UDC 616.381-002-036.17-089:616.34-008.6:338.45

ECONOMIC SUSTAINABILITY OF PRECISION-GUIDED HEMIHEPATECTOMY

Yusupov Temurbek Alisher Ugli
Independent Researcher
Department of Surgical Diseases No. 1 and Transplantology
Samarkand State Medical University

Salikhov Diyor Bahtiyarovich
Independent Researcher
Department of Surgical Diseases No. 1 and Transplantology
Samarkand State Medical University

Annotation. This article has examined the dual aspects of economic efficiency and technological advancements in hemihepatectomy (half-liver resection). We reviewed current evidence on clinical outcomes, costs, and the impact of modern innovations such as laparoscopic and robotic surgery, advanced imaging/navigation, and ERAS protocols. The findings indicate that minimally invasive techniques (laparoscopic and robotic hemihepatectomies) achieve equivalent or better clinical results compared to the open approach – including shorter recovery times, similar or lower complication rates, and maintained oncological effectiveness. Economically, laparoscopic surgery is shown to be cost-effective, yielding improved quality of life and faster return to work for a modest increase in direct costs. Robotic surgery, while incurring higher intraoperative expense, can offset costs by reducing hospital stays and complications, particularly in complex cases. Enhanced recovery programs further contribute to cost reduction and efficient care by accelerating patient convalescence. Technological innovations such as 3D planning, fluorescence-guided resection, and better transection devices have improved surgical precision and safety, translating into fewer postoperative interventions and complications. In summary, modern advancements in surgical hepatology have made hemihepatectomy safer and more patient-friendly, while also delivering high value. Hospitals that invest in these technologies and protocols often see acceptable or improved cost-benefit outcomes, as savings from shorter hospitalizations and avoided complications counterbalance the upfront expenditures. The continued evolution of surgical techniques – guided by rigorous outcome and cost evaluations – is essential to further enhance the efficacy and efficiency of liver cancer surgery.

Keywords. hemihepatectomy; liver resection; cost-effectiveness; laparoscopic surgery; robotic surgery; surgical technology; enhanced recovery; liver surgery outcomes

Hemihepatectomy – the surgical removal of approximately half of the liver (right or left lobe) – is a cornerstone treatment for various liver tumors, including hepatocellular carcinoma, cholangiocarcinoma, and colorectal liver metastases. This procedure is highly relevant in modern surgical hepatology as it offers the chance of cure or long-term survival for patients with otherwise lethal liver malignancies. Over the past several decades, there have been dramatic improvements in the safety and outcomes of liver resections, thanks to advances in surgical techniques, perioperative care, and technology. Early in the 20th century, major hepatectomies carried prohibitive risks, but today, in high-volume centers, the perioperative mortality for elective hemihepatectomy is often in the low single digits (on the order of 2–5%). This progress is attributable to better understanding of liver anatomy, improved anesthesia and critical care, refined surgical skills, and innovations such as vascular control methods and parenchymal transection devices. Patients who were once deemed unresectable can now be offered surgery with curative intent, reflecting the evolving capabilities of hepatic surgery.

In addition to clinical outcomes, the economic impact of hemihepatectomy has become increasingly important. Liver surgeries are resource-intensive, involving prolonged operative time, advanced equipment, and specialized postoperative care. The costs to healthcare systems are significant, and there is a growing need to ensure that innovations in surgical technique also translate into cost-effective care. For instance, the adoption of minimally invasive approaches (laparoscopic and robotic hepatectomy), while improving patient recovery, must be justified by overall value. Economic efficiency in this context refers to achieving the best possible clinical outcomes (e.g. higher survival or quality of life) per unit cost, or even reducing costs without compromising outcomes. Stakeholders – including hospitals, insurers, and patients – are interested in whether new surgical technologies actually reduce hospital stay, complications, and downstream expenses. Thus, the topic of how technological advancements influence both the clinical outcomes and the cost-benefit profile of hemihepatectomy is highly pertinent. With liver cancer incidence rising globally and more patients eligible for surgical intervention, optimizing both the effectiveness and the efficiency of hemihepatectomy has broad implications for healthcare systems.

