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Patient, hospital and environmental costs of unnecessary bloodwork: capturing the triple bottom line of inappropriate care in general surgery patients

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ABSTRACT

Objective To characterise the extent of unnecessary care in general surgery inpatients using a triple bottom line approach.

Design Patients with uncomplicated acute surgical conditions were retrospectively evaluated for unnecessary bloodwork according to the triple bottom line, quantifying the impacts on patients, healthcare costs and greenhouse gas emissions. The carbon footprint of common laboratory investigations was estimated using PAS2050 methodology, including emissions generated from the production, transport, processing and disposal of consumable goods and reagents.

Setting Single-centre tertiary care hospital.

Participants Patients admitted with acute uncomplicated appendicitis, cholecystitis, choledocholithiasis, gallstone pancreatitis and adhesive small bowel obstruction were included in the study. 304 patients met inclusion criteria and 83 were randomly selected for in-depth chart review.

Main outcome measures In each patient population, the extent of over-investigation was determined by comparing ordered laboratory investigations against previously developed consensus recommendations. The quantity of unnecessary bloodwork was measured by number of phlebotomies, tests and blood volume in addition to healthcare costs and greenhouse gas emissions.

Results 76% (63/83) of evaluated patients underwent unnecessary bloodwork resulting in a mean of 1.84 phlebotomies, 4.4 blood vials, 16.5 tests and 18 mL of blood loss per patient. The hospital and environmental cost of these unnecessary activities was \$C5235 and 61 kg CO_2e (974 g CO_2e per person), respectively. The carbon footprint of a common set of investigations (complete blood count, differential, creatinine, urea, sodium, potassium) was 332 g CO_2e. Adding a liver panel (liver enzymes, bilirubin, albumin, international normalised ratio/partial thromboplastin time) resulted in an additional 462 g CO_2e.

Conclusions We found considerable overuse of laboratory investigations among general surgery patients admitted with uncomplicated acute surgical conditions resulting in unnecessary burden to patients, hospitals and the environment. This study identifies an opportunity for resource stewardship and exemplifies a comprehensive approach to quality improvement.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Unnecessary diagnostics within healthcare are prevalent, and contribute to a considerable burden of avoidable resource use and cascading down-stream investigations. The consequences of over-investigation include patient harm, low-value healthcare expenditures and material resource consumption and pollution. Literature estimating the environmental harms from healthcare activities is an emerging field, including only one published comprehensive triple bottom line analysis of a commonly ordered laboratory investigation, carried out at a population level.

WHAT THIS STUDY ADDS

⇒ Our study captures the burden of over-investigation in uncomplicated general surgery patients; a population that has not been well characterized in the literature on unnecessary care. Using a triple bottom line approach, our study estimates the impacts of unnecessary bloodwork on general surgery inpatients, hospital costs and the environment. The carbon footprint of twenty commonly ordered laboratory investigations and panels was calculated, providing a framework for future carbon cost calculation across all medical specialties.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE, OR POLICY

⇒ This study provides transparency around the full impact of over-investigation, allowing, providers and institutions to internalize these costs of care and guide behaviour change and system strategies to reduce unnecessary investigations.

INTRODUCTION

Climate change has undermined social and environmental determinants of health and is recognised as this century's greatest global public health threat.[1] As a leading cause of morbidity and mortality, air and water pollution are responsible for 16% of all deaths worldwide.[2] Globally, healthcare contributes 5.2% of global greenhouse gas (GHG) emissions[3] and in Canada, pollution from the healthcare industry accounts for 23 000 disability-adjusted life-years lost annually.[4] Canada has a federal mandate to achieve net zero emissions by 2050[5] and has joined the WHO's commitment to develop low-carbon, sustainable, resilient health systems.[6] A framework for low-carbon health systems ('planetary healthcare') is organised around three operating principles, including appropriateness of care, defined by matching the supply and demand of health services.[7] Inappropriate or low-value care includes both underuse and overuse of health services,[8] representing 25% of care at an annual cost of US$100 billion in the USA alone.[9] In Canada, 30% of primary and specialist care is unnecessary, with routine bloodwork identified as a considerable source of low-value care.[10 11]

Choosing Wisely and the Academy of Medical Royal Colleges urge physicians to consider their role in laboratory stewardship as a therapeutic measure for patients' short-term and long-term well-being.[12 13] In addition to avoidable healthcare expenditures, the adverse consequences of unnecessary bloodwork on patient care have been well established, including discomfort, blood loss, iatrogenic anaemia, increased transfusion requirements, length of stay and mortality.[14 15] While the impacts of over-investigation on patient care and healthcare costs have been well characterised, the environmental costs of unnecessary care remain under-reported. These include consumption of materials and energy, and generation of solid waste. Literature quantifying the carbon footprint of laboratory testing[16] and unnecessary blood transfusions[17] underscores the importance of reducing unnecessary investigations in the pursuit of healthcare sustainability as a dimension of patient safety and quality care.

Collectively these social, financial and environmental costs comprise the 'triple bottom line', a business framework that has been conceptually applied to healthcare settings to reflect the true cost of clinical care.[18 19] In this study, we apply a triple bottom line framework to the problem of unnecessary bloodwork in a population of acute care surgical patients and estimate the burden of inappropriate care on patients, healthcare expenditures and the environment.

METHODS

Evaluation of patient cost

A retrospective cohort study was conducted of patients admitted to the acute care surgery service at Vancouver General Hospital (VGH) between 1 January 2018 and 31 December 2018. VGH is a 700-bed tertiary care centre performing approximately 24 000 operations annually. A prospectively maintained database was used to identify patients aged 18–70 admitted with one of five common surgical conditions: acute uncomplicated appendicitis, cholecystitis, choledocholithiasis, gallstone pancreatitis and non-operatively treated adhesive small bowel obstruction. This population sample was screened for patients who had an uncomplicated hospital course as defined by the criteria in figure 1.

