ANZ Journal of Surgery

WILEY | Royal Australasian College of Surgeons

GENERAL SURGERY

A Modified Step-Up Approach to Elective Laparoscopic Cholecystectomy Safely Reduces Cost and Carbon Impacts

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Received: 20 December 2024 | **Revised:** 10 January 2025 | **Accepted:** 9 June 2025

Keywords: carbon footprint | cholecystectomy | laparoscopy | operating theatre | sustainability

ABSTRACT

Background: Contemporary surgery expends often excessive quantities of consumables, resulting in high cost and carbon footprint. This study examined the cost and carbon impacts of elective laparoscopic cholecystectomy (ELC), a common procedure involving near-universal disposable equipment, and whether a modification of approach to minimising these consumables can safely reduce these impacts, alongside rationalised antibiotic and venous thromboembolism (VTE) prophylaxis according to validated risk scoring instead of routine use.

Methods: The modified step-up approach to ELC involved rationalised antibiotic and VTE prophylaxis, a minimal operative set-up, and opening of further equipment only as required. Consecutive patients undergoing ELC by this approach by a single surgeon across four metropolitan hospitals, both public and private, were prospectively audited over 12 months, and compared with a retrospective audit of a matched cohort treated by the same surgeon using a custom laparoscopic kit in a previous 12-month period. Primary outcomes were operating time, cost, weight, and carbon footprint of consumables from the custom laparoscopic kit. Secondary outcomes included post-operative complications and length of stay.

Results: Compared with the previous standard approach, the modified step-up approach significantly reduced weight of surgical consumables by 51.9%, carbon footprint by 50.6%, and cost by 43.1%, without increasing operating time, complications or length of stay.

Conclusion: This modified step-up approach to ELC demonstrates how rethinking common surgical practice can reduce consumable waste, carbon footprint, and costs, without compromising patient safety and outcomes or increasing operating time.

1 | Background

The healthcare sector accounts for nearly 7% of Australia's total carbon emissions [1], with the use and disposal of consumables in operating theatres (OTs) being a major contributor [2–4]. The widespread use of disposable surgical equipment increases both financial costs and environmental impact [5–10] without improving outcomes such as infection rates [8]. By issuing position statements on climate change and the environmental impact of surgical practice, surgical colleges around the world, including The Royal Australasian College of Surgeons [11], strongly advocate for reducing the ecological footprint of surgery.

A preliminary report of this study was presented and submitted by Tommy Thio Sulputra, Mahdid Azam, Zachary Jelbart and Oliver McCahill on November 15, 2022 as their MD research project in the University of Newcastle & University of New England Joint Medical Program, and was a poster presentation at RACS 91st Annual Scientific Congress, Adelaide, May 1–5, 2023 (P. Ananthan, S. Chen, et al.).

Elective laparoscopic cholecystectomy (ELC), a common procedure in Australia [12], usually employs near-exclusive use of disposable equipment, which creates a large carbon footprint [13]. A recent Dutch study [14] found single-use consumables to be contributing 40% of this carbon footprint, a hot spot being disposable laparoscopic equipment. Reducing the use of this equipment should be an important strategy. Using fewer disposable ports and equipment has been described as reducing cost in both the American private medical sector [15] and public sector in England [16], and as safe and cosmetically acceptable as standard port usage [17]. However, there are currently no data addressing the impact on carbon footprint of reducing laparoscopic instrumentation by simple technical modifications.

There are potential additional cost and carbon savings by rationalising perioperative care systems around ELC, specifically antibiotic and venous thromboembolism (VTE) prophylaxis. In our centre, patients undergoing ELC typically receive routine antibiotic prophylaxis, which is not supported by studies advocating selective prophylaxis based on validated risk stratification [18–21]. Triple VTE prophylaxis (low-dose heparin, graduated compression stockings, sequential compression device [SCD]) is also routine practice despite evidence of benefit only in those at high risk [22–24].

This study examines whether a modified approach to ELC involving minimal starting set-up followed by a step-up practice of opening further equipment only as required, alongside rationalising VTE and antibiotic prophylaxis, significantly reduces cost, waste, and carbon footprint, without increasing operating time or impairing surgical outcomes.

2 | Methods

This study was a prospective audit over 12 months of the modified approach, compared with a matched retrospective control cohort, comprising consecutive patients undergoing ELC under the care of the principal surgeon at two public hospitals (John Hunter Hospital [JHH] and Belmont District Hospital [BDH]) and two private hospitals (Newcastle Private Hospital [NPH] and Lingard Private Hospital [LPH]). The control cohort included any patient undergoing ELC using the previous standard approach from September 1, 2018 to August 31, 2019, ending 6 months before the development of the modified approach. The prospective cohort included any patient undergoing the modified step-up approach to ELC from September 1, 2021 to August 31, 2022.