Modern surgical hepatology has seen a surge of innovations: laparoscopic liver resection (LLR) has become widely performed for minor resections and is increasingly applied to major resections (right/left hemihepatectomies); robot-assisted surgery offers enhanced dexterity for complex liver resections; advanced imaging techniques (3D reconstructions, intraoperative ultrasound, fluorescence imaging) and navigation systems are being integrated to guide precise tumor removal; and perioperative care pathways like Enhanced Recovery After Surgery (ERAS) are shortening recovery time. All these advancements aim to improve patient outcomes such as lower morbidity, faster return to normal activity, and improved survival – but

they also come with costs (e.g. expensive equipment, training requirements). Evaluating the cost-effectiveness of these innovations is essential for evidence-based adoption. In summary, the relevance of this topic lies in its dual focus: ensuring that technological progress in hemihepatectomy translates into tangible health benefits while also maintaining or improving the economic efficiency of care delivery.

The objective of this research is to analyze and evaluate the economic efficiency and technological advancements in hemihepatectomy, with a focus on recent evidence from modern surgical practice. Specifically, this article aims to:

Materials and Methods. This article is structured as a narrative review and analysis. We gathered information from a wide range of sources, including clinical trials, systematic reviews, retrospective studies, and meta-analyses related to hemihepatectomy, published in the last 10–15 years. Particular emphasis was placed on studies published since 2020 to capture recent advancements in technology and their impacts on clinical practice and economics in liver surgery. Key sources of data included:

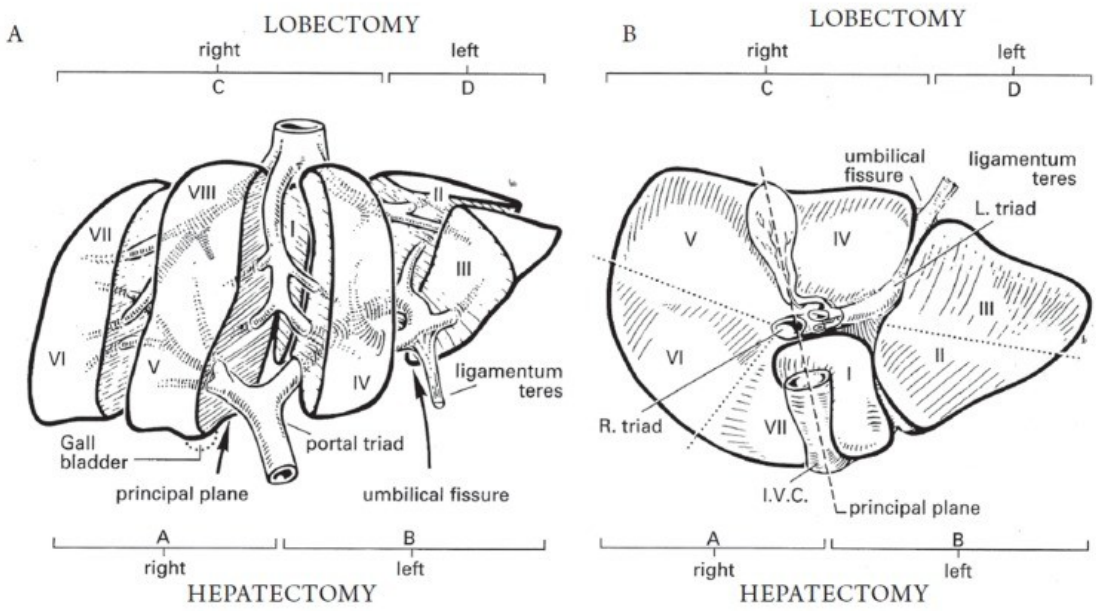

Figure 1: Segmental anatomy of the liver showing the functional left and right hemilivers divided by Cantlie's line (middle hepatic vein). Understanding this anatomy is fundamental for planning hemihepatectomy resections

Literature searches were conducted on databases such as PubMed, PMC, and Google Scholar using keywords like "hemihepatectomy", "laparoscopic liver resection cost", "robotic liver surgery economics", "liver resection outcomes", and "ERAS liver surgery". Articles were screened for relevance to economic or technological aspects. We also manually searched reference lists of pertinent papers (snowball method) to identify additional studies. For the technological advancements

section, we included not only clinical outcome studies but also engineering and feasibility studies to cover emerging tools.

