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Laparoscopic versus robot-assisted left hemicolectomy: A pilot study on sustainability

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Abstract

Background The National Health System is responsible for 8–10% of total greenhouse gas emissions. Operating rooms are responsible for 60–70% of all hospital waste. Over the last 30 years abdominal surgery transcended from a laparoscopic approach toward a robot-assisted approach. The role of robot-assisted laparoscopic surgery is still debated in some procedures, such as colorectal surgery. The studies available in scientific literature comparing laparoscopic and robot-assisted left hemicolectomy are focused on clinical outcomes. The environmental sustainability of these procedures remains largely unexplored, representing a key area that our study seeks to investigate.

Methods In this pilot study consecutive patients scheduled for a minimally invasive left hemicolectomy for diverticular disease or cancer were recruited and randomly assigned 1:1 to the laparoscopic or robotic groups. The “Green Team” supported the operating room staff in separate waste collection during the surgical procedures. Primary end point was CO₂ consumption and secondary endpoints the specific mass of the most important waste stream.

Results Ten patients were enrolled. Robot-assisted left hemicolectomy required more CO₂ consumption in liters to maintain pneumoperitoneum ($p=0.03$) compared with laparoscopic left hemicolectomy and required a longer operation time ($p=0.04$). In total, the robot and laparoscopic approaches produced a total of 74.5 and 54 kg of plastic, non-woven fabric (TNT), unsorted waste bins, and biohazardous waste combined, which cost €92 and €71 to dispose of.

Conclusion Robot-assisted left hemicolectomy seems to have a greater environmental impact compared with laparoscopic left hemicolectomy in terms of both CO₂ emissions and waste production. Given the growing focus on operating room sustainability, further studies are needed to compare laparoscopic and robotic techniques to inform surgical decisions.

Keywords Sustainability · Environmental · Left hemicolectomy · Laparoscopic surgery · Robotic surgery · Waste reduction

Introduction

The National Health System (NHS) is responsible for 8–10% of total greenhouse gas emissions [1, 2]. Healthcare contributes 4.9% of the world’s carbon emissions (CO₂E), more than aviation (1.9–2.4%) and shipping (1.7%) [3]. Since hospitals are large producers of carbon footprint, changes to reduce it would lead to a significant impact on the environment and climate change, related to greenhouse gas emissions [4].

Surgical waste is a growing phenomenon worldwide, increasing CO₂E. Operating rooms (ORs) are the largest producers of CO₂E, mainly due to the disposal of biohazardous waste [5, 6]. Several changes can be implemented to reduce the carbon footprint from surgical activity. In fact, careful sorting of waste in ORs has been shown to reduce biohazardous waste, resulting in reduced CO₂ emissions [7, 8] and economic savings for hospitals [9–11]. Another change could be to reduce material waste. In fact, a significant proportion of OR waste is due to opened but unused supplies [12], especially of disposable material, which has increased with the advent of new surgical approaches (laparoscopic and robotic) [13].

Minimally invasive surgery (MIS) represents the standard of care for almost all types of abdominal surgical procedures. In recent years, robot-assisted laparoscopic surgery

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(RALS) has gained greater acceptance among surgeons and, as a consequence, wider adoption [13].

RALS is nowadays widely used in colorectal surgery, especially in rectal resections for cancer, although a randomized clinical trial (ROLARR) did not show a clear superiority of RALS over laparoscopic surgery in this procedure [14, 15]. In addition, some studies suggest that RALS has higher costs and a greater impact on CO₂E compared with conventional laparoscopic surgery [16, 17].

As these kinds of studies are lacking for the hemicolectomy procedure, the aim of this randomized pilot study on sustainability, conducted according to the Consolidated Standards of Reporting Trials (CONSORT) guidelines, is to compare the environmental impact of conventional and robot-assisted laparoscopic left hemicolectomy in terms of carbon footprint, waste disposal, procedure time, and health-care costs.