For each condition, cohorts of 20 patients were selected for in-depth chart review using a random number generator. In groups with fewer than 20 patients meeting these criteria, all eligible patients were included. An equal number of patients were selected from January to June and July to December to account for resident turnover and potential discrepancies in ordering practices. The hospital electronic health record was used to capture bloodwork completed during a patient's stay. A modified Delphi consensus process engaging faculty in the division of general surgery at this facility was previously conducted to determine appropriate laboratory investigations for an uncomplicated hospital course for each of these conditions.[20] Actual investigations performed were compared against these established consensus recommendations (online supplemental figure 1). Unnecessary investigations for each surgical condition were then extrapolated to the total study population.

In-depth chart reviews captured demographic data, admission diagnosis, operation type, hospital length of stay, and the timing, quantity, and type of laboratory investigations ordered (figure 2).

Evaluation of financial cost

The cost of unnecessary bloodwork was calculated based on consultation with laboratory personnel and from publicly available government data,[21] and included the cost of labour, transport and the consumables, reagents and energy required to process each test (online supplemental table 11).

Evaluation of carbon cost

The carbon footprint of a phlebotomy and each laboratory test analysed (figure 2) was estimated using PAS 2050 (Publicly Available Specification) methodology.[22]

The study boundary included GHG emissions associated with the production, transport, processing and disposal of each consumable involved in laboratory testing and its associated packaging (online supplemental figure 2)[23–26] (online supplemental table 3–10). Processes such as heating, ventilation, air conditioning (HVAC) and refrigeration were excluded as their energy consumption does not vary with laboratory testing volumes. Emissions factors were obtained primarily from the Department of Environment, Food and Rural Affairs (DEFRA) database from the UK.[27] The Inventory of Carbon and Energy and Ecoinvent databases were used when emissions factors were unavailable from DEFRA.[28 29]

Patient and public involvement

Patients and the public were not involved in this study.

RESULTS

Of a total of 997 patients admitted with 1 of the 5 surgical diagnoses, 304 ('total study population') met inclusion

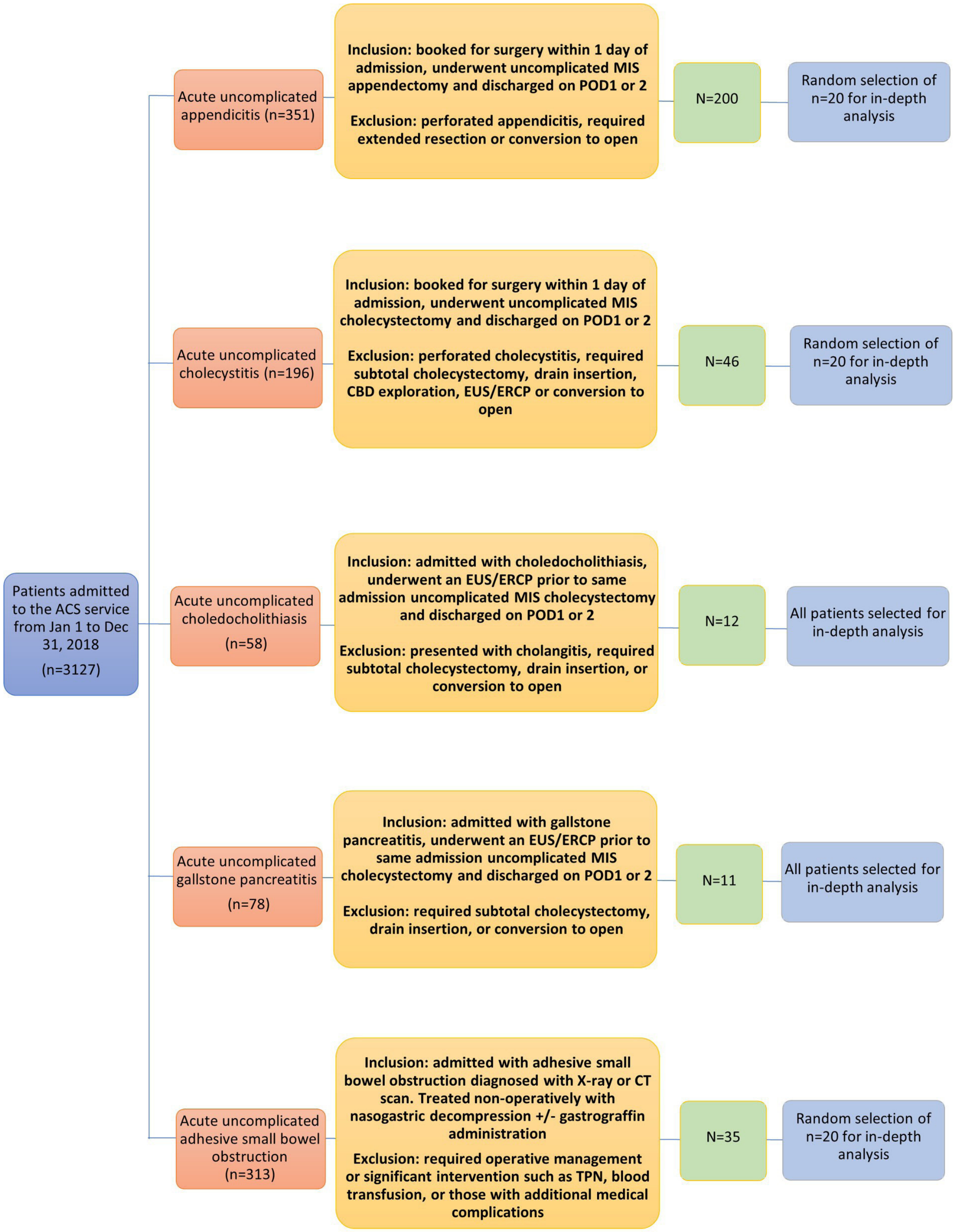

Figure 1 Inclusion and exclusion criteria for the five common acute surgical conditions studied, and corresponding patient populations. ACS, acute care surgery; CBD, common bile duct; ERCP, endoscopic retrograde cholangiopancreatography; EUS, endoscopic ultrasound; MIS, minimally invasive surgery, POD, postoperative day; TPN, total parenteral nutrition.