Extracted data were organized into thematic categories: (1) Clinical outcomes of hemihepatectomy by surgical approach; (2) Cost and cost-effectiveness comparisons; (3) Technological innovations (with subtopics like minimally invasive surgery, imaging/navigation, and perioperative protocols). Within each category, we synthesized quantitative outcomes (e.g. complication rates, cost figures) and qualitative insights (e.g. surgeon learning curve considerations, system-level implications). We present results in a combination of text, tables, and figures for clarity. Three tables summarize key data (outcomes comparison, cost breakdowns, and impacts of specific technologies), and three charts illustrate important comparisons (such as cost differences and recovery times). Three illustrative figures are included to help visualize anatomical and technological points.

No new patient data were collected for this article; all analyses are based on published literature (thus IRB approval was not required). Where numerical data from studies are reported, we provide citations to the original source. Cost figures are presented in original currency (with context if needed, e.g. Euros for European studies, US dollars for American studies). For consistency, when discussing "economic efficiency", we interpret it in terms of cost relative to outcomes (e.g. cost per QALY or overall cost savings with equal outcomes).

By combining evidence from multiple high-quality sources and recent studies, this review method allows a comprehensive overview of the current state of economic and technological considerations in hemihepatectomy. Any limitations (such as heterogeneity between studies, differences in healthcare systems affecting costs) are acknowledged in the discussion. The results below integrate these findings, and the discussion interprets their significance in the context of modern liver surgery.

Results and Discussion. The advent of laparoscopic techniques has significantly influenced patient recovery and outcomes in liver surgery. The ORANGE II PLUS randomized trial provides robust evidence in the context of hemihepatectomy. In this international multicenter RCT, 332 patients were randomized to laparoscopic hemihepatectomy (LH) or open hemihepatectomy (OH). The laparoscopic approach demonstrated a shorter time to functional recovery: median 4 days vs 5 days with open surgery ($p < 0.001$). This metric of "functional recovery" typically includes factors like pain control, mobilization, and resumption of oral intake, so a one-day improvement is clinically meaningful. Importantly, this faster recovery did not come at the cost of higher morbidity – the rate of major complications was similar between laparoscopic and open groups (approximately 14.5% vs 16.9%, $p = 0.58$, no significant difference). Oncologic efficacy was preserved as well: in patients with malignancies, R0 resection (negative margin) rates were equivalent (about 78% vs 84%, $p = 0.14$), indicating that the minimally invasive approach did not compromise tumor clearance. Short-term mortality was low in both arms (around 3% 90-day

mortality in each, with no difference) – reflecting the general safety improvements in modern liver surgery.

The laparoscopic group showed distinct advantages in patient-centered outcomes. Health-related quality of life (qol) scores, measured by standardized questionnaires, were better after laparoscopic surgery: global health status was higher by a small but significant margin in the LH group. Patients also reported better body image in the minimally invasive group (as expected, due to smaller incisions). Additionally, for those with cancer, laparoscopic surgery enabled earlier initiation of adjuvant chemotherapy – a median of ~46 days post-op vs ~63 days after open surgery (a difference of over two weeks). This is a crucial finding: delays to chemotherapy can adversely affect oncologic outcomes, so the ability to start systemic therapy sooner is a potential long-term benefit of the laparoscopic approach.

Beyond the trial data, numerous observational studies and meta-analyses have echoed these trends. Laparoscopic liver resection in general is associated with less postoperative pain, lower incidence of wound complications (e.g. Infections or hernias), and shorter hospital stays. A systematic review noted that laparoscopic liver resections had a significantly shorter length of hospital stay compared to open resections (by roughly 2–3 days on average) in multiple studies. Major liver resections (like hemihepatectomies) performed laparoscopically remain a challenging endeavor (requiring significant expertise), but experienced centers have reported favorable outcomes: low conversion rates to open surgery and perioperative mortality under 5%, even for complex laparoscopic hepatectomies.