Control cohort data were collected by reviewing medical record charts, operation reports and patient summaries/discharge summaries in the electronic medical record and private hospital clinical record archives. Prospective group data were gathered at the time of procedure and post-operative management. All patients were followed up in outpatients clinic at JHH or in private rooms 4 weeks post-operatively. Primary outcomes were operating time, weight, cost, and cradle-to-grave carbon footprint of surgical consumables. Secondary outcomes were post-operative complications, documented using the Clavien-Dindo classification, administration of VTE and antibiotic prophylaxis, length of hospital stay and hospital readmissions.

The study was approved as low-risk research by the Hunter New England Human Research Ethics Committee (2021/ETH10892).

2.1 | Approaches to Laparoscopic Cholecystectomy

2.1.1 | Standard Approach

All patients routinely received VTE prophylaxis using three modalities: SCD, graduated compression stockings and low-dose heparin. Intravenous antibiotics were routinely administered as a single dose on induction of anaesthesia.

The standard ELC technique employed a custom single-use laparoscopic cholecystectomy kit (Applied Medical, CA, USA) (Figure 1a) in the public sector, together with various brands of single-use diathermy hooks. In the private sector, the set-up mirrored the public hospital custom kit, with minor variations in brands of ports and at times reusable diathermy hooks.

The full custom kit was opened for every case. Using an open cut-down method, a first-entry 12 mm balloon Hasson port (Kii COR47) was placed for the laparoscope. Other ports were epigastric 11 mm (Kii Fios CTF33) and two right upper quadrant 5 mm (Kii Fios CTF12 Dual Pack). Included in the kit was disposable scissors (Epix CB030), while the disposable diathermy hook was separate. Routine operative cholangiography was

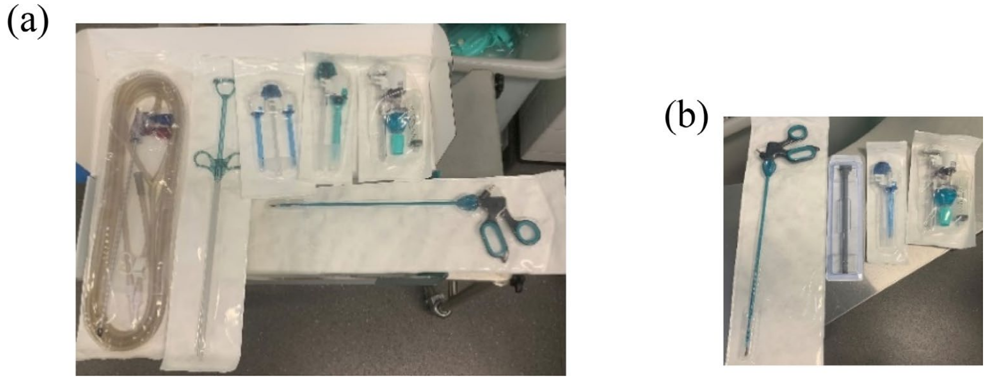

FIGURE 1 | (a, b) Set-ups for elective laparoscopic cholecystectomy.

performed via cystic ductotomy, and, when required, duct exploration was performed using a basket or transcystic stent. A suction-irrigation apparatus (C6001) was opened in every case, which also necessitated the use of a disposable suction bag and canister lid (Serres 2L, Finland). Specimen retrieval was done with the CD001 Inzii.

2.1.2 | Modified Step-Up Approach

The modified step-up approach involved VTE prophylaxis rationalised according to each patient's risk by the modified Caprini score [22, 25], selective antibiotic prophylaxis based on the presence or otherwise of risk factors for surgical site infection (SSI) (Table S1), and the opening of minimal elements of the custom laparoscopic cholecystectomy kit, with other components being opened only as required.

The operation commenced with a 12 mm Hasson port and one epigastric 5 mm operating port—the starting set-up (Figure 1b) plus scissors from the custom kit and a separate diathermy hook. Instead of two other retraction ports in the right upper quadrant, two laparoscopic graspers were placed percutaneously via stab wounds dilated with Crile artery forceps (Video S1). Extra ports were introduced only as necessary. The suction-irrigation device was opened only in cases of excessive bleeding or major bile spill from the gallbladder. One or more gauze swabs were introduced via the 12 mm port, tucked into the subhepatic space to absorb blood and bile, and retrieved together with the gallbladder specimen (Video S2). Operative cholangiography and duct exploration remained identical to the retrospective group. Instead of the Inzii specimen retrieval system, a lighter and simpler device (Endo Bag 25 030, Covidien) was introduced via the 12 mm port and removed by back-feeding (Video S3).

