Life Cycle Greenhouse Gas Emissions of Gastrointestinal Biopsies in a Surgical Pathology Laboratory

Ilyssa O. Gordon, MD, PhD,[1] *Jodi D. Sherman, MD,*[2] *Michael Leapman, MD,*[3] *Michael Overcash, PhD,*[4] *Cassandra L. Thiel, PhD*[5]

From the [1]Department of Pathology, Cleveland Clinic, Cleveland, OH, USA; [2]Department of Anesthesiology, Yale School of Medicine, and Department of Environmental Health Sciences, Yale School of Public Health, New Haven, CT, USA; [3]Department of Urology, Yale School of Medicine, New Haven, CT, USA; [4]Environmental Genome Initiative, Raleigh, NC, USA; and [5]Department of Population Health, NYU Langone Health, New York, NY, USA.

Key Words: Surgical pathology; Life cycle assessment; Greenhouse gas emissions; Gastrointestinal; Biopsy

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ABSTRACT

Objectives: *Given adverse health effects of climate change and contributions of the US health care sector to greenhouse gas (GHG) emissions, environmentally sustainable delivery of care is needed. We applied life cycle assessment to quantify GHGs associated with processing a gastrointestinal biopsy in order to identify emissions hotspots and guide mitigation strategies.*

Methods: *The biopsy process at a large academic pathology laboratory was grouped into steps. Each supply and reagent was catalogued and postuse treatment noted. Energy consumption was estimated for capital equipment. Two common scenarios were considered: 1 case with 1 specimen jar (scenario 1) and 1 case with 3 specimen jars (scenario 2).*

Results: *Scenario 1 generated 0.29 kg of carbon dioxide equivalents (kg CO_2e), whereas scenario 2 resulted in 0.79 kg CO_2e—equivalent to 0.7 and 2.0 miles driven, respectively. The largest proportion of GHGs (36%) in either scenario came from the tissue processor step. The second largest contributor (19%) was case accessioning, mostly attributable to production of single-use disposable jars.*

Conclusions: *Applied to more than 20 million biopsies performed in the US annually, emissions from biopsy processing is equivalent to yearly GHG emissions from 1,200 passenger cars. Mitigation strategies may include modification of surveillance guidelines to include the number of specimen jars.*

Key Points

- Health care delivery produces significant environmental emissions that adversely affect human health; processes affecting these emissions must be detailed to devise mitigation strategies.
- The greenhouse gas emissions stemming from a single pathology laboratory procedure may seem small but are significant when magnified across the entire health care sector.
- Opportunities to reduce pathology laboratory emissions include efficient use of biopsy jars, thoughtful prescribing of biopsy procedures, and green purchasing practices for equipment and supplies.

Awareness is growing with regard to the health effects associated with climate change, including increasing vector-borne disease, food and water scarcity, cardiovascular and respiratory illness, displaced populations with social and political instability, and mental health issues.[1-3] The health care sector contributes to these health effects, emitting 9% to 10% of US greenhouse gases (GHGs) and 9% of toxic air pollutants.[4,5] An estimated 614,000 disability-adjusted life-years are lost per year because of emissions attributable to the US health care sector.[6]

Sustainability efforts within the health care community have begun to gain traction. In 2016, the American College of Physicians charged the health care sector with implementing "environmentally sustainable and energy-efficient practices."[2] Internationally, the Lancet Commission on Climate Change called climate change the biggest threat to and opportunity for global public health, and health systems like the UK's National Health Service have begun to monitor and actively reduce health care–associated emissions.[7-10] Grounded in sustainability science and industrial ecology, consensus exists regarding the need to integrate environmental performance metrics into health care.[11]

Research frameworks for the evaluation of environmental impacts of specific medical processes are useful to guide targeted interventions.[12-14] Life cycle assessment (LCA) is an internationally standardized scientific systems analysis tool recommended to quantify GHG and other environmental emissions associated with a product or process throughout its life cycle—from raw material extraction, production, and use through reuse, recycling, and end of life.[15] LCA has been used in many disciplines since emerging in 1969, including product development, building construction, energy management, and transportation. LCA typically helps identify components of a system with disproportionate impacts and compare the environmental performance of 2 or more products or systems. Recently, LCA has been used within health care to measure baseline emissions of medical products and procedures to develop more sustainable care pathways.

To date, several LCA studies of health care processes exist,[13] such as those on operating rooms,[16-20] anesthesia,[21] dentistry,[22,23] radiology,[24,25] and telemedicine,[26-28] whereas others offer insights on individual medical products and supplies.[29-39] Laboratories are an important part of any health care system. Prior work from the field of laboratory medicine estimated carbon emissions from an amino acid analyzer[40] and 5 common blood tests.[41] To our knowledge, no studies have evaluated GHG emissions associated with tissue biopsy processing in a surgical pathology laboratory.