criteria for uncomplicated presentations and treatment courses (table 1). A random sample of up to 20 patients was selected from each diagnostic group and reviewed in depth, comprising the 'sample study population' (N=83). For choledocholithiasis and gallstone pancreatitis, all patients who met criteria (N=12 and N=11, respectively) were reviewed. The most common admission diagnosis was appendicitis (66%), followed by cholecystitis (23%) and adhesive small bowel obstruction (12%).

Patient cost

Within the sample study population, 63 patients (76%) underwent unnecessary bloodwork. The prevalence of unnecessary bloodwork was 40% (8/20) in appendicitis patients, 65% (13/20) in cholecystitis patients, 95% (19/20) in adhesive small bowel obstruction patients and 100% in patients with choledocholithiasis (12/12) and gallstone pancreatitis (11/11). A total of 278 vials of blood were drawn, and 1038 tests performed unnecessarily

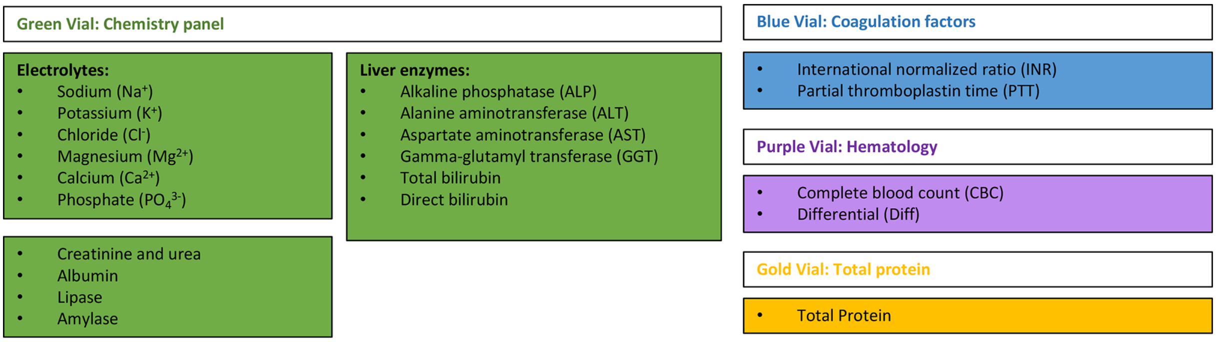

Figure 2 Analysed laboratory investigations.

(online supplemental table 1). On average, patients underwent 16.5 excess laboratory investigations and 1.8 unnecessary phlebotomies, resulting in 18 mL of excess blood loss and 4.4 excess blood vials used during their hospital admission (table 2).

Financial cost

The cost of unnecessary bloodwork was $C5235/year for the sample study population. Cholecystitis patients had the highest daily cost of unnecessary bloodwork ($C57.74) while gallstone pancreatitis patients incurred the highest cost per hospital stay ($C118.60) (table 2).

Carbon cost

For the 63 patients who underwent unnecessary laboratory testing, 974 g CO_2e per person was generated from over-investigation (online supplemental table 2). GHG emissions for patients admitted with choledocholithiasis, gallstone pancreatitis and adhesive small bowel obstruction were 2–3 times higher than for patients with appendicitis (table 2). Consumable manufacturing and processing of laboratory tests accounted for the majority of GHG emissions (92%), while processing of chemistry tests accounted for 47% of the total carbon footprint (online supplemental table 2).

The carbon footprint of a single phlebotomy was estimated at 150 g CO_2e, while processing a green, blue, purple and gold vial with all of their respective tests produced 689 g, 66 g, 39 g and 77 g of CO_2e, respectively (table 3). Table 3 can be used to estimate the carbon cost for common bloodwork. For example, ordering a complete blood count (CBC), international normalised ratio (INR), creatinine and electrolytes (Na^+, Cl^-, K^+) would require one phlebotomy (150 g CO_2e), one purple vial (34 g CO_2e), one blue vial (30 g CO_2e) and one green vial (32 g CO_2e) as well as the additional per test cost for CBC (2.4 g CO_2e), INR (18.1 g CO_2e), creatinine (67.8 gCO_2e) and electrolytes (11.5 g CO_2e), for a total of 346 g CO_2e.

Table 1 Patient demographics for total and sample study populations

Total study population (N=304)						
	Appendicitis	**Cholecystitis**	**Choledocholithiasis**	**Gallstone pancreatitis**	**Adhesive SBO**	**Total**
N (%)	200 (66)	46 (15)	12 (4)	11 (4)	35 (12)	304 (100)
Sex						
Male	103 (52)	18 (39)	5 (42)	4 (36)	15 (43)	145 (48)
Female	97 (48)	28 (61)	7 (58)	7 (64)	20 (57)	159 (52)
Sample study population (N=83)						
Age						
18–30	8 (40)	3 (15)	0 (0)	0 (0)	0 (0)	11 (13)
31–40	4 (20)	5 (25)	6 (50)	2 (18)	3 (15)	20 (24)
41–50	1 (5)	6 (30)	2 (17)	2 (18)	2 (10)	13 (16)
51–60	5 (25)	4 (20)	3 (25)	6 (55)	5 (25)	23 (28)
61–70	2 (10)	2 (10)	1 (8)	1 (9)	5 (25)	11 (13)
71–80	0 (0)	0 (0)	0 (0)	0 (0)	5 (25)	5 (6)
Sex						
Male	10 (50)	7 (35)	5 (42)	4 (36)	7 (35)	33 (40)
Female	10 (50)	13 (65)	7 (58)	7 (64)	13 (65)	50 (60)

SBO, small bowel obstruction.

