Human judgment remains vital for safe robotic surgery

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Elon Musk's prediction that surgical robots will outnumber surgeons within three years is not supported by the current evidence; autonomous surgery faces unresolved technical, regulatory, and ethical obstacles

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Elon Musk recently claimed that in three years, there will be more expert surgical robots than surgeons on the earth. The statement generated considerable excitement, speculation, and outrage in equal measure. While medicine is a deeply personal enterprise, it is also rooted in science.

The fundamental challenge in surgery is not precision but adaptability. Surgery in a young child is vastly different from that in an elderly person, even when the pathology and procedure are the same. This fact is further confounded by previous treatment, underlying health issues, and variations in anatomy and physiology.

The closest comparison for automation is driving and commercial aviation. Autonomous driving has had nearly 15 years of real-world testing, hundreds of millions of kilometres, and billions of dollars in investment in a relatively structured environment – yet it still operates without a federal approval framework in the U.S. and is confined to state permits in a handful of cities. In aviation, artificial intelligence (AI) remains limited to predictive maintenance and pilot assistance.

These limitations exist not because automation fails conceptually but because of unpredictable results in edge cases – situations outside the range of conditions the system was designed to handle. Surgery is fraught with them, and, unlike with a car, there is no safe emergency stop.

A July 2025 study by Johns Hopkins University researchers showed that an autonomous robot could perform gallbladder removal across non-uniform anatomical conditions, with tissue appearance altered by blood-like dyes, based on a 17-step task chain. Although it was a remarkable proof of concept, a systematic review of autonomous surgical robots approved by the U.S. Food and Drug Administration found that most robots demonstrated only level 1 autonomy (basic assistance), with four level 2 systems (specific task autonomy) and three level 3 systems (conditional autonomy) in clinical use. No semi- or fully autonomous systems are deployed anywhere.

AI-assisted robotic surgery, where the system guides rather than replaces the surgeon, is a different matter. Studies have shown reductions of 25% in operative time and 30% in intraoperative complications compared to conventional methods.

Surgery is more than completing a technical task. AI systems trained on historical datasets risk being misguided when the anatomy is anomalous or the context departs from the training data, and may mask the intuitive signals that inform experienced surgical judgment.

When an error occurs in autonomous surgery, the distribution of responsibility between manufacturing defects, medical negligence, and software failure is also unresolved, with no clarity on how stakeholders will share liability. Even if a consensus is reached, enforcement requires new legislation and regulatory frameworks, with applicable case law across every jurisdiction. Standard metrics to evaluate these systems are lacking, making clinical trial design difficult. And there is no quick fix for any of these problems on the horizon. Next, running a large vision or language model to guide a complex operation in real time is computationally intensive.

The scarcity of large open-source surgical datasets, plus the challenge of creating sufficiently realistic tissue environments for training and validation, has prevented the field from scaling at the same rate as other AI domains. Even rough estimates suggest that training an autonomous system to perform a single straightforward procedure could exceed the annual operating budget of a medium-sized hospital, even before regulatory costs are factored in. How this expenditure will be absorbed into existing healthcare systems, particularly resource-constrained ones, remains unanswered. The comparison currently favours human expertise.

The most credible near-term scenario is augmentation, not replacement. AI will improve at executing pre-specified tasks like dissecting tissue, sounding proximity alerts near critical structures, providing anatomical overlay, providing surgical navigation, and objectively evaluating techniques.

The systems are likely to remain human-dependent, with autonomy expanding incrementally rather than through a step change.

The aviation analogy holds: autonomous systems will handle cruise conditions but surgeons will still be needed for take-off, landing, and judgment calls that fall outside the training envelope. Medicine rarely obeys timelines set by press conferences.

The evidence suggests AI will make surgery safer, expand access through telesurgery, and compress the treacherous learning curve of complex procedures. In doing so, it will make surgeons who understand these tools considerably more effective than those who do not.

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Steady hand

Surgery's fundamental challenge is adaptability, not precision

Surgeons who understand AI tools will be more effective than those who do not. CÉSAR BADILLA MIRANDA

- Elon Musk's recent claim about surgical robots ignores the extreme difficulty of managing complex, unpredictable human anatomy
- Lessons from autonomous driving show that unpredictable edge cases prevent machines from operating without constant human supervision
- Current surgical technology remains limited to basic assistance because fully autonomous systems lack the required regulatory approval
- AI currently functions best as a tool for augmentation rather than as a total replacement for surgeons
- Surgeons must integrate clinical judgment and patient ethics — both qualities that machines can't currently replicate effectively
- High computational costs and unresolved liability issues present significant barriers to widespread adoption of autonomous surgery