The modified ELC procedure when done in the private sector at times employed different brands of disposable ports and reusable diathermy hook.

2.1.3 | Data Collection

The following baseline patient characteristics were recorded: age, sex, BMI, ASA grade, modified Caprini score and venue of surgery.

Surgical variables that were recorded included: role of principal surgeon, Nassar grade of surgical difficulty [26], SSI risk factors, performance of operative cholangiogram, any additional procedures and further interventions as required.

Modalities of VTE prophylaxis and prophylactic antibiotics administered were recorded, but details of their consumables weight, carbon footprint and cost were not.

The opening of components of the custom cholecystectomy kit was recorded, detailing ports, scissors, suction-irrigation device (including suction bag and canister lid), and specimen retrieval device. When items were erroneously opened, they were included in the analysis. The diathermy hook was excluded from analysis as it was common to both groups and was often a reusable version at NPH. The use and impacts of cholangiography and duct exploration equipment, as well as intravenous fluid bags in conjunction with the suction-irrigation device, were excluded from analysis.

The Nassar grade was used to record the degree of surgical difficulty [26], which in the prospective cohort was assigned intraoperatively, while in the retrospective cohort, it was determined through review of each patient's operation report, surgical correspondence, and discharge/patient summaries.

TABLE 1 | Baseline patient characteristics.

	Standard group ($n=61$)	Step-up group ($n=67$)	p
Age (years) mean ± SD	49.9 (±16.0)	48.8 (±16.4)	0.7020
Sex	Male: 18 (29.5%)	Male: 22 (32.8%)	0.6850
	Female: 43 (70.5%)	Female: 45 (67.2%)	
BMI (kg/m^2) mean ± SD	29.9 (±6.0)	31.1 (±8.3)	0.3545
ASA Grade (median)	2	2	0.5552
Modified Caprini score	0 (very low): 0 (0.0%)	0 (very low): 0 (0.0%)	0.1914
	1–2 (low): 1 (1.6%)	1–2 (low): 6 (9.0%)	
	3–4 (moderate): 53 (86.9%)	3–4 (moderate): 54 (80.5%)	
	≥ 5 (high): 7 (11.5%)	≥ 5 (high): 7 (10.5%)	
Site of surgery	JHH: 11 (18.0%)	JHH: 11 (16.4%)	0.7622
	BDH: 19 (31.1%)	BDH: 25 (37.3%)	
	NPH: 18 (29.5%)	NPH: 21 (31.3%)	
	LPH: 13 (21.3%)	LPH: 10 (15.0%)	

Abbreviations: ASA, American Society of Anaesthesiologists; BMI, body mass index.

TABLE 2 | Surgical variables.

	Standard group (n = 61)	Step-up group (n = 67)	p
Role of principal surgeon	PS: 46 (75.4%)	PS: 42 (62.7%)	0.1209
	SS: 15 (24.6%)	SS: 25 (37.3%)	
Nassar grade	Grade 3: 8 (13.3%)	Grade 3: 9 (13.4%)	1.0
	Grade 4: 2 (3.3%)	Grade 4: 3 (4.5%)	
SSI risk factors	No: 49 (80.3%)	No: 47 (70.1%)	0.1841
	Yes: 12 (19.7%)	Yes: 20 (29.9%)	
Operative cholangiogram	Yes: 57 (93.4%)	Yes: 60 (89.6%)	0.4328
	No: 4 (6.6%)	No: 7 (10.4%)	
Additional procedures	Bile duct exploration: 3	Bile duct exploration: 3	—
	Adhesiolysis > 5 min: 5	Adhesiolysis > 5 min: 3	
	Umbilical hernia repair: 5	Umbilical hernia repair: 1	
	Conversion to open: 1	CBD flushing: 1	
	Other: 2	Other: 2	
Further intervention	Yes: 2[a] (3.3%)	Yes: 1[b] (1.5%)	0.4451
	No: 59 (96.7%)	No: 66 (98.5%)	

Abbreviations: CBD, common bile duct; PS, primary surgeon; SS, supervising surgeon; SSI, surgical site infection.
[a]Endoscopic retrograde cholangiopancreatography (ERCP).
[b]ERCP + sphincterotomy.

TABLE 3 | Primary outcomes.