Table 2 Mean unnecessary number of vials, tests, phlebotomies, excess blood volume, cost and carbon emissions per admission for each surgical condition for patients who received unnecessary bloodwork

	Acute appendicitis (N=8)	Acute cholecystitis (N=13)	Choledocholithiasis (N=12)	Gallstone pancreatitis (N=11)	Adhesive SBO (N=19)
LOS (days)*	1.2±0.4	1.9±0.5	6.4±1.5	6±1.7	4±1.0
Phlebotomies	1	1	2.3±0.3	2.5±0.7	2.1±0.6
Vials	2.4±1.0	3.2±0.8	5.3±1.1	6.8±2.3	4.1±1.2
Tests	6.4±2.8	13.2±2.4	22.0±5.0	24.2±8.7	15.0±4.3
Blood volume (mL)	9.1±3.5	12.6±2.9	21.0±3.9	27.5±8.0	16.3±4.7
Cost ($C)	$C38.95±$C11.8	$C57.74±$C9.0	$C104.91±$C25.1	$C118.60±$C37.5	$C82.01±$C23.5
Carbon emissions (gCO_2e)†	407.41	768.08	1290.77	1483.95	856.94

*LOS was calculated from time of general surgery consultation to time to discharge.
†Mean carbon emissions per admission were calculated by dividing the carbon emissions for each surgical condition by the number of admissions.
gCO2e, grams carbon dioxide equivalents; LOS, length of stay; SBO, small bowel obstruction.

To calculate the impact of unnecessary testing on the total study population, results from the sample study population were scaled up based on the proportion of patients undergoing unnecessary bloodwork for each surgical diagnosis. Extrapolating our results to the total study population suggests that an estimated 562 vials were drawn, and 1934 laboratory tests performed unnecessarily over the course of 1 year, at a cost of 112 kg CO_2e and $C10 158.32.

DISCUSSION

This study builds on our previous work establishing recommendations for appropriate laboratory testing in common and uncomplicated general surgery inpatients.[20] By comparing actual clinical practices to these consensus-derived recommendations, we show that a majority of patients undergo unnecessary laboratory testing at considerable cost to the individual patient, the hospital and the environment.

This study captures the triple bottom line of unnecessary bloodwork including financial costs and environmental impacts, measured here by carbon costs.[30] Estimating social costs within healthcare is complex due to the integrated psychological, physical and emotional determinants of health.[19] Our study captures the social costs of over-investigation using elements of patient outcomes and experience, namely volume of blood loss and frequency of unnecessary phlebotomy. This approach is supported by recent literature using health impacts to represent the social cost of unnecessary vitamin D testing.[18]

The prevalence of over-investigation in our patient population (76%) was in keeping with the literature. In medical and critical care populations, 50%–85% of tests have been found to be non-essential[31 32] with providers underestimating the frequency of over-investigation.[31] Breth-Petersen *et al* found that 76.5% of vitamin D testing in Australia was unnecessary,[18] and in a surgical population, 95.6% of abnormal postoperative bloodwork in patients undergoing total knee arthroplasty did not alter clinical management.[33] The only prior study of over-investigation in general surgery patients involved surgical trainees self-reporting the frequency of unnecessary testing.[34] Irrespective of training level, nearly 70% of residents acknowledged unnecessary testing, attributing this behaviour to hospital culture, lack of cost transparency and absence of laboratory stewardship role models. While we did not investigate the drivers of over-investigation, these factors have been consistently identified in the literature.[15 34–38] Our study provides transparency around the prevalence of unnecessary testing and granular financial and environmental costs of these practices in general surgery patients within a teaching hospital.

As expected, patient populations with higher rates of unnecessary testing also had higher financial and carbon costs, with gallstone pancreatitis patients incurring 3–3.5 fold higher expenditures and greenhouse gas emissions per admission compared with appendicitis patients (table 2). Longer length of stays and a wider variety of laboratory tests including pancreatic and liver enzyme testing likely contribute to this trend (online supplemental figure 3). Chemistry investigations including electrolytes, which were most often unnecessarily ordered in small bowel obstruction patients (online supplemental figure 3) also contain a high carbon cost dominated by their electricity demands (online supplemental figure 4).

In addition to capturing the number of unnecessary phlebotomies and laboratory tests, our study also quantified the volume of blood loss as an additional measure of social cost to the patient. Patients lost an average of 18 mL of blood unnecessarily, which is equivalent to a 1.3 g/L drop in haemoglobin.[38] While unnecessary bloodwork is unlikely to result in clinically significant anaemia in uncomplicated patient populations, its impact can be considerable in patients with critical illness, and exacerbated by concurrent processes such as bone marrow suppression and sepsis.[39 40]