Robotic Hemihepatectomy: Robotic-assisted surgery is an extension of minimally invasive technique that has gained traction in hepatobiliary surgery. The robotic platform (e.g. The da Vinci Surgical System) addresses some limitations of straight laparoscopy by providing articulated instruments, magnified 3D vision, and improved ergonomics for the surgeon. These enhancements can be particularly useful in liver resections of the postero-superior segments and other challenging locations that are difficult to visualize or access laparoscopically. According to recent multicenter analyses, robotic liver surgery (RLS) offers comparable or improved perioperative outcomes relative to open and even laparoscopic approaches. In a 2024 study by Ingallinella et al., which compared 47 robotic, 101 laparoscopic, and 124 open major liver resections, both minimally invasive modalities (robotic and laparoscopic) showed reduced intraoperative blood loss, lower overall complication rates, and shorter hospital stays compared to open surgery. The robotic group had zero 90-day mortality in that series, whereas open surgery had a small number of mortalities – suggesting at least equivalent safety, if not an advantage for RLS in experienced hands.

One notable observation was that the robotic approach achieved a lower conversion rate (fewer cases needing to switch to open) compared to laparoscopy in this context. This implies that the robot's technical advantages (wristed instruments,

better stability) can enable surgeons to complete minimally invasive resection even in anatomically difficult cases that might otherwise require conversion when done laparoscopically. As a result, robotic surgery expands the range of patients who can benefit from minimally invasive hepatectomy, including some with large posterior tumors or cirrhotic livers where delicate dissection is needed. The trade-off is that robotic surgery tends to have longer operative times and higher intraoperative resource utilization (discussed further under economics). Nevertheless, the study concluded that robotic liver resection "offers economic advantages over open" in that the better perioperative outcomes (fewer complications, shorter length of stay) offset the higher upfront costs. It also emphasized that as the technology matures and becomes more widely available, the cost of robotic instrumentation is expected to decrease, potentially making RLS more routinely cost-effective.

In terms of long-term outcomes like survival or oncologic clearance, data are still maturing. Early reports indicate that robotic and laparoscopic approaches do not compromise oncological efficacy for malignant tumors, provided the surgical principles (achieving negative margins, proper lymphadenectomy when needed) are adhered to. Ongoing trials and registries will better clarify any differences in recurrence patterns. For now, minimally invasive hemihepatectomy – whether laparoscopic or robotic – has proven to be a safe alternative to open surgery, with clear benefits in patient recovery and at least equivalent short-term outcomes.

Overall, the shift from open surgery to minimally invasive techniques in hemihepatectomy exemplifies how technological and technique innovations can improve patient outcomes. It is a testament to modern surgical hepatology that a major operation like right or left hepatectomy can now be done with smaller incisions and yield equal or better results. However, these innovations also raise important questions about cost and resource utilization, which we explore next.

To put it simply, laparoscopic hemihepatectomy provides better patient-centered outcomes for a modest increase in cost, and falls within commonly accepted cost-effectiveness thresholds. For health systems, this is an encouraging message – it implies investing in minimally invasive capability (training surgeons, buying equipment) is worthwhile in the long run. There may even be indirect economic benefits not fully captured in hospital costs: for example, patients returning to work sooner or needing fewer post-discharge services.

The conclusion drawn was that while robotic surgery currently incurs a premium over conventional laparoscopy, it can pay off when it prevents a patient from undergoing a laparotomy (open conversion) in a complex case. In other words, if a difficult tumor resection is feasible robotically but not laparoscopically, the alternative might have been an open surgery with its attendant higher costs. In such cases, the robot's value is realized. The study also optimistically noted that an "evolving robotic marketplace" and wider adoption will likely drive down costs of RLS (for example, via competition or reusable instrument development). Therefore,

robotic liver resection is seen as an investment that can become cost-effective, especially as the technology improves and the initial capital costs are amortized over many cases.

