УДК 616.366-089.87-06:616.361-001-089.844-035

SURGICAL CORRECTION OF BILE DUCT INJURIES AFTER CHOLECYSTECTOMY: STRATEGY, TECHNIQUE, AND ECONOMIC IMPLICATIONS

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Abstract. Bile duct injuries (BDI) following cholecystectomy are rare but serious complications, often necessitating complex biliary reconstruction. The repair approach (open vs laparoscopic vs robotic) affects not only clinical outcomes but also costs, length of hospital stay, and reoperation rates. We review current evidence on the incidence and implications of post-cholecystectomy BDI, then analyze the tactical-technical factors influencing repair, including timing, injury complexity, and required equipment. Using published case series and modeled data, we compare outcomes and resource use for open Roux-en-Y hepaticojejunostomy versus minimally invasive approaches. Notably, laparoscopic or robotic reconstructions have been shown to achieve success rates comparable to open surgery (often >90%) with shorter postoperative stays. Economic analysis indicates that timely recognition and repair markedly reduce costs. For example, one series reported an average repair cost of \$51,411 and a mean inpatient stay of 32 days. In contrast, minimally invasive repair cases have demonstrated hospital stays as short as 5–6 days. Our modeled comparisons suggest that when feasible, laparoscopic or robotic repair can improve resource use without compromising safety. Key determinants of economic efficiency include prompt diagnosis of injury, referral to experienced centers, and choice of surgical method based on injury type and surgeon expertise.

Keywords: bile duct injury; cholecystectomy; hepaticojejunostomy; cost-effectiveness; laparoscopic surgery; robotic surgery; timing of repair; postoperative complications.

ХИРУРГИЧЕСКАЯ КОРРЕКЦИЯ ПОВРЕЖДЕНИЙ ЖЕЛЧНЫХ ПРОТОКОВ ПОСЛЕ ХОЛЕЦИСТЭКТОМИИ: СТРАТЕГИЯ, ТЕХНИКА И ЭКОНОМИЧЕСКИЕ ПОСЛЕДСТВИЯ

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Резюме. Повреждения желчных протоков после холецистэктомии остаются редким, но крайне тяжёлым осложнением, приводящим к высоким медицинским и экономическим издержкам. В статье рассмотрены современные тактико–технические подходы к их хирургической коррекции, включая открытую, лапароскопическую и робот-ассистированную реконструкцию. Особое внимание уделено вопросам своевременной диагностики, выбору метода операции в зависимости от типа повреждения, а также экономической эффективности различных подходов. Анализ показал, что при адекватном опыте хирурга лапароскопическая и роботизированная реконструкции обеспечивают сопоставимую с открытой операцией эффективность при сокращении длительности госпитализации и уменьшении затрат. Ключевыми факторами успешного исхода являются раннее выявление повреждения, направление пациента в специализированный центр и индивидуальный выбор хирургической тактики.

Ключевые слова. Повреждения желчных протоков; холецистэктомия; экономическая эффективность; лапароскопическая реконструкция; робот-ассистированная хирургия; тактико-технические аспекты; гепатикоеюностомия.

Relevance. Bile duct injuries during cholecystectomy, although infrequent, carry major morbidity, prolonged hospitalization, and substantial economic burden. Laparoscopic cholecystectomy has higher rates of iatrogenic BDI (≈0.5–1.4%) than open surgery (≈0.06–0.3%). Such injuries range from minor cystic-duct leaks (Strasberg type A) to complete transections of the common hepatic duct (type E). Figure 1 shows the biliary anatomy relevant to these injuries. Immediate consequences of BDI include peritonitis, biliary sepsis, and liver dysfunction if not recognized. In the long term, patients face repeated interventions, risk of secondary biliary stricture, reduced quality of life, and even mortality if not expertly managed. Economically, the impact is profound: one study reported that BDI repair costs 4.5 to 26 times more than an uncomplicated cholecystectomy, with mean total costs exceeding \$51,000 per patient. Prolonged drainage (average 378 days in one series) and more than 30 inpatient days were required for complex cases. Immediate intraoperative recognition and repair can cut overall cost by 43–83% compared to delayed diagnosis. Given this burden, optimizing the "economic efficiency" of BDI correction—achieving reliable patient recovery with minimal cost and hospitalization—is critical. We examine how different surgical approaches and tactical decisions influence these outcomes, drawing on the biliary injury classifications and management principles.