Table 3 Greenhouse gas emissions per phlebotomy, vial and laboratory test

Phlebotomy (150 g CO_2e)	Green vial: Chemistry (32 g CO_2e)	Amylase (40.9 g CO_2e)
		Lipase (29.2 g CO_2e)
		ALP (80.5 g CO_2e)
		ALT (64.0 g CO_2e)
		AST (60.5 g CO_2e)
		GGT (25.0 g CO_2e)
		Na^+, K^+, Cl– (11.5 g CO_2e)
		Calcium (17.4 g CO_2e)
		Magnesium (25.2 g CO_2e)
		Phosphate (35.3 g CO_2e)
		Creatinine (67.8 g CO_2e)
		Urea (32.1 g CO_2e)
		Direct bilirubin (56.7 g CO_2e)
		Total bilirubin (80.8 g CO_2e)
		Albumin (27.9 g CO_2e)
	Blue vial: Coagulation factors (30 g CO_2e)	INR (18.1 g CO_2e)
		PTT (18.2 g CO_2e)
	Purple vial: Haematology (34 g CO_2e)	CBC (2.4 g CO_2e)
		Differential (2.2 g CO_2e)
	Gold vial: Total protein (32 g CO_2e)	Total protein (44.9 g CO_2e)

Colours in table correspond to the stated colours of the vials (green, blue, purple, and gold).
ALP, alkaline phosphatase; ALT, alanine aminotransferase; AST, aspartate aminotransferase; CBC, complete blood count; Cl^-, chloride; gCO2e, grams carbon dioxide equivalents; GGT, gamma-glutamyl transferase; INR, international normalised ratio; K^+, potassium; Na^+, sodium; PTT, partial thromboplastin time.

Avoidable expenditures were estimated at $C10 158 per year in our total study population of 304 patients. A recent quality improvement initiative eliminating post-operative day 1 bloodwork in bariatric surgery patients found similar savings of $C12 202 annually across 303 patients.[41] Other studies have shown larger cost savings, up to US$2 million dollars ($C2.6 million) over 3 years across approximately 11 000 hospital admissions[42] or 500 000 inpatient days.[43] These interventions also demonstrated that reducing unnecessary testing does not adversely affect patient care, with no differences in emergency department presentations, readmissions, reoperations, missed diagnoses of anaemia or electrolyte disturbances or mortality.[41–43] The cost saving potential of eliminating inappropriate testing is consistently underestimated; studies only account for the cost of consumables without capturing the downstream effects of further investigations, interventions or prolonged hospital stays.

According to the Canadian Institute for Health Information, 71 121 appendectomies and cholecystectomies were performed in Canada in 2019.[44] Applying the rates of uncomplicated appendicitis (57%) and cholecystitis (23%) and the rate of over-investigation seen in our patient population, we estimate that out of 29 800 patients, 13 736 underwent excessive phlebotomies, resulting in $C625 546 in avoidable healthcare costs. We acknowledge that eliminating unnecessary testing entirely may be challenging as the determination of appropriateness is easier in retrospect and there may be situations that necessitate deviation from standard practice. Instead, through demonstrating the burden of over-investigation in the most uncomplicated patients, we hope to encourage critical evaluation of laboratory investigations in all patients.

In our study population, GHG emissions from unnecessary bloodwork were approximately 61 kg CO_2e, which is equivalent to driving 152 miles in a passenger vehicle, charging 7468 smartphones, or burning 31 kg of coal.[45] Unlike financial costs, carbon accounting is not widely practised or appreciated within healthcare. Our quantification of the carbon cost of each laboratory test estimates the climate impact of unnecessary testing and may motivate behaviour change, as previously demonstrated with provider-level feedback regarding costs of care.[42 43] Knowing that a chemistry panel produces nearly five times the impact of sodium, potassium, creatinine and urea may prompt more thoughtful ordering practices.

The extrapolated financial and environmental costs of over-investigation in our population were considerably lower than those reported in a recent study applying the triple bottom line to unnecessary vitamin D testing,[18] likely due to our focus on one surgical specialty compared with population-wide laboratory testing. On an individual laboratory test level, the carbon footprints of bloodwork reported here are comparable to those reported by McAlister *et al*.[16] Their estimated values of 116 g CO_2e for CBC/Diff and 82 g CO_2e for INR/partial thromboplastin time are slightly lower than our estimates of 189 g CO_2e and 216 g CO_2e, respectively. This is likely due to their consequential analysis, which only considered the impact of additional testing without the inclusion of variables such as machine use, which would otherwise be present even if additional tests were avoided. Importantly, both studies found that the majority of emissions arose from the production of consumables and processing of laboratory tests, emphasising the need to focus on reducing unnecessary resource use rather than optimising waste management.

LIMITATIONS

Our inclusion criteria were intentionally conservative, capturing an uncomplicated patient population that followed the expected clinical course. Although this resulted in a small sample size, there is a high level of confidence that the laboratory investigations performed outside of consensus recommendations were truly unnecessary, and therefore, the 76% rate of unnecessary bloodwork is likely an underestimate. Given the retrospective nature of the study, it would be difficult to ascertain whether investigations ordered were the result of clinical judgement, or whether these led to changes in management, but the adherence of all included patients to the expected clinical trajectory and date of discharge would suggest that investigations were more likely ordered as a matter of course. We did not investigate whether unnecessary investigations led to changes in clinical decision-making, including electrolyte replacement for incidental hypomagnesaemia or hypophosphataemia. Given that the evidence around electrolyte replacement in non-critical care populations is limited, the relevance of this omission is difficult to interpret.

The generalisability of the prevalence of unnecessary testing beyond academic hospitals is potentially limited as laboratory investigations in these centres are ordered primarily by trainees. This may not reflect practice at community hospitals or private medical centres, though unnecessary tests and care have been reported across a range of clinical settings.[13 15]

The carbon costs reported here provide an estimate of the scale of environmental damages from laboratory testing that is generally applicable across healthcare facilities. These costs will vary, however, based on regional and site differences in energy sources, transport distances and procurement and waste management practices. Our environmental impact assessment methodology focused only on GHG emissions rather than a comprehensive suite of impacts. HVAC and refrigeration were excluded as the amount of over-investigation in the studied population would not significantly alter the outputs of these continuously running systems. However, on a whole hospital scale, eliminating over-investigation could reduce the demand for laboratory services such that some capital equipment could potentially be decommissioned.

