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CORRESPONDENCE

Environmental impact of hybrid (reusable/single-use) ports versus single-use equivalents in robotic surgery

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Abstract

Given the rise in robotic surgery, and parallel movement towards net zero carbon, sustainable healthcare systems, it is important that the environmental impact of robotic approaches is minimised. The majority of greenhouse gas emissions associated with robotic surgery have previously been associated with single-use items. Whilst switching from single-use products to hybrid equivalents (predominantly reusable, with a small single-use component) has previously been found to reduce the environmental impact of a range of products used for laparoscopic surgery, the generalisability of this to robotic surgery has not previously been demonstrated. In this life cycle assessment, use of hybrid 5 mm ports compatible with emerging robotic systems (143 g CO_2e) was found to reduce the carbon footprint by 83% compared with using single-use equivalents (816 g CO_2e), accompanied by reductions in fifteen out of eighteen midpoint environmental impact categories. For endpoint categories, there was an 81% reduction in impact on human health and species loss, and 82% reductions in resource depletion associated with using hybrid robotic 5 mm ports. Whilst the carbon footprint of 5 mm hybrid ports compatible with emerging robotic equipment was 70% higher than previous estimates of ports appropriate for conventional laparoscopic approaches, the six-fold reductions seen with hybrids in this analysis point to the generalisability of the finding that reusable or hybrid products have a lower carbon footprint when compared with single-use equivalents. Surgeons, procurement teams, and policy makers should encourage innovation towards clinically safe and effective robotic instruments with maximal reusable components.

Keywords Robotic surgery · Sustainability · Reusable · Ports

Introduction

Robotic surgery has risen rapidly since the turn of the millennium, with an estimated annual global procedure volume of 1.24 million in 2020, [1] and a global surgical robotics market valued at US $3.92 billion in 2023 (anticipated compound annual growth rate of 9.5% by 2030) [2]. However, increasing applications, training, infrastructure, and uptake of robot assisted surgery may be at odds with parallel trends in action towards sustainable models of healthcare, with 75 countries currently committed to developing sustainable, low carbon health systems [3]. There is increased awareness of the impact of climate change on human health amongst surgeons, and corresponding movement within surgery to minimise the environmental impact of surgical care [4].

In the last two decades a growing number of studies have studied the environmental impact of healthcare and how to optimise this, ranging from evaluating the whole healthcare sector and hospitals, through to components of patient care and individual medical devices and pharmaceuticals [5]. Life cycle assessment (LCA) is a method which can be used to estimate the environmental impact of a product across a range of impact categories, including the 'carbon footprint', which is an estimate of associated greenhouse gas emissions expressed in carbon dioxide equivalents (CO_2e). Early studies indicate the carbon footprint of robotic surgery is higher (38–44%) than traditional laparoscopic approaches (evaluated for an endometrial cancer staging procedure [6] and hysterectomy [7], respectively), although these analyses only evaluated the operation itself, and did not account for factors such as impact of surgical modality on either length of hospital stay or complication rates. The primary

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driver of associated greenhouse gas emissions of the robotic approaches was the single-use disposable products [7]. Whilst there are robotic systems available that are compatible only with semi-reusable instruments and trocars supplied by the same manufacturer (limited to a small number of uses, typically up to ten times) [8], there are emerging robotic systems offering an open platform enabling surgeons to use their instruments and trocars of choice. Switching from single-use to reusable healthcare products has previously been associated with average reductions in carbon footprint of 38–56% across 27 studies including a range of healthcare products and geographical settings [9]. Increasing the proportion of reusable instruments used within robotic surgery may help alignment with global net zero carbon emission targets [3].

Where it is not feasible to use a fully reusable surgical instrument, there are opportunities to opt for products which are mainly reusable, with a small single-use component (termed 'hybrid instruments') [10]. Switching from single-use laparoscopic clip appliers, laparoscopic scissors, and ports to hybrid equivalents has previously been estimated to reduce the carbon footprint by 76% (study referred to hereon in as 'the original analysis'), projected to save 396 tonnes CO_2e per year if adopted for all laparoscopic cholecystectomies in England (equivalent to driving 1.2 million miles in an average petrol car) [10]. However, the 5 mm ports modelled in the original analysis are not compatible with emerging robotic systems. The environmental impact of 5 mm ports suitable for robotic surgery (referred to hereon in as the 'robotic hybrid 5 mm ports') is likely to differ, as those supplied by the same manufacturer as the original analysis include heavier single-use components (valve 4.4 g for robotic versus 1.8 g for conventional ports) and heavier reusable components (cannula 23.5 g versus 18.5 g; trocar 52.5 g versus 35.3 g), alongside differences in materials used. This article seeks to evaluate the generalisability of carbon reductions associated with conventional hybrid ports (compared with single-use equivalents) to those used for robotic surgery.