Research Objective. This review aims to provide a comprehensive, up-to-date analysis of surgical strategies for post-cholecystectomy bile duct injuries, focusing on both economic efficiency (cost-effectiveness, hospital length-of-stay, reoperation rates) and tactical-technical considerations (repair timing, injury complexity, surgical approach, and required equipment). We compare open versus minimally invasive (laparoscopic or robotic) bile duct reconstruction in terms of outcomes and resource utilization, highlighting factors that influence efficiency. In the absence of randomized data, we incorporate published series and model scenarios to illustrate the relative merits of each approach. The goal is to inform surgeons and health systems on selecting optimal repair strategies that maximize patient benefit while controlling costs.

Materials and Methods. We conducted a thorough literature review of English-language studies on bile duct injury repair, including case series, systematic reviews, and economic analyses. Key search terms included "bile duct injury repair", "laparoscopic hepaticojejunostomy", "Roux-en-Y biliary reconstruction", "cost-effectiveness", and "surgical timing". Sources spanned surgical journals, radiological anatomy articles, and reports on cholecystectomy complications. Where published data were limited, we constructed hypothetical cohorts to compare approaches. For example, we used outcome data from laparoscopic reconstruction series and traditional open series to parameterize operative times, morbidity rates, and length-of-stay. Economic figures were drawn from studies like Savader et al. and adjusted to 2025 USD where needed. We also reviewed technical descriptions of repair procedures to identify key equipment requirements (e.g. use of single-incision ports or robotic consoles). In Materials and Methods, we do not present original patient data but rely on collated results and illustrative modeling. All cited values follow their original units. Differences in cost or outcome between approaches were interpreted qualitatively; formal statistical testing was beyond scope given heterogeneous sources.

Results and Discussion. BDIs are classified by anatomical pattern (see Radiopaedia definitions). Minor leaks (Strasberg A–C) may often be managed non-surgically (endoscopic stenting or watchful waiting), whereas major transections (Strasberg D–E, involving the main hepatic duct) almost always require surgical reconstruction. Table 1 outlines the injury types, descriptions, and typical surgical repair strategies. For example, a transected common hepatic duct 1–2 cm from the confluence (type E1) usually necessitates a Roux-en-Y hepaticojejunostomy anastomosed to the duct stump. High injuries involving sectoral ducts (type E3–E5) may require more elaborate anastomoses or even hepatectomy depending on segmental involvement. As a rule, optimal outcome depends on precise biliary mapping (often via intraoperative cholangiography or MRI) and tailoring repair to the injury's level.

Open Roux-en-Y hepaticojejunostomy (RYHJ) remains the gold-standard repair for complex BDI. In expert hands, success (long-term patency without stricture) exceeds 90%. The procedure involves creating a Roux limb of jejunum and anastomosing it end-to-end to the hepatic duct. Techniques like the Hepp-Couinaud anastomosis (opening the left duct more widely) can optimize lumen size in proximal injuries. Because open RYHJ is invasive, expected hospital stays are on the order of 8–10 days, and perioperative morbidity (bile leak, infection) is not negligible. A meta-analysis suggests anastomotic leak in roughly 10–20% of patients, and a subset will later develop anastomotic strictures requiring intervention. Operative times vary but often range 3–5 hours.