Methods

Patients scheduled for a minimally invasive left hemicolectomy for cancer or diverticular disease at a single institution were randomly assigned to the following groups: laparoscopic left hemicolectomy (LLH) or robot-assisted left hemicolectomy (RALH). Inclusion criteria were an age between 18 and 80 years, symptomatic diverticular disease of the sigmoid colon and left or sigmoid colon cancer up to clinical stage cT3NxM0, and a body mass index (BMI) ≤ 30 . Patients over the age of 80 years were excluded due to the potential for comorbidities that could influence postoperative hospitalization. Furthermore, we included only patients with a clinical stage up to cT3Nx to mitigate potential bias arising from possible intraoperative changes. However, patients with diverticular disease were included because this condition represents a substantial part of colorectal surgical practice, enabling the assessment of the sustainability of both approaches in a common benign scenario. All surgeries were performed by a single surgeon experienced in both Conventional laparoscopic left hemicolectomy (CLLH) and RALH.

Surgical technique

In CLLH procedures, after the establishment of a 12 mm Hg pneumoperitoneum, three reusable (one 10 mm and two 5 mm, Karl Storz-Endoskope) and one 5/12 mm disposable (Medtronic, Minneapolis, MN) trocars were placed. Dissection was carried out by means of monopolar hook, bipolar forceps, and Johann's graspers; sealing devices were not routinely used. The left and sigmoid colon, as well as the splenic flexure, were mobilized, keeping intact Gerota's fascia and Toldt's fascia. The inferior mesenteric artery was cut at its origin among clips (Hem-o-lok[®] Ligation System, Teleflex

Incorporated, Wayne, PA) as was the inferior mesenteric vein close to the ligament of Treitz. The proximal rectum was transected at the level of the sacral promontory with a 60 mm single cartridge of a linear stapler (Endo GIA[™] Tri-Staple[™], Medtronic, Minneapolis, MN). The mobilized colon was extracted via a suprapubic mini-laparotomy, after the positioning of a wall protector with a diameter of 2.5–6 cm (Alexis[®] Laparoscopic System, Applied Medical Resources Corporation, Rancho Santa Margarita, CA). The left colectomy was then completed including the vascular pedicle, after checking the perfusion of the colonic stump by means of intravenous indocyanine green injection and inspection with a near infrared optical system (IMAGE1 S[™] Rubina[®], Karl Storz, Tuttlingen, Germany). After colonic transection and fixation of the 28/31 mm circular stapler anvil (EEA[™] with DST Series[™] Technology, Medtronic, Minneapolis, MN) into the colonic stump, a tension-free double-stapling anastomosis was constructed under laparoscopic guidance.

In RALH, four 8 mm reusable multipurpose robotic trocars and one 5/12 mm disposable trocar were used. Surgical instruments employed were monopolar hook, Cadie's forceps, bipolar Cadie's and Tip-Up forceps; energy devices were not routinely used. After trocar placement and abdomen exploration, the fully draped da Vinci Xi[®] system (Intuitive Surgical, Sunnyvale, CA) in a four-armed configuration was docked. The technique was then the same described for CLLH. CO₂ consumption was measured, and careful waste sorting was carried out during all surgeries by the "Green Team": a group of experienced operating room staff assisted by professionals (surgeons, anesthesiologists, and nurses) [6, 9]. Paper, plastic, TNT (nonwoven fabric), unsorted solid waste, and biohazardous waste were collected. Notably, the biohazardous waste was sorted in a different bin called a Sanibox. All bins, including the Sanibox, had the same 60 L capacity and were positioned throughout the operating room for convenient separate collection of materials. Clear labels identified the contents for each bin. We considered material not contaminated with biological liquids to be "clean" and therefore separable and recyclable. Everything that encountered biological liquids was disposed of as biohazardous waste in Sanibox bins.

Surgical waste bins were emptied before each surgery and closed after the patient left the operating room. The same person, responsible for data acquisition, counted the number of bins produced for each waste type and weighed the biohazardous waste by subtracting the tare weight of the Sanibox bins (weight of an empty Sanibox bin is 2 kg).

