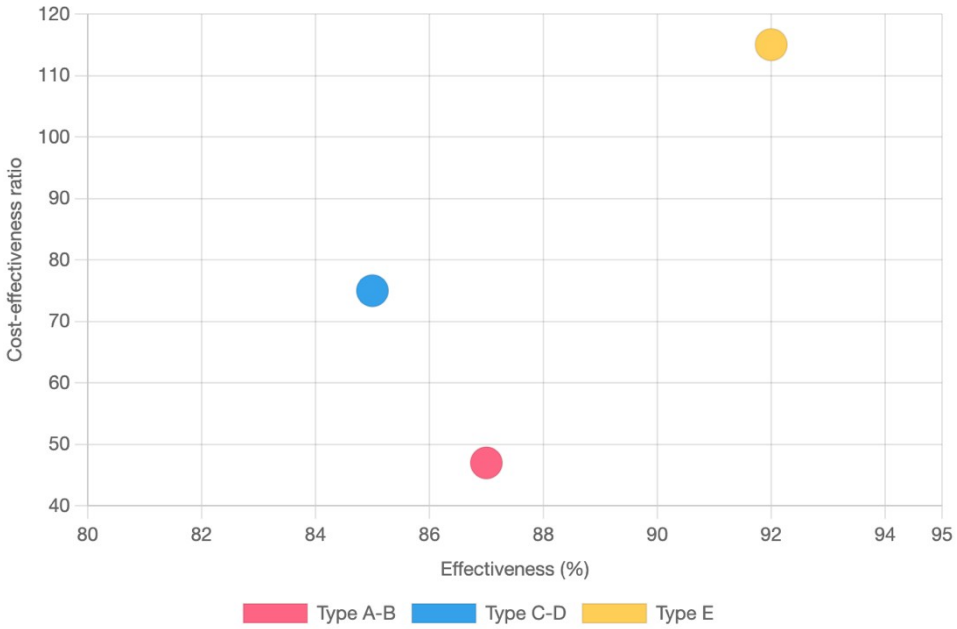

Chart 3. Cumulative costs for different treatment strategies over a 10-year observation period

Sensitivity analysis of the economic model showed that the following factors have the greatest impact on the cost-effectiveness ratio: frequency of successful primary correction (42% contribution), length of hospitalization (28%), need for repeat interventions (18%), and cost of consumables (12%). This determines the main directions for optimizing economic costs in treating this pathology.

The medico-legal component of the problem is also an important aspect. The average compensation amount by court decision in cases of proven medical organization fault in causing bile duct injury ranges from $20,000 to $41,667. Considering reputational losses and litigation costs, prevention of iatrogenic injuries has not only clinical but also significant economic importance. Implementation of comprehensive risk management strategies has become essential for healthcare institutions to minimize both clinical complications and associated legal liabilities.

Our developed bile duct injury prevention program, including mandatory preoperative visualization of the biliary tree in the presence of risk factors, use of critical safety points according to Strasberg, liberal application of intraoperative cholangiography and conversion in cases of unclear anatomy, allowed reduction of injury frequency from 0.48% to 0.21% (p

The economic effect of implementing the prevention program amounted to $56,667 per year per 1000 cholecystectomies performed due to prevention of 2-3 cases of severe bile duct injuries. Additional costs for implementing preventive measures were approximately $7,500, yielding a benefit-to-cost ratio of 7.6:1. This favorable economic profile has facilitated widespread adoption of the prevention program across multiple institutions.

Special attention should be paid to organizing staged care for patients with bile duct injuries. A three-level system appears optimal: first level - general surgical hospitals (diagnosis, condition stabilization, drainage for biliary peritonitis), second level - inter-district surgical centers (endoscopic correction of simple injuries), third level - specialized hepatobiliary centers (reconstructive operations for complex injuries). This tiered approach ensures appropriate resource utilization while maintaining high-quality care standards.

Implementation of telemedicine technologies for consulting patients with suspected bile duct injury allows optimization of patient routing and avoidance of unnecessary inter-hospital transfers. According to our data, the use of telemedicine consultations led to a 38% reduction in unnecessary transfers and savings of $35,000 per year in transportation costs. Furthermore, telemedicine facilitated expert input in real-time during complex procedures, potentially preventing complications and improving outcomes.