CONCLUSIONS

There is considerable overuse of laboratory investigations in uncomplicated acute care general surgery patients. This study highlights the role of laboratory stewardship as a central tenet of planetary healthcare. Eliminating healthcare activities that contribute no clinical value is a strategic target for decarbonising the health sector, with co-benefits of avoiding patient harm and accruing cost savings. We recommend that healthcare practitioners follow local or national guidelines such as Choosing Wisely recommendations and adopt thoughtful ordering practices guided by clinical judgement. This study also contributes environmental costs of laboratory tests that can be used in future studies and operationalises a triple bottom line approach to health services that should be embedded within quality improvement frameworks.

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Patient consent for publication Not applicable.

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Data availability statement Data are available on reasonable request. All data relevant to the study are included in the article or uploaded as online supplemental information. Data used to calculate financial and carbon cost of laboratory investigations included in online supplemental materials. Raw data on volume of unnecessary bloodwork available on request.

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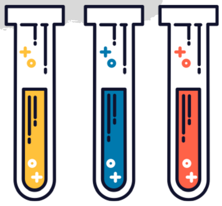
Recommendation 1

For all patients: Order a maximum of three consecutive days of daily blood work at a time. Reassess the need for ongoing laboratory investigations daily.



Recommendation 2

For **stable patients** with **acute uncomplicated appendicitis** who are **discharged on post-operative day 1** after undergoing an **uncomplicated laparoscopic appendectomy,** do not order post-operative blood work.

Recommendation 3

For **stable patients** with **acute uncomplicated cholecystitis** and no evidence of choledocholithiasis who are **discharged on post-operative day 1** after undergoing an **uncomplicated laparoscopic cholecystectomy**, do not order post-operative blood work.

Recommendation 4

For **stable patients** with **acute gallstone pancreatitis**:

- Use lipase as the preferred test to evaluate for pancreatitis
- Do not trend lipase or amylase

Recommendation 5

For **stable patients** with **acute choledocholithiasis** or **gallstone pancreatitis** who have demonstrated **biochemical or mechanical common bile duct clearance*** and are awaiting same admission cholecystectomy:

- Stop trending liver enzymes once a clear downward trend has been established, then stop all routine blood work once patient is booked for surgery**
- Do not order post-operative blood work after uncomplicated same-admission laparoscopic cholecystectomy.

Recommendation 6

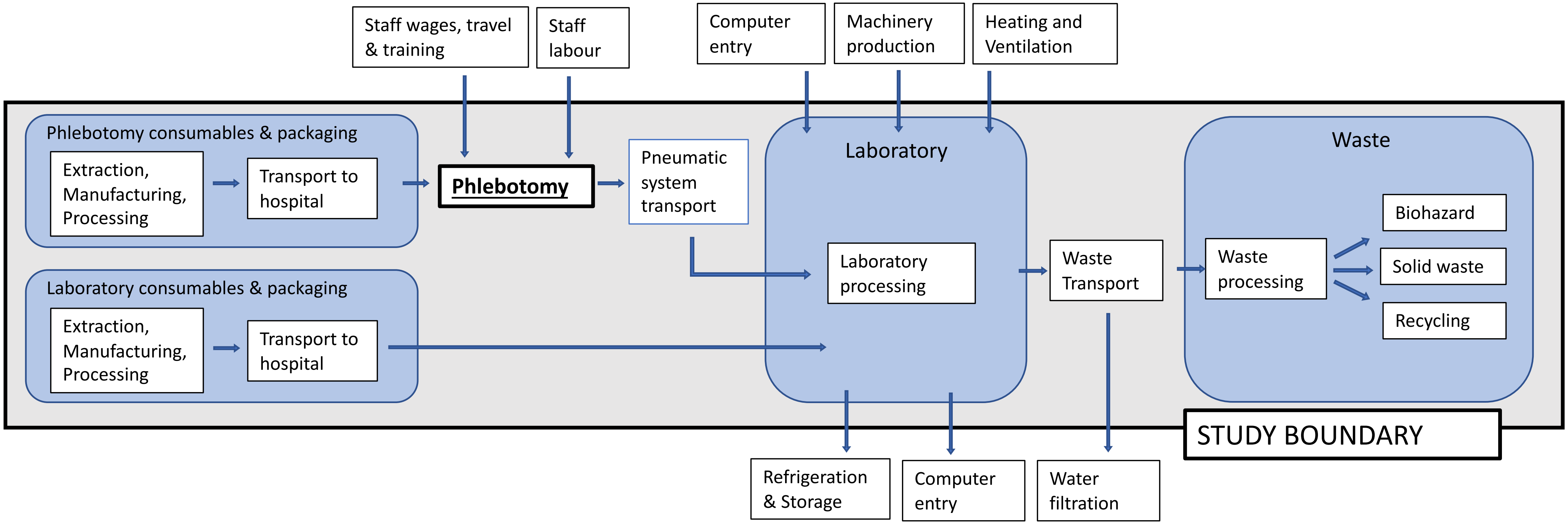
For **stable patients** with an **uncomplicated adhesive small bowel obstruction**:

- Stop routine blood work once the nasogastric tube has been removed and the patient is tolerating a fluid diet.
- Continue to re-assess patients' intake and fluid status, and order blood work as clinically indicated.