The process described above was carried out by the same staff for all the surgical procedures.

Primary endpoint was CO₂ emissions (in liters). Secondary endpoints were amount of waste produced, sorted by type (paper, plastic, TNT and biohazardous waste), and

disposal costs. Patients have been randomized on a 1:1 basis to receive either robot-assisted or laparoscopic left hemicolectomy. The operating surgeon performed the randomization in advance of the study. The Green Team leader and his team who were responsible for waste counting and weighing were blinded to the surgical technique used. Although the assessing researchers could recognize the procedure from the waste, this could not influence the obtained data. After the establishment of 12 mm Hg pneumoperitoneum, smoke evacuation during dissection was warranted by leaving the valve of a 5 mm laparoscopic trocar or an 8 mm robotic trocar open while a forceps is inside the abdomen through the trocar itself. To maintain a stable intra-abdominal CO₂ pressure, a continuous CO₂ mean flow of 6.7 L/min was generated by the automatic insufflator. The CO₂E values were automatically calculated by the CO₂ insufflator. Based on our series, the mean time for CLLH was 150 min, while for this was RALH 210 min. The reported operative time includes the docking procedure, which had an average duration of 10 min. The mean time of extracorporeal phase of the operation was 20 min. An expected consumption of 1200 L of CO₂ was then estimated for RALH versus 867 L for CLLH. Therefore, using a 25% relative reduction in CO₂ consumption between RALH and CLLH, with 80% power and a 5% (two-sided) significance level, ten patients were required, five for each group.

Continuous variables were reported as mean and standard deviation (SD), and categorical variables were reported as number of events and percentages. After the evaluation of normality with the Shapiro–Wilk test, differences between the two groups were tested for continuous variables with the *t*-test or the Mann–Whitney test depending on the distribution. All *p*-values were two sided, with a conventional level of significance of 5%.

Results

Between 1 January and 29 February 2024, ten patients were randomized: five were scheduled for LLH and five for RALH. In both groups, four patients suffered from diverticular disease and one from sigmoid cancer. The same surgeon, expert in both laparoscopic and robotic colorectal surgery, performed all procedures. The main results can be found in Fig. 1.

The overall mean surgical time was 144 ± 46 min in LLH group and 207 ± 34 min in the RALH group. The difference was statistically significant ($p = 0.04$). To maintain a constant abdominal pressure of 12 mm Hg, mean consumption of CO₂ was 33% less in the LLH group than in the RALH group (838 ± 289 L, versus 1252 ± 207 L; $p = 0.03$) (Table 1).