Approximately 20 million biopsies are performed annually in the United States, and processing biopsies is the most common procedure performed in a surgical pathology/histology laboratory setting.[42] Laboratories are energy-intensive workspaces, given the combination of equipment and requirements for heating, ventilation, and air conditioning (HVAC).[40,43,44] Concern about the potentially infectious and toxic nature of laboratory work has led to an abundance of single-use disposable products and the generation of hazardous and nonhazardous waste. Given the large numbers of biopsies conducted in the United States, this study seeks to quantify emissions and identify opportunities for reducing their environmental footprint.

Materials and Methods

Study Location and Biopsy Type

The study was conducted in a surgical pathology laboratory that processes more than 150,000 surgical pathology cases annually, including more than 50,000 biopsies. Interpretation is performed by more than 60 subspecialty pathologists. The on-site histology laboratory utilizes a Leica processing system.

In this study, we evaluated a common type of specimen process, the gastrointestinal (GI) biopsy. We analyzed 2 common approaches for extracting multiple tissue biopsies from a single patient: using a single jar of formalin to process multiple samples or using separate jars of formalin for each sample. Typically, regardless of whether the biopsy is from the GI tract, the gynecologic tract, skin, or the genitourinary tract, a single biopsy jar results in creating 1 paraffin block of tissue. Consequently, these results on GI biopsies are expected to be generalizable to other anatomic sites.

LCA Methods

According to ISO 14040 standards,[15] LCA is conducted in 4 steps: (1) goal and scope definition, in which the system's functional unit of comparison is defined; (2) life cycle inventory (LCI), in which system inputs are collected; (3) life cycle impact assessment, in which various emissions are categorized and characterized into categories such as GHGs; and (4) interpretation, in which assumptions are tested through sensitivity analyses.

The goal of this study is to assess the environmental footprint of conducting a standard GI biopsy in a clinical laboratory. To account for process variation, this study analyzes 2 approaches. In scenario 1, one patient's GI biopsy sample is sent to the laboratory in a single jar, resulting in 1 cassette processed by the lab. In scenario 2, one patient's GI biopsy sample is sent to the laboratory in 3 jars, resulting in 3 cassettes processed by the lab. The functional unit of comparison for this study is the processing of one patient's GI biopsy sample. This is an attributional analysis at the level of one patient's biopsy, calculated for the 2 scenarios of the biopsy tissue being placed in a 1 jar or in 3 jars.

Study boundaries include all biopsy materials and supplies used within the laboratory space (including gowns, gloves, single-use disposable and reusable tools), associated electricity used within the space (from capital equipment, lighting, and the HVAC system), and the upstream production and the downstream treatment or disposal of these resources **Figure 1**. Transportation of commuting laboratory staff was also included, as some studies have shown large portions of emissions are associated with medical-related travel.[45,46] Manufacturing of capital equipment and buildings was excluded, as these are likely to have a small per-patient footprint when averaged over a lifetime. Notably excluded is nonelectricity energy demand (eg, gas used for heating), given data acquisition issues.

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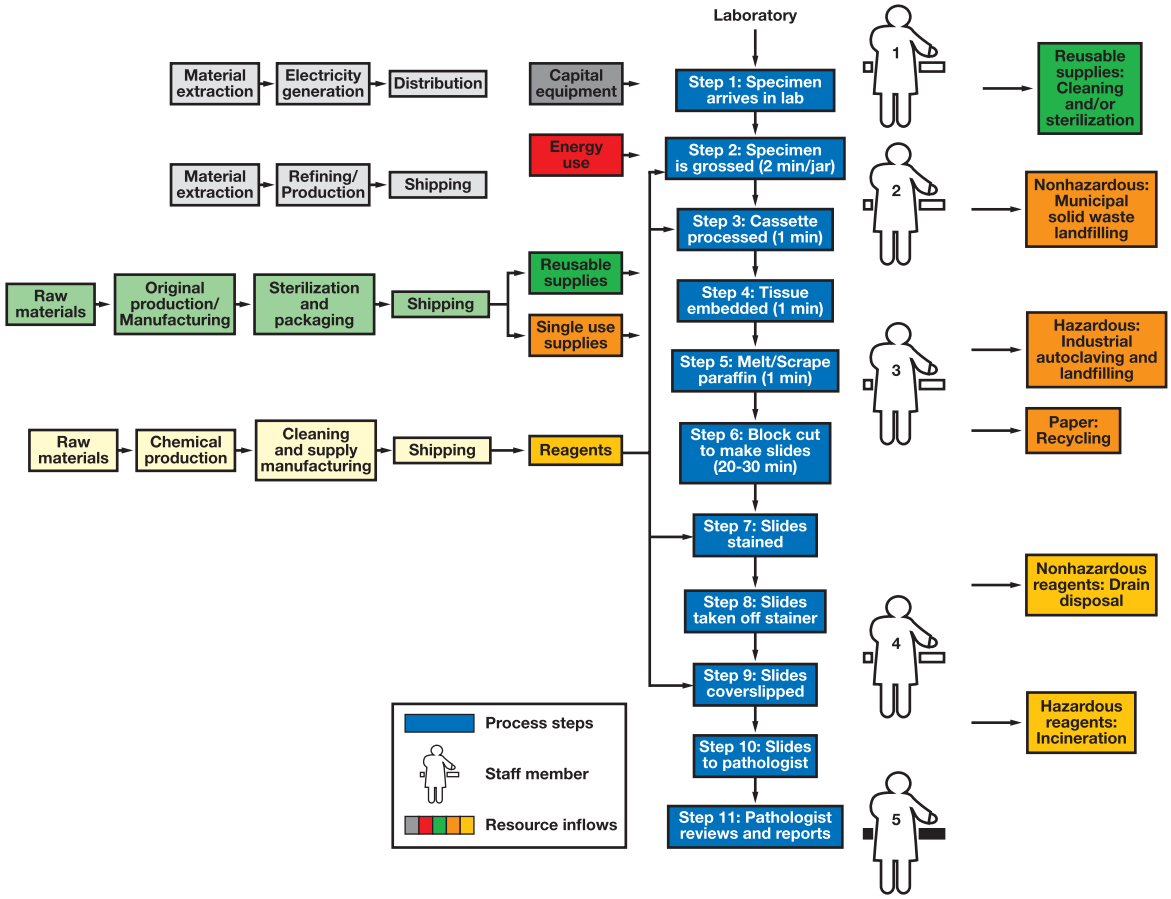