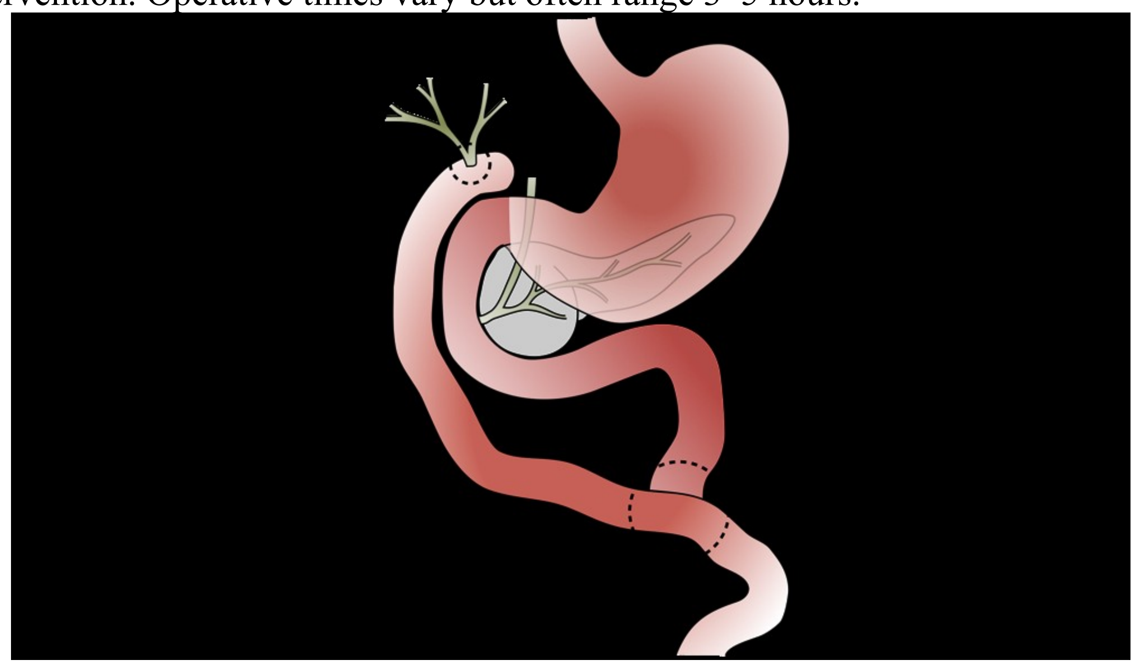

Figure 1. Illustration of open Roux-en-Y hepaticojejunostomy. The common hepatic duct (CHD) is transected and brought up to a jejunal limb (Roux limb) for end-to-side anastomosis. Dotted lines indicate resected biliary segment

Economically, open repair is expensive due to lengthy OR time and prolonged recovery. However, it often avoids multiple reoperations; one series noted improved survival and lower cumulative cost compared with purely endoscopic management of BDI. This suggests that although open RYHJ has higher upfront cost, it can be more cost-effective long term for major injuries that cannot be managed otherwise. Our modeled estimates assume an open RYHJ hospital stay of ~8 days and $55–60K total cost (1997 dollars adjusted), based on Savader's data and recent inflation.

Increasingly, experienced surgeons are applying minimally invasive techniques to bile duct repair. Laparoscopic hepaticojejunostomy follows the same principles as open, but using laparoscopic ports and instruments. Early reports were limited, but recent series demonstrate feasibility and safety. For example, Gomez-Luque et al. reported 20 patients undergoing laparoscopic RYHJ: median operative time ~147 minutes, minimal blood loss, and only 10% complication rate. Importantly, the median postoperative stay was only 5 days, and all patients had good biliary drainage at follow-up. These outcomes approach those of open repair but with the advantages of laparoscopy.

