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Editorial

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Accelerating the path to sustainable robotic surgery

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Recent evidence suggests that the increased environmental impact of robotic assisted surgery (RAS) may not sufficiently offset its clinical benefits, with RAS estimated to generate 43% higher greenhouse gas emissions and 24% higher waste production than laparoscopic alternatives[1]. Adoption has expanded rapidly, although robotic surgery offers advantages where enhanced precision, shorter recovery, and lower complication rates are required. In certain operations, these gains have been used to offset and justify increased resource consumption and environmental impact. However, while some robotically delivered procedures demonstrate benefits over open or conventional laparoscopic approaches, many high volume, low complexity procedures have not been proven to deliver such benefits and the additional environmental burden may prove difficult to justify[2,3].

As use of RAS increases, reduction of its environmental footprint is possible with advances in robotic technology are likely to play a central part. As systems become more widespread, competition among manufacturers should stimulate innovation that improves energy efficiency, manufacturing processes, and instrument reusability. Calls from healthcare providers to extend the lifespan of nominally single use instruments may also encourage design for greater durability and repeated use[4-5].

With growing surgical experience, procedural efficiency tends to improve, with shorter operating times, lower energy consumption, and reduced reliance on disposable equipment[7]. These trends mirror the evolution of laparoscopic surgery, which initially depended heavily on single use instruments, incurred higher costs, and involved longer procedures[1]. Within the Dutch GreenCycl initiative, these instruments are now decontaminated and components are harvested and reused in several pilots. Realising this potential requires sustained innovation and a commitment to sustainable practices within healthcare institutions and among manufacturers of robotic systems.

Individual surgeons cannot deliver large scale change alone, yet each has an important role in reducing the environmental impact of robotic surgery. Surgeons exert influence throughout the healthcare pathway, from the operating theatre to procurement discussions. They should act as informed advocates for sustainability, educating colleagues and promoting awareness within surgical teams and across organisations. Harris et al. reported a substantial gap in sustainability education, with only 12% of respondents having received training in environmental sustainability, despite 85% expressing interest[8]. This finding underlines the need to foster a culture of sustainability that empowers colleagues, trainees, and other healthcare staff to prioritise environmentally responsible practice. By systematically reporting waste and inefficiencies observed during procedures, surgeons can provide insights to decision makers, procurement teams, and hospital administrators. This type of bottom up feedback generates tangible data on waste generation and workflow inefficiency[9]. Professional societies and conferences should support this agenda through evidence based research that clarifies the environmental consequences of surgical choices.

Greater use of reusable instruments, standardisation of procedure specific sets, and promotion of sustainable instrument production will all have influence. Prioritising durable, multi-use instruments in collaboration with manufacturers, who can refine sterilisation methods and develop modular designs, extends instrument lifespan and reduces waste10-12. By sharing expertise and emphasising precision and efficiency, experienced robotic surgeons can support the spread of habits that lower resource use and improve practice. These actions should be complemented by a commitment to research directed at reducing the environmental footprint of robotic surgery, to generate robust recommendations for clinicians and policy makers[13].

Careful case selection and systematic study of the environmental consequences of different approaches are essential if the ecological impact of robotic surgery is to be minimised[14]. Surgeons should assess whether robotic surgery is necessary or whether a less resource intensive option, such as laparoscopy or open surgery, could achieve equivalent clinical results without increasing the carbon footprint, waste, power consumption, or instrument use[15]. Selecting cases that are well suited to robotic techniques and avoiding complications that necessitate intraoperative conversion can further limit resource consumption. Training programmes that improve surgeons' robotic skills may reduce technical complications and associated waste. Comparative studies of robotic, laparoscopic, and open procedures will provide further data into both clinical and environmental outcomes and will support patient centred decision making[1]. In parallel, research into the features of robotic instruments that most contribute to tissue manipulation may enable the development of new sustainable instruments that deliver improved function without the need for a robot or electric actuation.

Progress towards sustainability in robotic surgery requires coordinated action from multiple stakeholders. Engagement from the RAS industry is essential, with early efforts already directed at extending instrument lifespan and developing modular designs with replaceable components to reduce waste. Companies must lead in sustainable manufacturing, including use of environmentally preferable materials and optimised energy use during production[16]. As hospitals increasingly incorporate sustainability into procurement criteria, manufacturers will need to adopt such practices to remain competitive. Hospital administrations and operating theatre leadership are equally important, because they can embed sustainability in routine practice through training, adoption of reusable equipment, and procurement policies that favour environmentally responsible products. Patients benefit from these efforts, which aim to lessen healthcare's environmental impact while maintaining or improving quality of care. Regulation experts must help ensure that regulations permit circular use of materials. Sterilisation specialists should optimise decontamination processes, and financial decision makers should evaluate long term cost savings from sustainable strategies.

Approaches to mitigating the environmental impact of robotic surgery differ across countries and health systems, shaped by funding models, infrastructure, cultural priorities, regulation, and access to technology. The Netherlands, Italy, and the UK have shown early commitment to sustainability in this field. For example, a collaborative project between the Netherlands and the UK on decontaminating and recycling robotic instruments found that replacing single use plastic arm covers with reusable drapes could substantially reduce waste. However, in settings with fewer resources or limited awareness of sustainability, financial constraints and regulatory barriers may impede implementation of advanced sustainable practices. These differences indicate the need for adaptable and scalable strategies that can be tailored to local conditions, with leading centres acting as exemplars to promote wider adoption[17].

The integration of a computer interface between surgeon and patient, through advanced visualisation, enhanced instrumentation, data capture with artificial intelligence (AI), telepresence, and robotic platforms, has the potential to improve surgical precision and outcomes while supporting sustainability objectives[16]. Advanced visualisation can increase accuracy, reduce error, and limit the need for additional procedures and materials. AI assisted systems may optimise energy use in real time, including in electrosurgical devices, thereby reducing waste and energy demand[7]. Telepresence

can decrease travel for surgeons, patients, and teams, lowering the carbon emissions associated with transport and widening access to care. Robotic platforms can streamline operations, improve precision and efficiency, and reduce unnecessary use of consumables. Digital systems that monitor material flow can provide insight into consumption and waste, and several platforms are now available that support real time waste reduction in the operating theatre.

For robotic surgery to become more sustainable, technological innovation must be accompanied by a shift in collective values and practice. With growing awareness, stronger evidence, and concerted action, the field of robotic surgery can move towards a greener future in which sustainability is recognised as integral to high quality patient care.

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