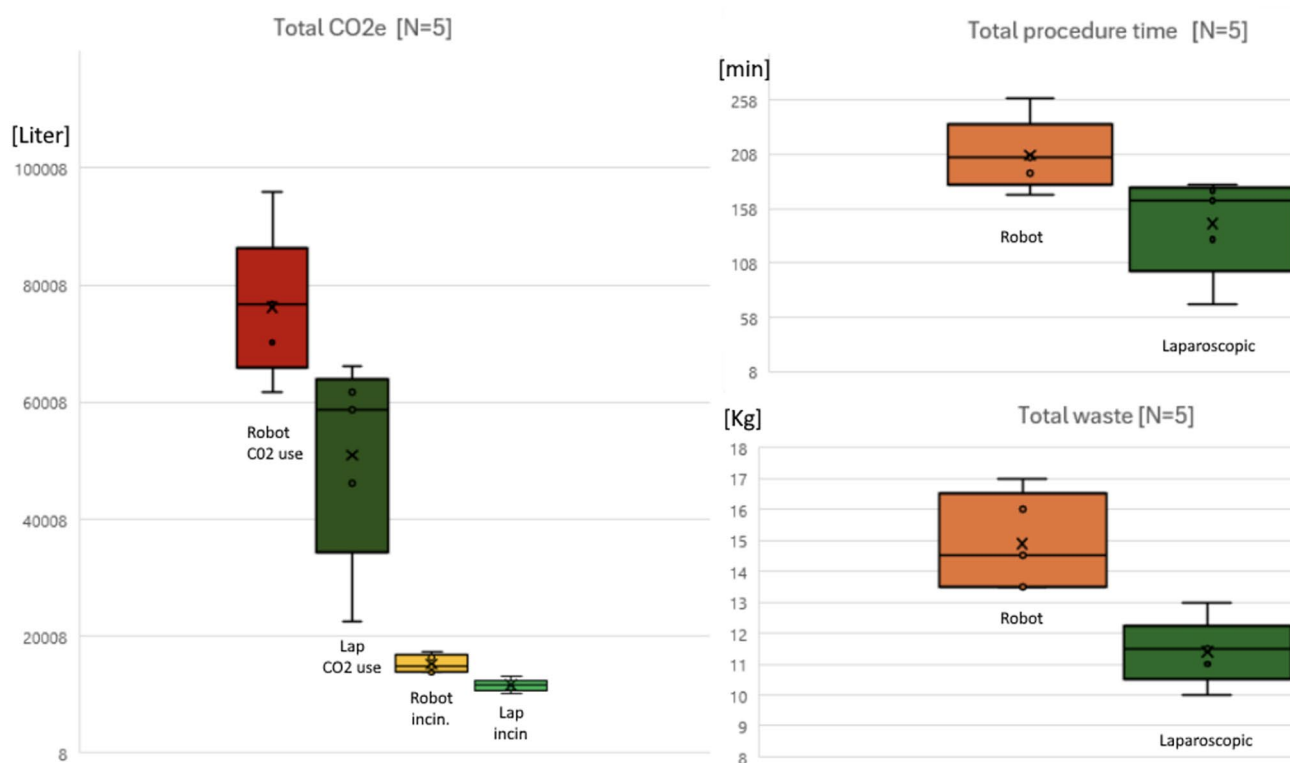


Fig. 1 Total CO₂e generated in Liter; Total procedure time in minutes; Total waste in Kg produced

Laparoscopic surgery generated less total waste compared with robot-assisted surgery (74.5 versus 54 kg), including plastic, paper, unsorted waste, TNT, and Sanibox content (Table 2). On average, the mean Sanibox weight was 13.4 ± 1.1 kg in the LLH group but 16.9 ± 1.6 kg in the RALH group, although this difference was not statistically significant ($p=0.32$). The biohazardous waste was disposed as a regulated medical waste. Plastic, paper, and TNT were collected and sent for recycling. However, unsorted waste was disposed of as regular municipal waste.

Disposal of biohazardous waste generated higher health-care costs for robot-assisted compared with conventional laparoscopic operations ($\text{€}18.5 \pm 1.9$ versus $\text{€}14.1 \pm 1.3$) per procedure, although the difference did not reach statistical significance ($p=0.06$) (Table 3).

Discussion

Over the past 14 years, robotic surgical procedures have seen a dramatic increase: more than 1.75 million robotic surgeries have been performed worldwide [18], even if evidence-based data on superiority over conventional laparoscopy regarding both short- and long-term outcomes have never been shown [19]. While recent studies comparing laparoscopic and robotic surgery focused on oncological outcomes, post-operative course [20–27], and the surgeon's ergonomics [28, 29], a crucial aspect—the environmental impact of these procedures—has been neglected.