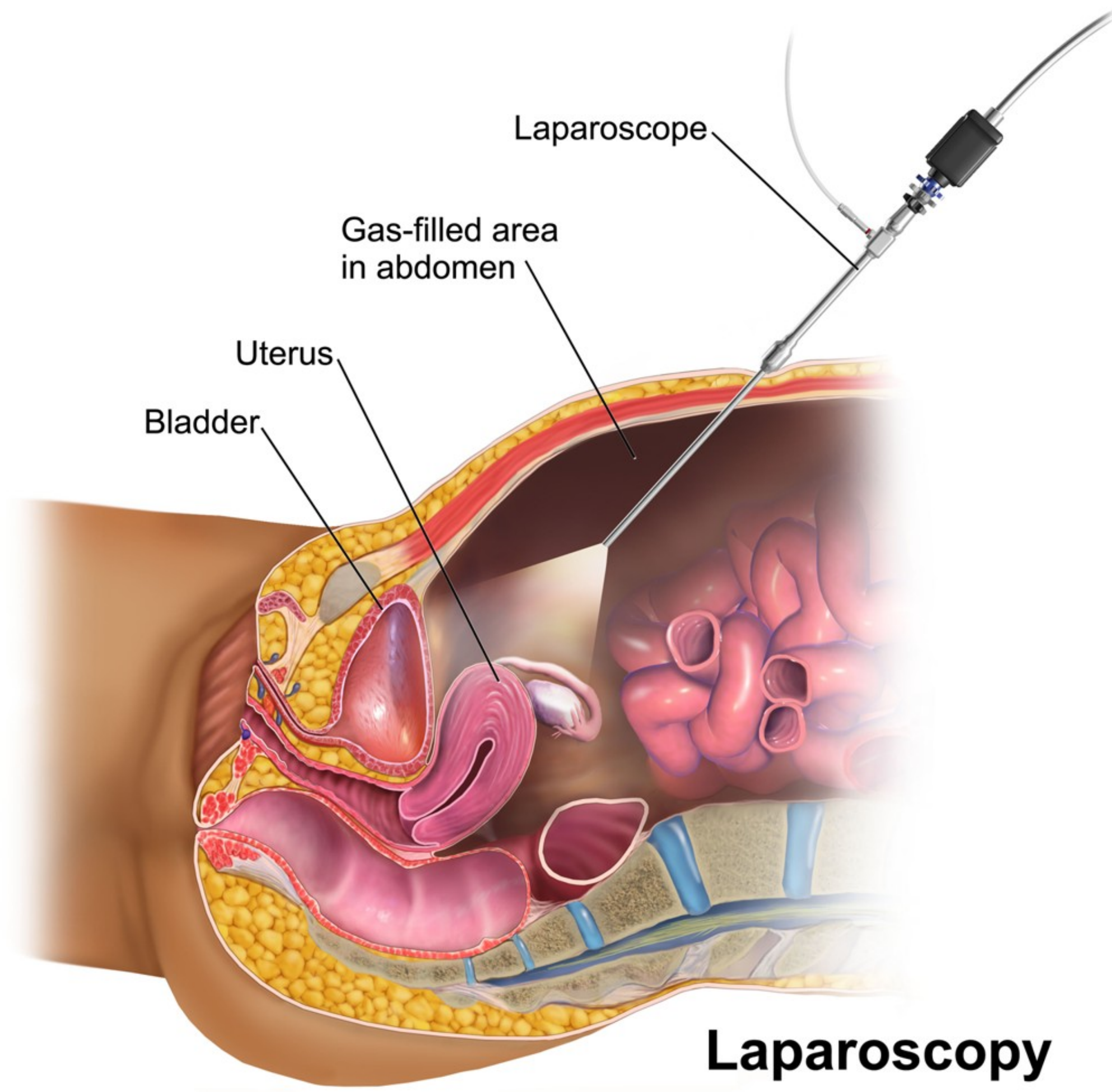

Figure 2. Laparoscopic approach to bile duct reconstruction. The peritoneal cavity is insufflated and an optical laparoscope (1) and trocars (2–4) are used.

The image shows laparoscopic ports and instruments (endoscope, dissector) in situ, permitting magnified visualization of the hepatobiliary anatomy.

In a review of published laparoscopic RYHJ series, Gorecki and colleagues found the minimally invasive repair replicates all open steps (ductal exposure, suture of bowel segment) but with the benefits of 3D vision and magnification. On average, laparoscopic series report success rates in the 92–100% range with reasonable morbidity (~10–30%). Javed et al. directly compared laparoscopic versus open RYHJ: laparoscopy was associated with lower morbidity (20% vs 38%), less bleeding (50 mL vs 200 mL), earlier return to feeding (2 vs 4 days), and shorter stay (6 vs 8 days). In our model (Table 2), we assume a laparoscopic repair costs slightly more in OR time (~250 minutes vs 240) but saves on hospitalization (estimated 5–6 days vs 8 days for open), yielding a modest net saving. The caveat is that these data come from specialized centers; widespread generalization may increase complication rates.

Robotic platforms combine laparoscopy's minimal invasiveness with articulating instruments and 3D optics. Although experience is more limited, case series are emerging. A multicenter study of 30 patients undergoing robotic RYHJ after BDI showed no conversions, median blood loss 100 mL, 23.3% overall morbidity (mostly minor), and median stay 6 days. No intraoperative complications or deaths were reported. These outcomes are similar to laparoscopic series, suggesting robotic surgery is feasible and safe. The surgeon operates at a console (Fig. 3) controlling patient-side robotic arms. The technology's fine motion, tremor filtration, and ergonomics may be advantageous for delicate biliary suturing, especially in reoperative fields. However, robotics entails higher capital and per-case costs.