It's also important to consider indirect costs and broader economic impacts. From a societal perspective, minimally invasive surgery can confer benefits like reduced lost productivity (the patient returns to work sooner) and lower need for post-discharge rehabilitation. Enhanced recovery not only frees hospital beds sooner (which has an opportunity cost – a freed bed can be used for another patient) but also alleviates the economic burden on patients and families. A Chinese study performing a comprehensive economic evaluation of ERAS (Enhanced Recovery After Surgery) in hepatectomy illustrated this point well: ERAS protocols shortened the average length of stay by a few days and roughly halved complication rates, which reduced the direct and indirect economic burden on patients and society. Hospitals had to invest in ERAS coordinators and education (increasing some input costs), but they benefited from faster bed turnover and potentially could treat more patients in the same timeframe. Thus, improved perioperative care is a win-win in many scenarios – patients recover faster and with fewer costs on their end, and hospitals operate more efficiently.

Finally, we should address the cost of not adopting new technology: If a technique significantly improves long-term outcomes (e.g. Enables curative surgery for more patients or reduces recurrence), the downstream savings (or gains in life-years) might be substantial. For example, consider portal vein embolization (PVE) as a prelude to extended hemihepatectomy – this is an interventional radiology technique (technological advancement in a broad sense) that increases future liver remnant and prevents postoperative liver failure. By doing so, it allows more extensive resections to be performed safely that otherwise might be impossible. The economic effect is enabling a curative surgery (with its cost) instead of leaving a tumor unresected (incurring the cost of progressive disease or less effective therapies). While a full cost analysis of such scenarios is complex, it underlines that technology that improves efficacy (curing more patients) has immense value beyond immediate perioperative costs.

In summary, modern advancements in hemihepatectomy generally show favorable economics: laparoscopic surgery is cost-effective and can be cost-saving in many instances, robotic surgery is trending toward cost-effectiveness especially for complex cases, and enhanced recovery protocols reduce costs to patients and payers alike. The initial higher expenditures on technology and training are offset by reductions in complications and length of stay in most analyses. Next, we delve into specific technological innovations that have driven these improvements.

Hemihepatectomy has benefitted from a suite of technological innovations in recent years. These range from improved surgical instruments to high-tech imaging

and navigation tools. Below, we discuss key innovations and how they impact both the procedure's success and its efficiency.

1. Advanced Surgical Equipment for Parenchymal Transection: Liver parenchymal transection (cutting through the liver tissue while sealing vessels) is a critical and time-consuming part of hepatectomy. Bleeding control is paramount, as excessive blood loss is linked to worse outcomes. Traditional methods like the crush-clamp technique with intermittent Pringle maneuvers (periodically clamping inflow vessels to reduce bleeding) are effective and still widely used, but newer energy devices have made transection faster and blood-sparing. Tools such as the Cavitron Ultrasonic Surgical Aspirator (CUSA), which uses ultrasonic vibrations to emulsify liver parenchyma while preserving vessels, allow precise dissection. When combined with bipolar cautery or advanced bipolar/sealing devices, surgeons can achieve meticulous hemostasis. Randomized trials have compared CUSA to other methods (e.g. Radiofrequency-based devices or crush-clamp) and found no large differences in overall morbidity or mortality, but some devices can reduce blood loss or transection time in certain settings. For instance, using harmonic scalpels or water-jet dissectors can shorten the transection duration and may reduce transfusion rates in experienced hands. From an economic standpoint, reducing blood loss has direct benefits (transfusions are costly, and anemia can prolong hospital stay). Modern hepatic surgery often employs a combination of techniques: vascular staplers for large vessels, energy devices for small channels, and intermittent inflow occlusion. This synergistic approach is part of the "technological advancements" that have improved safety. The cost of such devices is non-trivial, but studies suggest that the most effective method is often the fastest one – saving OR time (which is a very expensive resource) can justify the expense of the device. For example, the crush-clamp technique is time-honored and virtually cost-free, and one trial (the CRUNSH trial) showed it was as effective as newer methods in blood loss control while being faster and less costly. Thus, innovation doesn't always mean using the newest gadget – sometimes it's optimizing existing techniques or combining them smartly. The bottom line is that today's hemihepatectomy is conducted with far superior tools than decades ago, contributing to shorter operative times and fewer complications like coagulopathy or liver failure from massive bleeding.