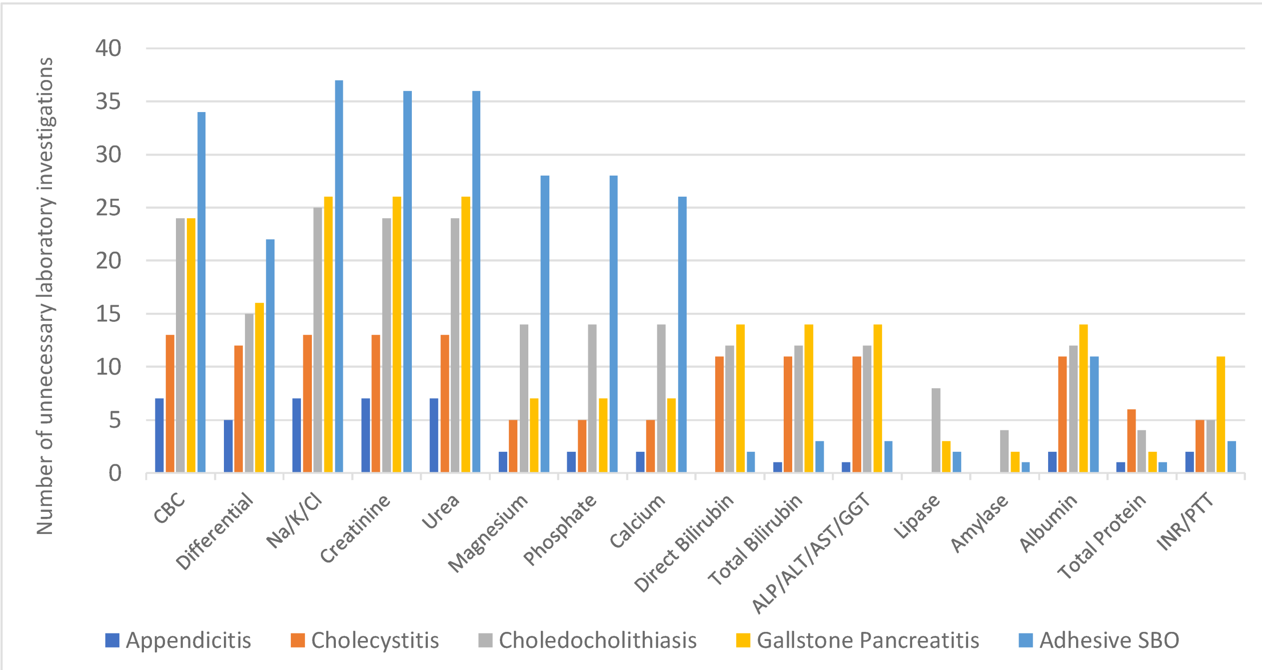
*Common bile duct clearance includes both spontaneous clearance (as demonstrated biochemically with a normalization of bilirubin or radiologically with MRCP or EUS) as well as therapeutic clearance using ERCP.

**Lab work may be repeated every 72 hours if the surgery is significantly delayed or sooner if the patient's clinical status changes

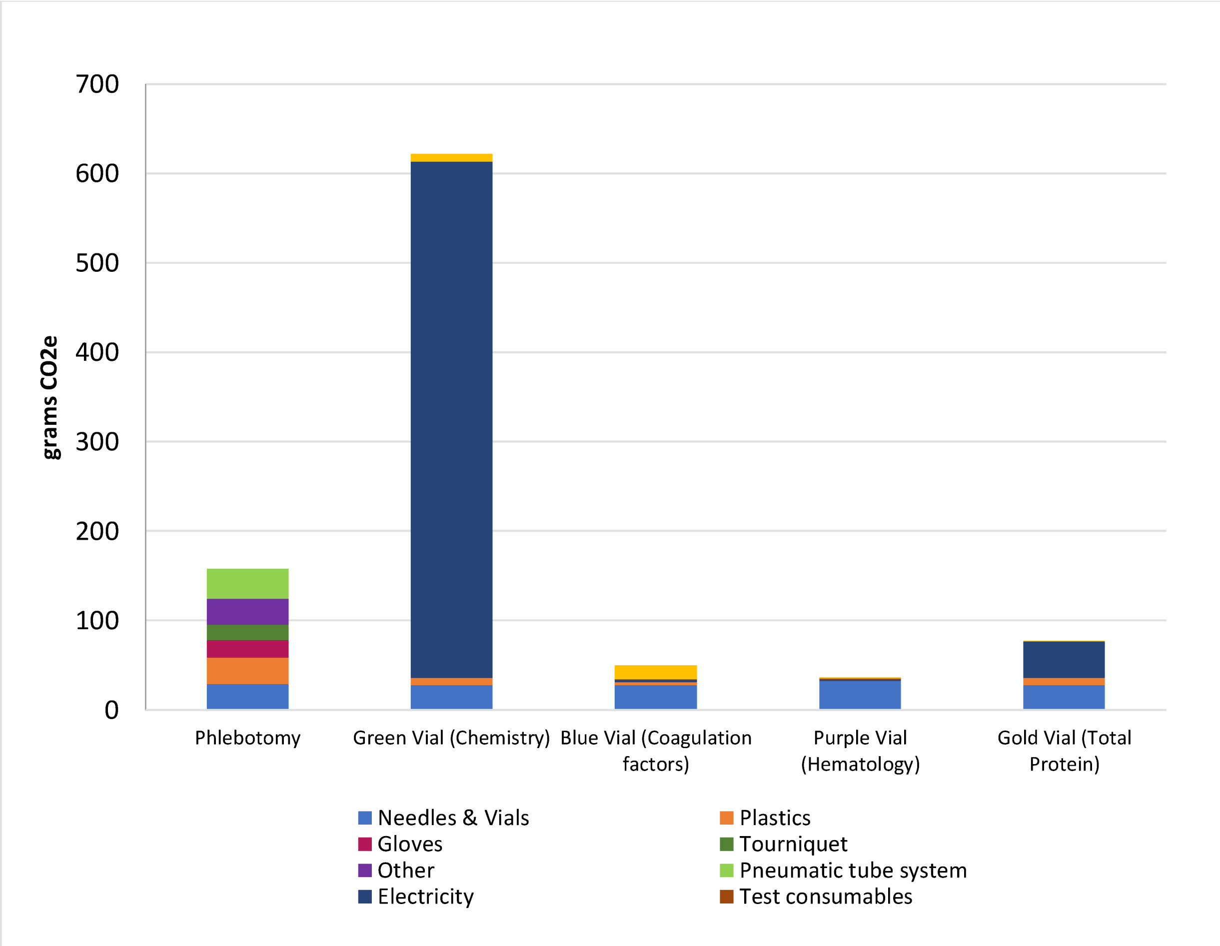
Supplemental Figure 1: Appropriate investigations for each surgical diagnosis for uncomplicated and medically stable patients as determined by modified Delphi consensus (19). Abbreviations: EUS = Endoscopic Ultrasound, ERCP = Endoscopic Retrograde Cholangiopancreatography, MRCP = Magnetic Resonance Cholangiopancreatography



