Abstract / Povzetek predavanja

Minimal Liver Surgery: Past, Present, and Future

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THE HISTORY OF LIVER SURGERY

Liver surgery has undergone a profound transformation, reflecting the evolution of surgical practice from high-risk, open procedures to minimally invasive and image-guided techniques. In the late 19th and early 20th centuries, early hepatic surgeries were primarily performed in response to trauma or infection, such as liver abscess drainage. These procedures were dangerous, hampered by a lack of effective anesthesia, poor hemostasis, and limited anatomical understanding.

Significant progress occurred in the mid-20th century with the introduction of safer anesthetic protocols, blood transfusion systems, and especially the Couinaud classification of hepatic segments (Couinaud, 1957). This anatomical framework allowed for precise, segment-oriented resections and made liver surgery more systematic. By the 1960s, liver resections were commonly performed for hepatocellular carcinoma (HCC) and colorectal liver metastases (CRLM), particularly as diagnostic imaging improved and surgical techniques matured (Kingham et al 2015).

THE SHIFT TO MINIMALLY INVASIVE TECHNIQUES

The late 20th century marked the beginning of the minimally invasive revolution. The first laparoscopic liver resection (LLR) was reported by Reich *et al.* in 1991, initially limited to small, peripheral lesions (Reich *et al.*, 1991). Over the next two decades, laparoscopic liver surgery expanded significantly with the development of high-definition cameras, advanced instrumentation, and growing surgeon experience.

Studies comparing open and laparoscopic resections demonstrated that LLR was associated with lower intraoperative blood loss, reduced postoperative pain, shorter hospital stays, and faster recovery, while maintaining equivalent oncological outcomes for selected patients (Fretland *et al.* 2018, Aghayan et al 2021).

The 2000s saw the emergence of robotic liver surgery, offering increased dexterity, 3D visualization, and improved ergonomics. Robotic systems, like the da Vinci platform, have extended minimally invasive techniques to more complex resections and anatomically challenging areas (Tsung *et al.*, 2014). As a result, robotic-assisted hepatectomy has become a growing part of modern liver surgery practice.

LOCAL ABLATION OF LIVER TUMORS: A MINIMALLY INVASIVE FRONTIER

In parallel with surgical advancements, local ablative therapies have emerged as transformative tools in the management of liver tumors. Techniques such as radiofrequency ablation (RFA) and microwave ablation (MWA) provide a non-resection-based alternative for tumor destruction, particularly for patients with small tumors or high surgical risk.

For hepatocellular carcinoma, studies have demonstrated that RFA can achieve outcomes comparable to surgical resection in tumors less than 3 cm, with reduced complication rates and shorter recovery times (). RFA and MWA are often repeatable, minimally invasive, and can be guided with high precision using ultrasound or CT imaging (Livraghi *et al.* 2008)

In the treatment of colorectal liver metastases (CRLM), local ablation is gaining traction. Although resection remains the gold standard for curable disease, several studies have validated the efficacy of ablation in patients who are unresectable or medically inoperable. The EORTC CLOCC trial, a landmark randomized phase II study, found improved progression-free survival in patients treated with systemic therapy plus RFA compared to systemic therapy alone (Ruers *et al.*, 2017). Meta-analyses and cohort studies have shown that ablative therapies can achieve long-term survival and local control in selected CRLM patients, particularly when lesions are fewer than three and smaller than 3 cm (Van Amerongen *et al.*, 2017; Tinguely P et al 2023).

As ablative technology continues to improve and is paired with real-time image guidance and navigation, it is increasingly considered not just an adjunct but a potential alternative to traditional liver resection in select patients. This shift may significantly alter surgical algorithms and pave the way for a hybrid approach combining ablation, resection, and systemic therapy.

FUTURE DIRECTIONS IN LIVER SURGERY

The future of liver surgery is being shaped by a convergence of digital technology, personalized medicine, and regenerative biology. Artificial intelligence (AI) is already being utilized to assist in surgical planning—enabling automatic liver segmentation, tumor detection, and preoperative simulations to optimize resection or ablation strategies (Gao *et al.* 2025). Intraoperative navigation systems, powered by AI and machine learning, are improving real-time decision-making.

Augmented and virtual reality (AR/VR) platforms are being used both for education and operative support. AR allows surgeons to overlay 3D reconstructions of the liver and tumor onto the operative field, enhancing orientation during complex procedures (Gavriilidis *et al.* 2022).

Regenerative medicine is another promising frontier. Advances in 3D bioprinting and liver tissue engineering may one day allow for the replacement of resected segments or support liver regeneration in patients with inadequate liver reserve. Stem cell therapies are also being explored as supportive treatments in liver failure or chronic liver disease.

Lastly, genomic medicine is revolutionizing oncology and is beginning to influence surgical decisions. With tumor profiling, surgeons can better assess prognosis, tailor perioperative treatment plans, and even decide between resection, ablation, or combined modalities based on tumor biology (Gao *et al.* 2025).

CONCLUSION

The history of liver surgery—from the first high-risk open resections to today's robotic and image-guided interventions—demonstrates the power of surgical innovation. Minimally invasive techniques, once seen as niche, are now standard for many hepatic resections. The rise of local ablative thera-

pies is reshaping treatment strategies for both primary and metastatic liver tumors, offering effective alternatives with fewer risks.

As we look to the future, liver surgery will increasingly be defined not by scalpel and incision, but by digital tools, personalized treatment strategies, and regenerative approaches. Whether through AI-assisted planning, ablative precision, or biologically tailored therapy, the field is moving toward a more individualized, less invasive, and highly effective era in hepatobiliary care.

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