2. Imaging and Intraoperative Navigation: Preoperative imaging (high-quality CT and MRI scans) and 3D volumetric planning are now standard in evaluating patients for hemihepatectomy. The ability to calculate future liver remnant volume and simulate resection virtually has improved patient selection and helped avoid postoperative liver insufficiency. Taking this a step further, computer-assisted surgery companies have developed navigation systems that use augmented reality to guide surgeons during the operation. In soft tissue like liver, navigation is challenging (due to deformability of the organ), but promising attempts exist. A 2023 pilot RCT by Heinrich et al. Tested an intraoperative 3D navigation system (CAS-One Liver) vs

standard procedure. While the trial did not show a significant difference in resection accuracy or safety with navigation (likely due to its small sample of 16 patients), it demonstrated that the technology is feasible and safe to use – it did not hinder the operation or increase complications. The authors noted that surgical accuracy was "not yet superior" to the traditional method of relying on surgeon experience and intraoperative ultrasound, but they are optimistic that with further refinements (especially better liver deformation algorithms and AR visualization), navigation could enhance precision. Another cutting-edge development is fluorescence-guided surgery using indocyanine green (ICG). In liver surgery, ICG can be used to demarcate segments or highlight tumors (depending on injection timing and technique). The combination of ICG fluorescence with 3D imaging was evaluated in a 2025 meta-analysis by Xu et al.: they looked at fluorescence navigation + 3D imaging (FN+3DI) vs conventional approach in liver resections. The results were impressive – the FN+3DI group had significantly less intraoperative blood loss (almost 100 ml less on average), lower transfusion rates, shorter hospital stay (by ~0.9 days), and fewer overall complications. The only drawback was a longer operative time by about 57 minutes on average. Crucially, there was no compromise in oncologic outcomes (no difference in negative margin rates or recurrence). This suggests that augmented imaging can make resections "precise" – surgeons can better see critical structures and tumor boundaries, leading to safer dissection at the cost of some additional OR time. The economic implication here is a classic trade-off: longer OR time increases cost, but reduced complications and shorter stay decrease cost. If a fluorescence-navigated hemihepatectomy avoids a major complication (e.g., bile leak or reoperation), it likely pays for the extra hour of OR time many times over. Moreover, the ICG and imaging technology itself is relatively cheap compared to, say, a surgical robot. Many centers now employ near-infrared cameras (often integrated into laparoscopic or robotic systems) for liver surgery. This is an innovation that clearly aligns with improved outcomes and potentially cost savings by averting complications.

3. Enhanced Recovery After Surgery (ERAS) Protocols: Not all innovations are hardware – some are process innovations. ERAS programs in liver surgery represent an evidence-based bundle of perioperative care elements (optimized anesthesia, pain control, early feeding, mobilization, etc.) Designed to accelerate recovery. Multiple studies have confirmed that ERAS in hepatectomy can shorten primary length of stay by a few days and reduce complications, without increasing readmissions or compromising outcomes. As mentioned earlier, the economic evaluation by Dong et al. Found ERAS reduced direct costs (by shortening hospitalization and lowering complication treatment costs) and indirect costs (by reducing productivity loss from prolonged illness). Hospitals incur some extra costs to implement ERAS (e.g. Hiring a coordinator, staff training), but these are outweighed by improved efficiency (higher bed turnover, possibly better throughput of surgical cases per unit time). In practical

terms, an ERAS pathway for hemihepatectomy might involve prehabilitation, avoidance of prolonged fasting (shorter pre-op fasting and early post-op oral intake), multimodal analgesia to minimize opioids, and early ambulation. Each of these has small benefits that add up: for example, less opioid use means less ileus and sooner discharge; early mobilization means fewer dvts or pneumonias. The result is a cascade of cost savings (fewer days in hospital, fewer expensive complications). A meta-analysis has even shown that ERAS can cut overall morbidity by as much as 30-40% in liver surgery, which is significant. Therefore, adopting ERAS is a high-value intervention – it improves outcomes and reduces costs, fulfilling the very definition of improved economic efficiency. As more centers standardize ERAS for liver resection, we expect the average length of stay for hemihepatectomy to continue to decrease (already, many centers target ~4–5 days for uncomplicated cases, whereas historically it was 8–10 days or more).