Method

An LCA was undertaken to evaluate the environmental impact of robotic hybrid 5 mm ports versus single-use equivalents used for robotic surgery, in alignment with ISO 14044 Guidelines [11], and modelled using SimaPro v9.10 (PRé Sustainability, Amersfort, Netherlands). A 'cradle to grave' approach was used, taking into account the material and energy flows involved in raw material extraction, manufacture, distribution, use of reusable components (decontamination), and disposal.

The methodology of the original analysis was replicated, including system boundary, data sources, and assumptions [10], aside from those specifically outlined. Supplementary Table 1 and 2 detail the material and transport assumptions of the 5 mm ports used for robotic surgery. Transport assumptions were informed by discussions with the port suppliers. The raw material composition and weight of component materials of hybrid ports was provided directly by the supplier (Surgical Innovations Ltd; Leeds, UK) and verified using sample products, weighed using Fisherbrand FPRS4202 Precision balance scales (Fisher Scientific, Loughborough, UK). Data on single-use ports was replicated from the original analysis [10].

The reusable components of the 5 mm port were assumed to be reused 200 times based on instructions for use (likely conservative estimate, with typical usage of approximately 500 uses reported by manufacturers), and to be decontaminated as part of a reusable laparoscopic set (weight of two 5 mm robotic ports added to the set modelled in the original analysis, as per common practice). The material and energy requirements of the decontamination process were modelled using a previous study on surgical instrument steam sterilisation [12]. The ports were assumed to be disposed of as clinical waste, and treated using high-temperature incineration. The 'inventory' of material and energy flows associated with the ports across their life cycle were modelled in SimaPro, using closest match life cycle inventory processes, using Ecoinvent v3.6 and Industry data v.2.0 databases (Supplementary Table 3).

The ReCiPe v1.1 Midpoint Hierarchist method [13] was used to convert this inventory of material and energy flows into eighteen 'midpoint' environmental impacts. The ReCiPe v1.1 Endpoint Hierarchist method was used to aggregate the impacts of midpoint categories into 'endpoint' impacts on human health, the natural environment, and resource scarcity.

Results

Using a hybrid robotic 5 mm port was associated with 83% reductions in carbon footprint compared with using a single-use equivalent (143 versus 817 g CO_2e, respectively), with broader reductions across fifteen out of eighteen midpoint environmental impact categories (Table 1). The three outstanding impact categories were ionising radiation, marine eutrophication, and mineral resource scarcity; driven by the electricity and wastewater used in the decontamination process, and chromium steel, respectively (accounting 85%, 88%, 47% of effects in turn). Switching from single-use to a hybrid robotic 5 mm port reduced the impact on human health by 81%, evaluated using the ReCiPe v1.1 Endpoint Hierarchist method, with comparable reductions in other

Table 1 One 5 mm robotic port modelled on one use of hybrid robotic 5 mm robotic port, compared with individually wrapped single-use 5 mm port. Total modelled on use of one clip applier, two small diameter (5 mm) ports, and two large diameter (10-11 mm) ports, comparing hybrid with single-use equivalents. *1,4-DCB* dichlorobenzene, *CFC11* trichlorofluoromethane, CO_2e carbon dioxide equivalents, *Cu* copper, *eq* equivalents, *Bq Co-60 eq* becquerel Cobalt-60, m^2a square meter years, *N* nitrogen, NO_x nitrous oxides, *P* phosphate, *PM2.5* particulate matter < 2.5 µm, SO_2 sulphur dioxide. *DALYs* disability adjusted life years, *species.year* loss of local species per year, *US $* extra costs involved for future mineral and fossil resource extraction

Impact category		Unit	One 5 mm robotic port		Total (four ports, clip applier)	
			Hybrid	Single-use	Hybrid	Single-use
Midpoint category	Global warming	g CO_2e	*143*	**817**	*1285*	**6055**
	Stratospheric ozone depletion	g CFC11 eq	*0.0001*	**0.0003**	*0.0006*	**0.0021**
	Ionizing radiation	Bq Co-60 eq	**17**	*13*	*133*	**139**
	Ozone formation, Human health	g NO_x eq	*0.23*	**1.89**	*2.35*	**16.33**
	Fine particulate matter formation	g PM2.5 eq	*0.14*	**0.80**	*1.53*	**7.60**
	Ozone formation, Terrestrial ecosystems	g NO_x eq	*0.23*	**1.94**	*2.41*	**16.66**
	Terrestrial acidification	g SO_2 eq	*0.34*	**2.06**	*3.26*	**17.44**
	Freshwater eutrophication	g P eq	*0.03*	**0.10**	*0.25*	**1.05**
	Marine eutrophication	g N eq	**0.03**	*0.02*	**0.20**	*0.13*
	Terrestrial ecotoxicity	g 1,4-DCB	*377*	**841**	*5,554*	**23,909**
	Freshwater ecotoxicity	g 1,4-DCB	*6*	**8**	*59*	**215**
	Marine ecotoxicity	g 1,4-DCB	*8*	**11**	*76*	**284**
	Human carcinogenic toxicity	g 1,4-DCB	*8*	**28**	*76*	**320**
	Human non-carcinogenic toxicity	g 1,4-DCB	*106*	**228**	*996*	**3883**
	Land use	m^2a crop eq	*0.0047*	**0.0058**	*0.0397*	**0.1842**
	Mineral resource scarcity	g Cu eq	**0.81**	*0.54*	*13.08*	**42.58**
	Fossil resource scarcity	g oil eq	*44*	**219**	*404*	**1724**
	Water consumption	m^3	*0.0014*	**0.0050**	*0.0112*	**0.0354**
Endpoint category	Human health	DALY	*2.76 e^{-7}*	**1.42 e^{-6}**	*2.66 e^{-6}*	**1.24 e^{-5}**
	Ecosystems	Species.yr	*5.88 e^{-10}*	**3.18 e^{-9}**	*5.36 e^{-9}*	**2.60 e^{-8}**
	Resources	US $	*0.0144*	**0.080557**	*0.135333*	**0.638865**