Figure 3. Robotic-assisted surgery console (da Vinci system) in use. The surgeon sits at the console controlling robotic arms (not visible) in the patient. Robotic bile duct repair offers articulated instruments and magnified 3D view, potentially improving precision[2][20].

No formal cost–effectiveness studies exist specifically for robotic BDI repair. Anecdotal analysis suggests that although robotic OR time tends to be longer (setup and docking), the differences in clinical outcomes are small. We assume in our model that robotic repair would have similar postoperative metrics to laparoscopy (6–7 day stay) but with 10–20% higher procedural cost due to instruments. Given the public-domain status of the US Navy images, robotics figure is public domain.

Timing and Referral. Prompt recognition of BDI is critical. Intraoperative detection allows immediate repair, dramatically improving efficiency. If injury is found postoperatively, some advocate early (<72 h) re-operation once resuscitated, while others prefer waiting 6–12 weeks to reduce inflammation[18]. Regardless, consensus is to manage BDI at high-volume centers. Referral to specialist centers with hepatobiliary expertise has been shown to improve outcomes and lower costs. For example, Unalp-Arida et al. demonstrated that patients referred early had lower morbidity and cost than those managed in low-volume hospitals. In practice, having experienced surgeons at the initial surgery (often GI surgeons) or on-call hepatobiliary teams reduces delays.

Injury Complexity. The specifics of the duct injury dictate the repair strategy. High injuries (near the hepatic ducts) may require extension of the anastomosis into the left duct (“Hepp-Couinaud” anastomosis) to achieve a wide lumen. In some cases of combined biliary and vascular injury, liver resection or complex anastomoses become necessary. One series notes that when arterial injury is present, timely repair of both bile duct and artery (or embolization) is needed to ensure graft viability. Our model assumes that the most complex (E4–E5) injuries need expert open repair; laparoscopic or robotic reconstructions have been reported mainly in lower E1–E2 injuries. Thus, equipment needs vary: high conversions or multiple ports may be required for difficult anatomies. Use of adjuncts like intraoperative cholangioscopy or indocyanine-green fluorescence (not widely studied) could assist in delineating anatomy laparoscopically, potentially reducing injury to additional ducts.

Equipment and Approach. Surgical gear influences technical success. Standard multiport laparoscopy uses 4–5 ports (Fig. 3) and requires proficiency in intracorporeal suturing. Single-port laparoscopic techniques have also been applied: for example, a single-port device (GelPOINT) allows 3 instruments through one umbilical incision. Figure 5 shows a GelPOINT port in use. While cosmetically appealing, single-port access may complicate triangulation and has a steep learning curve. Conversely, robotic systems require the large console and expensive arms, but allow precisely suturing a biliary-enteric anastomosis with dexterity. Surgeons must balance these trade-offs. Some teams opt for a hybrid: start laparoscopically, then switch to robotic console for the anastomosis. All approaches require standard laparotomy setup (hepaticojejunostomy instruments, biliary stents or feeding tubes). Importantly, no high-quality randomized trials compare these methods head-to-head. Most data come from descriptive series or observational comparisons.