It is evident that technology and technique in liver surgery are advancing in tandem. Importantly, many of these innovations have a synergistic effect – for example, combining laparoscopic surgery with fluorescence navigation under an ERAS pathway could yield an optimal scenario: minimal incisions, maximum visualization, and rapid recovery. The challenge, however, is ensuring equitable access to these advancements. High upfront costs (like purchasing a robot or training staff in ERAS) might be barriers, especially in lower-resource settings. Cost-benefit data such as those discussed in this article can help administrators justify investments by showing the downstream savings or value.

Another consideration is the learning curve associated with new technology. During the initial phase of adopting laparoscopy or robotics, operations may take longer and complications might be higher, which could temporarily worsen economic efficiency. But as teams gain experience, the benefits are realized. High-volume centers have the best outcomes and typically the lowest costs per case (because efficiency improves with volume). For instance, studies have shown liver resections at experienced centers, while slightly more costly due to more aggressive approach, achieved better long-term survival – effectively giving better value for the money spent. This underscores that training and case volume are crucial “soft” technologies that need attention alongside hardware.

In conclusion of the results and discussion: Hemihepatectomy today is safer, more effective, and more efficient than ever before, thanks to a range of technological advancements and refined practices. Patients benefit from less invasive operations and faster recoveries; healthcare systems benefit when these improvements lead to cost savings or favorable cost-effectiveness. While some innovations come with hefty price tags, the evidence so far indicates that their adoption can be justified by the improved outcomes they confer. The key moving forward will be to continue rigorously evaluating new techniques – for both clinical efficacy and economic impact – to ensure that surgical progress remains aligned with value-based care.

Conclusion

Clinical Outcomes Have Improved: Advances in surgical techniques – particularly the shift toward minimally invasive approaches – have made hemihepatectomy a safer procedure with quicker recovery. Laparoscopic hemihepatectomy offers clear benefits in terms of reduced pain, shorter functional recovery times, and improved postoperative quality of life, without compromising surgical radicality or patient survival. Robotic surgery further extends the capability to perform complex liver resections minimally invasively, maintaining low complication rates even in challenging cases. Overall, perioperative mortality and morbidity for hemihepatectomy have significantly declined compared to historical benchmarks, reflecting improvements in patient selection, anesthesia, and surgical technique.

Technological Innovations Drive Efficiency: The introduction of advanced tools (CUSA, energy devices), imaging modalities (intraoperative ultrasound, fluorescence imaging), and navigation systems has enhanced surgical precision. These technologies help surgeons preserve healthy liver parenchyma, achieve negative margins, and avoid injuries to vital structures. In turn, this reduces complications like bleeding, biliary leaks, or liver failure, which are not only dangerous for patients but also costly to manage. Enhanced Recovery protocols, although not “technology” in the hardware sense, are a process innovation that synergizes with surgical advances to speed up recovery and shorten hospital stay. The net effect is that many patients can undergo a hemihepatectomy and be discharged in under a week in good condition, which was rarely possible in the past.

Economic Efficiency is Achievable: Modern practices in hemihepatectomy demonstrate that better outcomes need not come with runaway costs. Laparoscopic surgery, while slightly more expensive intraoperatively, is cost-effective by widely accepted standards due to downstream benefits. Robotic surgery, currently more costly, is on a trajectory toward cost-effectiveness as the technology matures and competition increases. Importantly, avoiding or mitigating complications yields substantial cost savings – and many of the advancements discussed (e.g. minimally invasive approaches, improved imaging, ERAS) are aimed precisely at complication reduction. The evidence shows that when clinical teams adopt these best practices, hospitals can expect lower utilization of high-cost resources like ICU beds, blood products, and prolonged ward care. For example, ERAS programs shorten hospitalization and reduce readmissions, translating to improved bed turnover and lower expenditure per case. In the big picture, an intervention like laparoscopic hemihepatectomy can provide more quality-adjusted life time to patients for a reasonable incremental cost, supporting its value-based adoption.