The present study directly comparing CCLH and RALH showed that RALH has a significantly greater environmental footprint compared with traditional laparoscopy. This

Table 1 Patients' characteristics, pathology, operating time, and CO₂ consumption in laparoscopic versus robot-assisted left hemicolectomy

	LLH	RALH	Unpaired <i>t</i> test (<i>p</i> -value)
Patients (<i>n</i>)	5	5	
Age (years)	63.6 ± 13.2	69.8 ± 5.5	0.36
BMI (kg/m ²)	28.5 ± 0.7	26.0 ± 4.2	0.28
Sex (M/F)	2/3	2/3	
Pathology			
Diverticular diseases	4	4	
Adenocarcinoma	1	1	
Mean $\pm$ SD operating time (min)	144 ± 46	207 ± 34	0.04
Mean $\pm$ SD extracorporeal phase operating time (min)	19 ± 4	20 ± 3	0.59
Mean $\pm$ SD intraoperative CO ₂ consumption (L)	838 ± 289	1252 ± 207	0.03

F female, *LLH* laparoscopic left hemicolectomy, *M* male, *RALH* robot-assisted left hemicolectomy, *SD* standard deviation

Table 2 Total number of plastic, paper, TNT, and unsorted waste bins produced during laparoscopic versus robot-assisted left hemicolectomy

	LLH	RALH	Mann–Whitney test (<i>p</i> -value)
Mean $\pm$ SD number of plastic bins	0.6 ± 0.2	1 ± 0	0.05
Mean $\pm$ SD number of paper bins	0.7 ± 0.3	0.9 ± 0.2	0.35
Mean $\pm$ SD number of TNT bins	0 ± 0	0.8 ± 0.3	0.01
Mean $\pm$ SD number of unsorted waste bins	0.5 ± 0	0.8 ± 0.3	0.14
Mean $\pm$ SD number of Sanibox bins	2.2 ± 0.3	2.6 ± 0.4	0.17
Mean $\pm$ SD total number of bins	4 ± 0.5	6.1 ± 0.4	0.09
Mean $\pm$ SD Sanibox weight (kg)	13.4 ± 1.1	16.9 ± 1.6	0.32

LLH laparoscopic left hemicolectomy, *RALH* robot-assisted left hemicolectomy, *SD* standard deviation

Table 3 Biohazardous waste disposal costs in euros (€)

	CLLH	RALH	<i>p</i> -Value
Mean $\pm$ SD biohazardous waste total costs (€) + VAT	14.1 ± 1.3	18.5 ± 1.9	0.06

LLH laparoscopic left hemicolectomy, *RALH* robot-assisted left hemicolectomy, *SD* standard deviation, *VAT* value-added tax

was evident from the larger amount of CO₂ consumed, the higher weight of biohazardous waste generated, and the increased use of specific waste categories: plastic bins (5 versus 3), unsorted waste bins (4 versus 2.5), and TNT bins (4 versus 0). Interestingly, there was no difference in paper waste (4.5 versus 4.5). Unsorted waste was disposed of as urban waste; plastic, paper, and TNT were sent for recycling. Each kilo of plastic, paper, and TNT that is recycled saves approximately 0.5 kg, 0.15 kg, and 0.58 kg of CO₂ emission, respectively, for each waste stream [9, 10]. The incineration of 1 kg of unsorted waste generates approximately 2 kg of CO₂E. To put this into perspective, if all left hemicolectomy procedures (e.g., 5000 a year) were performed with LLH instead of RALH, 10,000 plastic bins, 20,000 TNT bins, and 7500 unsorted waste bins—with a combined CO₂E footprint of 75,200 kg—would be prevented. This CO₂E reduction is equivalent to that of a passenger taking 39 round-trip airplane flights between Rome and New York (approximately 267,368 km) or a family car on 356 trips between Rome and Paris (approximately 508,000 km).