	Standard group (n = 61)	Step-up group (n = 67)	p
Operating time (min)	73.1 (±35.6)	67.4 (±24.6)	0.2904
Ports opened	4.0 (±0.2)	2.2 (±0.4)	< 0.0001
Weight of consumables including packaging (g)	940.3 (±0.0)	452.1 (±265.6)	< 0.0001
Carbon footprint (gCO_2e)	5503.8 (±0.0)	2717.81 (±1375.9)	< 0.0001
Cost (AUD)	$258.70 (±0.0)	$147.10 (±33.0)	< 0.0001

Note: Data above are shown as mean (±SD).

Operating time was recorded from the initiation of surgical intervention to completion of the final procedure by the surgical team. For the retrospective cohort, operating start times were collected from the MR18 operating room registry forms, while finishing times were collected from OT utilisation forms.

Surgical consumables and their packaging were weighed using NWS Nuweigh JAC838 Bench Scale (Newcastle, Australia). Cost was calculated from purchase price as supplied by procurement officers, plus the cost of clinical waste management as supplied by the Hunter New England Local Health District Sustainability Unit. Cradle-to-grave carbon footprint was modelled on SimaPro using Ecoinvent v3.10. For ease of calculation and interpretation, the cost, weight and carbon footprint of consumables used in the private hospitals were analysed as for the public hospital custom kit components.

2.2 | Statistical Analysis

Data were collected and stored via REDCap, and statistical analysis was performed on JMP Pro 16. Continuous variables were assessed using two-sample Student t-tests if normally distributed and Mann–Whitney U tests if not. Chi-squared and Fisher's tests were used for categorical variables. The level of statistical significance was set as $p < 0.05$.

3 | Results

In the retrospective group, 61 consecutive patients underwent standard approach ELC. One patient did not proceed to cholecystectomy due to the finding of gallbladder cancer but was included in the analysis. The prospective group comprised 67 consecutive patients. Both groups were comparable in baseline characteristics (Table 1) and surgical variables (Table 2).

3.1 | Primary Outcomes

Specific weights, carbon footprints and costs of elements of the custom kit for the standard approach, and the starting set-up for the step-up approach, are provided in Table S2.

In 43 of 67 modified step-up cases (64.2%) no extra surgical consumables were opened beyond the starting set-up, while in 24 cases extra items were opened (Table S3). Considering components of the custom kit, compared with the standard group, the surgical consumables for the step-up group involved significantly lower consumable weight (452.1 g vs. 940.3 g; $p < 0.0001$), carbon footprint (2717.81 gCO_2e vs. 5503.8 gCO_2e; $p < 0.0001$), and cost ($147.1 vs. $258.7; $p < 0.0001$). The suction-irrigation device, the largest contributor to the consumable weight and carbon footprint of the set-up, was opened in 20 step-up cases (including three times inadvertently). An additional three 11 mm ports and five 5 mm ports were required, while five ports were inadvertently opened.

There was no significant difference in mean operating times between the step-up and standard groups (67.4 vs. 73.1 min; $p = 0.2919$) (Table 3).

3.2 | Secondary Outcomes

There was a statistically significant difference in the number of patients who received antibiotic prophylaxis in the retrospective and prospective groups (88.52% vs. 31.34%; $p < 0.0001$). Patients in the retrospective group received SCDs more than the prospective group (86.9% vs. 17.9%). There were no significant differences between groups relating to length of stay, post-operative complications, or number of readmissions to hospital (Table 4).

4 | Discussion

The widespread use of single-use surgical equipment is associated with a large carbon footprint [13], which behoves surgeons to avoid overage and to ensure rationalised use of consumables. The step-up approach to ELC described here was developed with the recognition that instrument changes are rarely required via the two right upper quadrant ports, most cases can be accomplished using a 5 mm rather than an 11 mm operating port, and the suction-irrigation device is superfluous in many cases. In this prospective audit, compared with a retrospective audit of a matched cohort undergoing ELC with routine opening of all elements of a custom cholecystectomy kit, the reduction in surgical equipment of the step-up approach resulted in 51.9% lower consumables weight, 50.6% lower carbon footprint, and 43.1% lower cost. In 64% of these cases, no extra equipment was opened beyond the starting set-up, resulting in reductions of 70% in weight, 66.8% in carbon footprint, and 51.4% in cost.

This step-up approach proved to be efficient and safe, without increases in operating time, complications, length of stay, readmissions, or further procedures. Rationalising VTE [22, 25] and antibiotic prophylaxis [18–21] in accordance with risk assessment resulted in no increased adverse events, while also significantly reducing consumables, notably a 69% reduction in use of SCDs and a 61% reduction in antibiotics. The cost and carbon impacts of these reductions were not analysed, but would clearly augment the impacts of reducing surgical consumables.