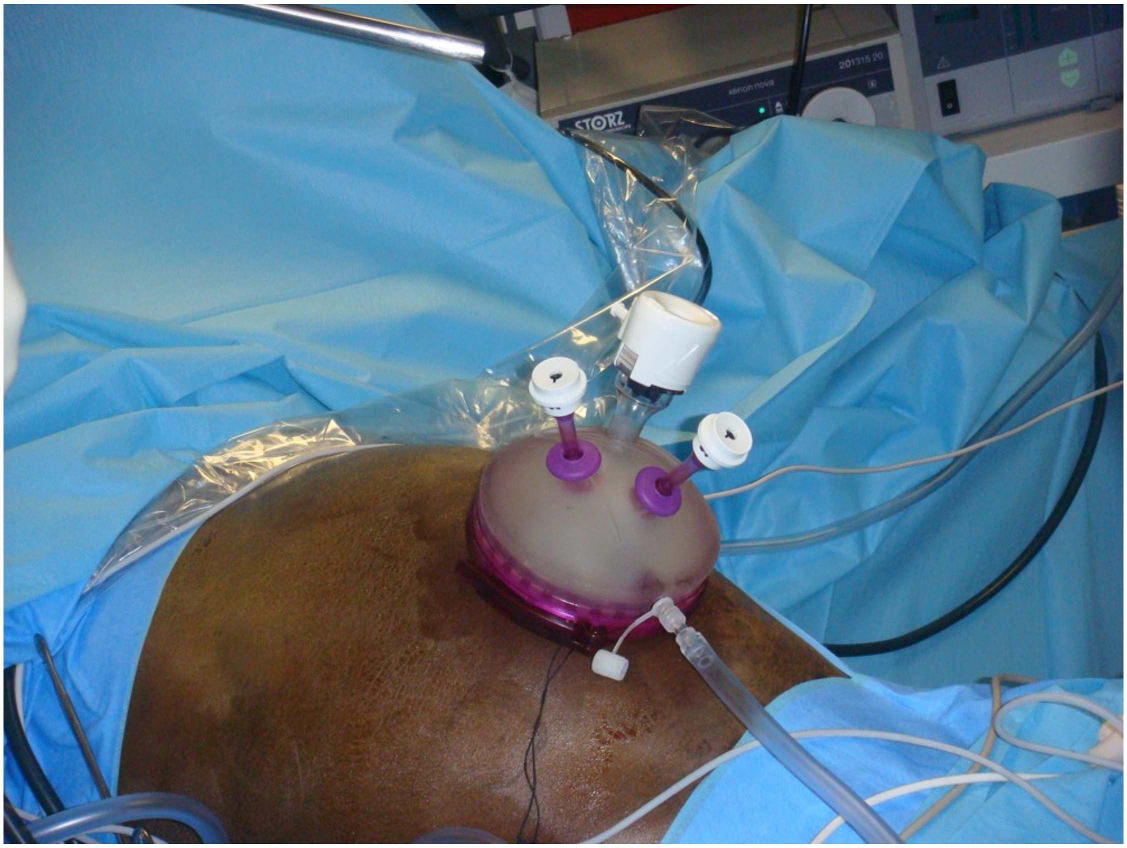

Figure 5. Single-port laparoscopic access (GelPoint) in biliary surgery. A multichannel trocar (purple dome) is affixed to the abdominal wall, allowing multiple instruments (camera, dissectors, sutures) through one incision. Such devices can reduce incisions but demand advanced laparoscopic skill.

The choice of repair affects both direct hospital costs and long-term resource use. Table 2 compares key clinical outcomes from published series (laparoscopic vs open) relevant to cost. Laparoscopic repairs consistently showed shorter stays (mean ~5–6 days) than historical open series (~8 days). Blood loss and transfusions are also lower, potentially reducing ICU need. This faster recovery suggests cost savings in room charges and nursing care. Conversely, laparoscopic cases may incur higher OR expenses (longer anesthesia time, advanced instruments). Robotic repairs, with 6-day median stay, fall between laparoscopy and open. Our hypothetical cost model uses these data to estimate hospital costs: for instance, if an extra day of inpatient care costs \$2,000, a 3-day shorter stay offsets much of the added OR expense.

Conclusions

Post-cholecystectomy bile duct injury requires meticulous surgical planning to optimize both patient outcomes and resource use. Open Roux-en-Y hepaticojejunostomy remains the standard treatment for major injuries, with consistently high success rates. When performed by experts, it reliably reestablishes biliary continuity, though at the expense of a longer hospital stay. Laparoscopic (and emerging robotic) reconstructions can match these outcomes while reducing length-of-stay and blood loss. However, these minimally invasive approaches require advanced skills and appropriate cases (generally less complex injuries).

In summary, achieving economic efficiency in BDI repair hinges on tactical factors: timely diagnosis, referral to specialized centers, and selection of the optimal surgical technique. Improving training in advanced laparoscopic/robotic suturing and expanding multidisciplinary care pathways could further reduce costs and morbidity. Future comparative studies (especially on robotic repair) and formal cost-utility analyses are needed to refine these conclusions. Ultimately, ensuring that every major bile duct injury is managed promptly by a specialized team is likely the single most effective strategy for maximizing both clinical and economic outcomes.

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