Holistic Benefits: Technological advancements in hemihepatectomy also carry intangible or long-term benefits that are not immediately reflected on a balance sheet. Patients having smaller incisions (laparoscopic/robotic) experience less psychological

stress and better cosmetic outcomes, which improves overall well-being. Faster recovery means patients can return to normal life and work sooner, benefiting society and families. These aspects reinforce the positive impact of innovations beyond the hospital walls. Moreover, by making surgery more tolerable, more patients (especially the elderly or those with borderline fitness) can be considered for curative resection rather than being relegated to non-surgical therapies. In oncology, this can improve population-level survival and potentially reduce the need for prolonged systemic treatments (which have their own costs).

Continued Progress and Caution: The field of hepatobiliary surgery continues to innovate – from better systemic therapies that shrink tumors preoperatively, to potential future applications of artificial intelligence in surgical planning or intraoperative decision support. As we embrace new technologies (e.g. AI-driven image analysis, next-generation robots, etc.), it will be crucial to maintain rigorous evaluation of their impact. Not every new gadget will be worth the cost, and some may offer only marginal gains. The lessons learned from the current generation of advances are instructive: multidisciplinary collaboration (surgeons, anesthesiologists, nurses, engineers, economists) is key to designing pathways that maximize patient benefit and minimize waste. High-volume centers and training will remain important – technology is best leveraged by skilled teams, and centralization of complex liver surgeries often yields both better outcomes and more efficient resource use.

References

1. Olij B. et al. (2025). “Healthcare Utilization, Costs, and Cost-Effectiveness of Patients Undergoing Laparoscopic and Open Hemihepatectomy: A Secondary Analysis of the ORANGE II PLUS Randomized Controlled Trial.” Annals of Surgical Oncology. (Findings: Laparoscopic vs open cost €18,982 vs €17,141; ICER €36,677/QALY; 77% probability cost-effective)

2. Ingallinella S. et al. (2024). “Evaluation of the economic impact of the robotic approach in major and postero-superior segment liver resections: a multicenter retrospective analysis.” Hepatobiliary Surgery and Nutrition, 13(2): 209–222. (Findings: Robotic vs laparoscopic vs open total cost €10,637 vs €9,543 vs €13,960; robotic reduced LOS and complications vs open)

3. Fichtinger RS. et al. (2024). “Laparoscopic versus Open Hemihepatectomy: The ORANGE II PLUS Multicenter Randomized Controlled Trial.” Journal of Clinical Oncology, 42(15): 1799–1809. (Findings: Laparoscopy shortened functional recovery 4 vs 5 days; similar complications and margins; earlier chemo and better QoL with laparoscopy)

4. Dong Y. et al. (2021). “Comprehensive economic evaluation of enhanced recovery after surgery in hepatectomy.” International Journal for Equity in Health, 20(1): 245. (Findings: ERAS reduced length of stay ~11.4 to 8.9 days; halved complication rate ~12.4% to 6.3%; lowered patient economic burden and improved hospital efficiency)

5. Xu C. et al. (2025). “Efficacy and safety of fluorescence navigation combined with 3D imaging in precise liver resection: a systematic review and meta-analysis.” Photodiagnosis and Photodynamic Therapy, 51: 104446. (Findings: Fluorescence + 3D navigation reduced blood loss (~98 mL less), transfusions (OR 0.34), complications (OR 0.60), and LOS (~0.9 days shorter); slightly increased OR time by ~57 min)

6. Shoup M. et al. (2012). “Techniques of hepatic resection.” Journal of Gastrointestinal Oncology, 3(1): 28–40. (Overview: Historical development of liver surgery techniques; notes improved morbidity/mortality over 60 years, role of Pringle maneuver, CUSA vs crush-clamp etc.; concludes no one technique fits all, but combination of advances improved outcomes)

7. Limongelli P. et al. (2014). “Costs of laparoscopic and open liver and pancreatic resection: A systematic review.” World Journal of Gastroenterology, 20(23): 8265–8271. (Findings: Laparoscopic liver resection had lower total costs than open in pooled analysis – e.g. $19.3k vs $23.4k; laparoscopic saved on hospital stay and ICU costs despite higher OR costs)