Recycling these materials avoided their disposal by incineration, preventing the emission of about 15.66 kg of CO₂E (Table 4). If the plastic, paper, and TNT had not been recycled, they would have increased the CO₂ emission by 13.5 kg and 2.16 kg for RALH and LLH, respectively. These results also suggest that TNT, if not recycled, is the largest CO₂E producer compared with plastic and paper. In addition, in LLH, fully reusable instruments were employed, minimizing waste generation. In contrast, RALH inherently produces more waste due to limitations in the number of times instruments can be reused (as recommended by the manufacturer of the da Vinci Xi). Throughout our procedures, we consistently employed standardized instrument sets including a monopolar hook (10 uses), Cadierre forceps (18 uses), bipolar Cadierre forceps (14 uses), and tip-up forceps (10 uses). The cumulative use of these instruments contributes to overall waste production, increasing the associated environmental impact. Our operating room staff is experienced in both laparoscopic and robotic surgery. We routinely perform these and other types of surgeries in the same operating rooms with the same teams, utilizing both laparoscopic

and robotic approaches. Furthermore, while core materials are typically opened before the start of surgery, disposable trocars and other devices are opened only upon the first surgeon's instruction. However, any effort to reduce waste and environmental impact must be supported by an educational plan for operating room staff [9].

This study also examined operative time, revealing a statistically significant difference ($p = 0.04$), consistent with prior literature [29]. LLH is faster than RALH (144 versus 207 min), and this is another factor that directly increases CO₂ emissions. The experience that the surgeon and OR staff has with colorectal robotic procedures may progressively shorten operative time, but probably, as reported in literature, the time a colorectal robotic resection takes will never be equal to or shorter than a laparoscopic one.

RALH not only impacts the environment but also hospital costs in several ways. First, the prolonged occupation of the operating room and the need for additional CO₂ cylinders increase expenses. Second, the ability to use robotic instruments for only a predetermined number of times increases waste. Finally, the disposal of greater amounts of biohazardous waste adds a further cost burden. At our hospital, the price per kilogram for the biological waste disposal service was 1.24 euro/kg + value-added tax (VAT). Medical management therefore spent an extra €21.70 to dispose of the biohazardous waste from the five robotic left hemicolectomy procedures. Moreover, it is reported in the literature that the robotic approach may lead to shorter hospital stays for specific types of surgical interventions. In our case, all ten patients were discharged on the fourth postoperative day.

While this study has limitations, mainly due to the small sample size, its merit can be seen in the randomization of patients who underwent a very well-standardized surgical procedure performed by the same surgical team at a single institution. Further studies with a larger sample sizes executed in multiple centers should be conducted in the future to solidify our results. To put our data into perspective, it is interesting to relate it to the economic and environmental impact that the approaches have over the total life cycle of all used materials. Therefore, a full life cycle assessment (LCA) and a full health technology assessment (HTA) for both approaches are advised in the future.

Table 4 Saved CO₂ emission calculated on the basis of the total number of the TNT, plastic, and paper bins

Type of waste	Bins	Volume (m ³)	Volume efficiency factor—bin (0.5)	Density (kg/m ³)	Kilograms	Recycling versus the raw footprint reduction CO ₂ factor	Saved CO ₂ footprint (kg)
TNT	4	0.24	0.12	150	18	0.58	10.44
Plastic	8	0.48	0.24	30	7.2	0.5	3.6
Paper/cardboard	9	0.54	0.27	40	10.8	0.15	1.62
Total	21	1.26			36		15.66

Conclusion

This study suggests that RALH has a greater environmental impact than LLH in terms of CO₂ emissions and waste production. Provided that clinical outcomes are comparable, the environmental impact of robotic surgery should be considered when selecting the most suitable surgical approach for left hemicolectomy.

Author contributions Nicola Leone designed the study, performed surgical procedures, acquired data and analyzed data, drafted the article, and approved its final version. Simone Arolfo designed the study, performed surgical procedures, acquired data and analyzed data, drafted the article, and approved its final version. Tim Horeman analyzed data, drafted the article, and approved its final version. Alberto Arezzo revised the article and approved its final version. Mario Morino designed the study, analyzed and interpreted data, revised the article, and approved its final version.

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Data availability The data in the study are available for consultation.

Declarations

Conflict of interest Authors have no conflicts of interest or financial ties to disclose.

Ethical approval Ethics approval or patient consent were not required, as the data were obtained before and after a routinely performed surgical procedure.

Informed Consent For this type of study formal consent is not required.

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