Development of the modified technique evolved over the 12 months before this study and has since been the corresponding author's default technique for all laparoscopic cholecystectomies, including acute cases. It is slightly more labour-intensive than the standard technique, but there is room for flexibility. For example, the suction-irrigator can be pre-emptively opened after initial inspection revealing an anticipated difficult dissection, an 11 mm operating port can be employed instead of a 5 mm, and an extra 5 mm port can be placed in the right mid-clavicular line. However, ports are preferred wherever there is a need for instrument changes.

The principles of the step-up approach can be applied to any laparoscopic procedure involving single-use items in order to prevent overage and its cost, waste, and carbon impacts. We recommend a shift in culture towards rationalising prophylactic regimens, rethinking port placement and surgical technique, and opening equipment only as necessary.

TABLE 4 | Secondary outcomes.

	Standard group ($n = 61$)	Step-up group ($n = 67$)	p
Length of stay (days)	1 (median)	1 (median)	0.2113
	1.41 (mean)	1.04 (mean)	0.9097
Antibiotic administered	54 (88.52%)	21 (31.34%)	< 0.0001
Types of VTE prophylaxis administered	GCS: 60 (98.4%)	GCS: 66 (98.5%)	—
	Chemical: 50 (82.0%)	Chemical: 50 (74.6%)	
	SCD: 53 (86.9%)	SCD: 12 (17.9%)	
	Nil: 1 (1.6%)	Nil: 0	
Post-operative complication	8 (13.1%)	3 (4.5%)	0.0816
Clavien-Dindo grade	I: 4	I: 1	—
	II: 4	II: 1	
		IIIb: 1[a]	
Readmissions	2 (3.3%)	2 (3.0%)	—

Note: Data above are shown as patient numbers *n* (%).
Abbreviations: chemical, heparin; GCS, graduated compression stockings; SCD, sequential compression device.
[a]ERCP for retained CBD stones.

4.1 | Strengths and Limitations

This study has been analysed by intention to treat, and compares two groups well-matched in patient demographics and characteristics, and surgical variables. The setting encompassed both public and private sectors.

One limitation is that the study focuses on a relatively small number of ELC as conducted by one surgeon, which may limit its generalisability to a broader patient population or in different surgical contexts. Another is the lack of blinding in data collection and analysis. In an effort to reduce risk of bias, data collection and preliminary analyses of both groups were conducted by four medical students (T.T.S., M.A., Z.J., O.McC.) as part of their MD Research Project. The retrospective estimate of Nassar grade of surgical difficulty may introduce inaccuracies, but the relevant surgical variable here is the truly difficult dissection (Nassar 3/4) which was straightforward to identify from records, and was equivalent in both groups.

One other limitation actually favours the retrospective group. Bile spills and dropped instruments were recorded for the prospective but rarely the retrospective group. Also, the use of saline bags for irrigation, which would further increase cost and carbon impacts, was excluded from the study.

Finally, we acknowledge that this study does not prove the safety of limiting VTE and antibiotic prophylaxis.

5 | Conclusion

The modified step-up approach to ELC is presented as an example of rethinking the conduct of a common surgical intervention in order to rationalise and reduce the use of surgical consumables and prophylactic treatments, with the object of minimising the cost, carbon footprint and waste impacts inherent in contemporary surgical practice utilising single-use equipment, while maintaining surgical outcomes.

Author Contributions

Sanjna Gangakhedkar: writing – original draft, formal analysis, writing – review and editing. **Stanley Chen:** conceptualization, methodology, data curation, supervision, writing – review and editing, project administration. **Tommy Thio Sulputra:** investigation, formal analysis, writing – original draft. **Mahdid Azam:** investigation, writing – original draft, formal analysis. **Zachary Jelbart:** investigation, writing – original draft, formal analysis. **Oliver McCahill:** investigation, writing – original draft, formal analysis.

Acknowledgements

We gratefully acknowledge the assistance of Scott McAlister (Wiser Healthcare, University of Sydney) for life cycle assessment of surgical consumables, Dr. Nicholas Bull (Division of Surgery, John Hunter Hospital) for advice on the manuscript, Rosemary Carroll (Surgical Research Co-ordinator, JHH) for project administration, and Applied Medical (CA, USA) for kindly supplying comprehensive product specifications. We also thank Ken Shilling (Equipment Administration Officer, JHH Operating Suite) and Justin Gilbert (Procurement Officer, JHH Operating Suite) for pricing data.

Conflicts of Interest

The authors declare no conflicts of interest.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.