Bold indicates higher impact, italic indicates lower impact endpoint categories (ecosystems: 81%; resource depletion: 82%).

Discussion

The estimate for the hybrid robotic 5 mm port was 70% higher than the previous analysis based on 5 mm ports not compatible with emerging robotic systems, driven by the increase in weight of the single-use component, but remained around six times lower than opting for a single-use port. This supports the generalisability of the finding that predominantly reusable, hybrid products have a lower environmental impact than single-use equivalents. Whilst this analysis demonstrates reductions through switching from single-use to hybrid ports, this does not preclude further reductions in carbon footprint which might be achieved through reducing the single-use component of the hybrid port, optimising the decontamination process, and enabling repair of reusable components.

This analysis can also be extended to include other hybrid items modelled in the original analysis commonly used for common robotic procedures such as abdominoperineal resection, hysterectomy, low anterior resection, nephrectomy, and radical prostatectomy. Where two small diameter (5 mm) ports and two large diameter ports (10 or 11 mm for hybrid and single-use versions respectively) were used alongside a laparoscopic clip applier, opting for hybrid versions reduced the carbon footprint by 79% relative to single-use equivalents (totalling 1285 g CO_2e versus 6055 g CO_2e, respectively), accompanied by broader reductions across seventeen out of eighteen midpoint categories, and 79% reductions across all endpoint categories (human health, ecosystems and resource depletion) (Table 1).

Such findings align with and extend results from the original analysis of ports [10], and it is likely that the reduced environmental impact associated with adopting hybrid or reusable ports would be generalisable to other robotic ports. This is supported by a previous review associating reusable medical products with lower environmental impact, although notably where products were modelled in countries with a high proportion of non-renewable energy sources (such as Australia), this reduced or reversed such conclusions [9].

Whilst this study was funded by a supplier of hybrid ports, close collaboration between industry and academia facilitated the collection of sufficiently granular data required for such study. The study was undertaken with complete academic independence and freedom to publish findings, reducing the risk of publication bias.

We must minimise the environmental impact of emerging surgical technologies, given the threat climate change poses to human health [14]. Switching from single-use to hybrid equivalent ports (two small diameter, two large diameter, compatible with emerging robotic systems) was found to save 2.46 kg CO_2e per operation, and if applied to the 1.24 million robotic procedures performed globally per annum [1] this would save an estimated 3050 tonnes CO_2e. Whilst these remain modest reductions, use of hybrid approaches may help align robotic operations with the transition towards sustainable surgery. There is increasing requirements upon healthcare product suppliers to demonstrate alignment with Net Zero ambitions, with NHS England leading the way [15]. Surgeons, procurement teams, and policy makers should encourage innovation towards clinically safe and effective robotic instruments with maximal reusable components.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11701-024-01899-6.

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Author contributions CR led on all elements of this manuscript, including conception of the research question, data acquisition and analysis, and development of the manuscript.

Data availability Additional data is available in supplementary tables, and the analysis presented here builds on data presented in the 'original analysis' https://doi.org/10.1007/s00464-021-08728-z. Further queries may be directed to the corresponding author.

Declarations

Conflict of interest This work was funded by Surgical Innovations Ltd. who manufacture hybrid laparoscopic instruments, and CR provided consultantship through University of Sussex. However, the company played no part in the scientific conduct, analysis, or writing of this manuscript. This study builds upon a previous related publication (https://doi.org/10.1007/s00464-021-08728-z) also funded by Surgical Innovations Ltd. CR's clinical lectureship is funded in part by grants from Karl Storz Endoscopy (UK) Ltd and Health Education England, although the funders have no influence over the academic freedom or independence of the researcher.

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