Supplemental Figure 2: Study boundary depicting processes included in the calculation of the carbon footprint of laboratory investigations.



Supplemental Figure 3: Per test breakdown of unnecessary laboratory tests performed for each surgical condition. Abbreviations: SBO = small bowel obstruction, CBC = Complete blood count, Na+ = Sodium, K+ = Potassium, Cl- = Chloride, ALP = Alkaline Phosphatase, ALT = Alanine Aminotransferase, AST = Aspartate Aminotransferase, GGT = Gamma-glutamyl Transferase, INR = International Normalized Ratio, and PTT = Partial Thromboplastin Time.



Supplemental Figure 4: Sources of greenhouse gas emissions within each component of laboratory testing. Abbreviations: g CO2e = grams carbon dioxide equivalents. "Other" includes sterile wipe, tape, gauze, food tray, and laboratory requisition forms.

Blood draws	115
Green vial: Chemistry	
$Na^+/K^+/Cl^-$	108
Calcium	54
Magnesium	56
Phosphorus	56
Creatinine	106
Urea	106
ALP/ALT/AST/GGT	41
Direct bilirubin	39
Total bilirubin	41
Amylase	7
Lipase	13
Albumin	50
Total tests:	800
Total vials:	110
Blue vial: Coagulation factors	
INR	26
PTT	26
Total tests:	52
Total vials:	26
Purple vial: Hematology	
CBC	102
Diff	70
Total tests:	172
Total vials:	102
Gold vial: Total protein	
Total protein	14
Total tests:	14
Total vials:	14

Supplemental Table 1: Number of unnecessary tests and vials for each analyzed laboratory investigation. Abbreviations: Na^+ = Sodium, K^+ = Potassium, Cl^- = Chloride, ALP = Alkaline Phosphatase, ALT = Alanine Aminotransferase, AST = Aspartate Aminotransferase, GGT = Gamma-glutamyl Transferase, INR = International Normalized Ratio and PTT = Partial Thromboplastin Time, CBC = Complete blood count, Diff = Differential
***Note: Vial count for INR/PTT includes the excess vials wasted during phlebotomy (Supplemental materials: "*Blood collection and transport*")**

Process	Phlebotomy	Green vial (Chemistry)	Blue vial (Coagulation factors)	Purple vial (Hematology)	Gold vial (Total protein)	Total emissions (g CO_2e)
Consumable manufacturing	10,707	6741	1730	3010	426	**22,614**
Consumable transport	2376	778	568	436	56	**4213**
Laboratory processing	3904	28,925	86	138	566	**33,655**
Waste	318	228	106	234	26	**911**
Total	**17,305**	**36,672**	**2489**	**3819**	**1073**	**61,358**

Supplemental Table 2: Processes contributing to the carbon footprint of laboratory testing. This table breaks down life cycle processes contributing to the total carbon footprint for investigations across the sample population that underwent unnecessary bloodwork(N=63). Abbreviations: g CO2e = grams carbon dioxide equivalents.

Laboratory Test	Cost ($CAD)	Source
CBC	12	St. Paul's Hospital Laboratory
Differential	11.7	St. Paul's Hospital Laboratory
Na^+, K^+, Cl^-	3	St. Paul's Hospital Laboratory
Creatinine	1.5	St. Paul's Hospital Laboratory
Urea	1	St. Paul's Hospital Laboratory
Magnesium	7	St. Paul's Hospital Laboratory
Phosphate	1.5	St. Paul's Hospital Laboratory
Calcium	1.5	St. Paul's Hospital Laboratory
ALP, ALT, AST, GGT	7.5	St. Paul's Hospital Laboratory
Total bilirubin	1.6	BC Ministry of Health
Direct bilirubin	1.5	St. Paul's Hospital Laboratory
Lipase	6.6	BC Ministry of Health
Amylase	5.3	BC Ministry of Health
Albumin	1.6	BC Ministry of Health
Total protein	1.6	BC Ministry of Health
INR/PTT	18.5	St. Paul's Hospital Laboratory

Supplemental Table 10: Cost of each laboratory test. Prices for laboratory testing were obtained for St.Paul's Hospital, a tertiary care centre with previously calculated costs including labour, quality control, energy, consumables, and reagents. Similar data was unavailable at VGH. Abbreviations: CBC = Complete blood count, Na^+ = Sodium, K^+= Potassium, Cl^- = Chloride, ALP = Alkaline Phosphatase, ALT = Alanine Aminotransferase, AST = Aspartate Aminotransferase, GGT = Gamma-glutamyl Transferase, INR = International Normalized Ratio and PTT = Partial Thromboplastin Time. BC Ministry of Health website: http://www.bccss.org/bcaplm-site/Documents/Programs/laboratory_services_schedule_of_fees.pdf.