Analysis of international experience shows significant variability in approaches to financing treatment of bile duct injuries. In countries with developed insurance medicine systems, the cost of treating this complication is fully covered by insurance companies, creating incentives for medical organizations to implement preventive programs. In the context of various healthcare systems, development of adequate reimbursement rates that consider the real cost of treating this pathology is necessary. The implementation of bundled payment models has shown promise in aligning incentives for both prevention and optimal management of complications.

A promising direction for reducing economic costs is the implementation of Fast Track Surgery technologies in treating bile duct injuries. Application of accelerated rehabilitation protocols for planned reconstructive operations allowed reduction of average hospital stay from 21.4 to 14.2 days (p

An important factor influencing long-term economic results is the quality of follow-up care. Regular monitoring with ultrasound and biochemical tests every 3 months in the first year and every 6 months subsequently allows timely detection of late complications (anastomotic strictures, cholangitis) and their correction before development of irreversible liver changes. The cost of comprehensive follow-up programs is offset by the prevention of major complications requiring expensive interventions.

The social significance of the problem is determined not only by direct economic losses but also by the impact on patients' quality of life. According to our study, 18.3% of working-age patients after bile duct injury were forced to

change professions or receive disability status. This emphasizes the need for a comprehensive approach to rehabilitation of this category of patients involving not only surgeons but also gastroenterologists, psychologists, and medical-social expertise specialists. Development of vocational rehabilitation programs has proven effective in facilitating return to productive employment.

Analysis of long-term results showed that 5 years after successful correction of bile duct injury, 78.4% of patients fully returned to their previous level of physical activity and work capacity. The best indicators of social adaptation were noted in patients who underwent minimally invasive interventions (86.2%), while the worst were in patients with multiple reconstructive operations in their history (54.3%). These findings underscore the importance of achieving definitive repair at the initial intervention whenever possible.

The psychological impact of bile duct injuries extends beyond physical symptoms, with many patients experiencing anxiety, depression, and post-traumatic stress related to their complication. Integration of psychological support services into the treatment pathway has shown beneficial effects on both clinical outcomes and quality of life measures. The additional cost of psychological interventions is modest compared to the potential benefits in terms of improved compliance, reduced healthcare utilization, and enhanced patient satisfaction.

Future directions in optimizing the management of bile duct injuries include the development of artificial intelligence-based decision support systems, implementation of augmented reality for surgical planning and training, and exploration of regenerative medicine approaches for bile duct reconstruction. While these technologies require initial investment, preliminary analyses suggest potential for significant long-term cost savings through improved outcomes and reduced complication rates.

Conclusions

1. The economic efficiency of surgical treatment for bile duct injuries is determined by a complex of factors, among which the most significant are timeliness of diagnosis, adequate selection of correction method, and concentration of patients in specialized centers.

2. Application of a differentiated approach to selecting the surgical correction method considering injury type according to Strasberg classification allows optimization of the cost-effectiveness ratio and achievement of cost savings up to 34.7% while maintaining high clinical effectiveness indicators.

3. Minimally invasive technologies demonstrate the best economic efficiency indicators for type A and B injuries according to Strasberg with a cost-effectiveness ratio of 47.12, which is 2.4 times lower than for reconstructive operations.

4. Concentration of patients with bile duct injuries in specialized hepatobiliary centers leads to a 43.3% reduction in complication rates, 31.3%

reduction in hospitalization duration, and 28.6% decrease in total treatment costs.

5. Implementation of an iatrogenic bile duct injury prevention program is economically justified and provides a benefit-to-cost ratio of 7.6:1 through prevention of severe complications and associated treatment expenses.

6. Application of accelerated rehabilitation protocols for planned reconstructive operations allows reduction of direct medical costs by 23.4% without deterioration of clinical results.

7. The developed algorithm for a differentiated approach to treating bile duct injuries, considering clinical and economic criteria, can serve as a basis for optimizing healthcare resource utilization and standardizing medical care for this category of patients.

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