Figure 1 Process flow diagram of the gastrointestinal biopsy process in a surgical pathology laboratory.

Data Collection and LCI

Data collection began with observation of the step-by-step biopsy process (Figure 1). Each supply, reagent, and capital equipment item was catalogued, along with the number of individuals required for each step and the amount of time each step took on average.

Each supply item was weighed, and the primary material types of each item were identified by labeling on the item or on the manufacturer's website (eg, polypropylene, stainless steel). The life span of each reusable item was estimated. Disposal pathways for all items were also noted and included landfilling (for municipal solid waste or nonhazardous waste) and autoclaving and landfilling (for biohazardous waste). In this clinical laboratory, only residual body tissues are incinerated; however, for the GI biopsies studied here, all tissues were used in the process and stored indefinitely as formalin-fixed, paraffin-embedded tissue blocks. The footprint associated with storing biopsied tissue was not included in this study. Paper reports were sent to a secure recycling stream.

For reagents, quantities were allocated to a single case based on the total number of bottles used and the total number of biopsies performed in the entire histology laboratory over the course of 1 week. After use, most of these liquid items were disposed of through wastewater systems (drain), whereas 2 chemicals (xylene and ethanol) were disposed of by incineration with energy recovery (chemical waste treatment pathways).

This laboratory space does not submeter electricity or energy usage, and as with other LCA-based studies, an allocation method was developed to assign the quantities used to the functional unit. The total annual electricity usage of the building was allocated to the biopsy laboratory space based on floor area. To estimate electricity use from a single biopsy, the annual electricity use of the laboratory space was divided by the total number of biopsy cases processed in this laboratory annually. To allocate electricity usage to each process step, watt meters and equipment power ratings were used to estimate the energy consumption of each piece of capital equipment in the process, shown in Supplemental Table 1 (all supplemental materials can be found at *American Journal of Clinical Pathology* online). The estimate of a single case's electricity consumption was allocated to each process step based on the relative percentage of electricity used

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by the equipment in that step. Of note, because the allocation was based on annual electricity consumption, it is inclusive of equipment plug loads, lighting, and any use of electricity in the HVAC system and includes electricity used during the laboratory's off-hours. Building-level records were not available to estimate steam usage from a district steam heating system; therefore, this aspect of energy demand was excluded.

Equation 1 shows the allocation of electricity to the process step of a single biopsy, where E is electricity, FA is floor area, q represents quantity or number of biopsies performed, n indicates the process step number (steps 1-11):

$$E_{step\,n} = \left(E_{annual,building} \times \frac{FA_{lab}}{FA_{building}} \div q_{annual,biopsies}\right) \times \frac{\sum Plug\ Loads_{Step\,n}}{\sum Plug\ Loads_{biopsy}}$$

The GI biopsy process involved 5 staff members. Each staff member was assumed to commute 25 km round trip each day, with 80% traveling by car, 15% traveling by bus, and 5% traveling by bike. Staff members work 255 days per year and process an average of 988 cassettes per day (based on annual statistics); therefore, each staff member travels an estimated 0.025 km per case. To allocate each staff member's per-case commute to the case's process steps, the transportation estimate was divided by the number of process steps performed by each person. Staff worker 4, for example, completes biopsy process steps 7 through 10, so the transportation allocation of step 7 is one-quarter of a staff member's per-case transportation estimate. Staff travel was based heavily on assumptions and thus was included in a sensitivity analysis.

LCI and Impact Assessment

The LCI stage often uses existing databases to assign various environmental emissions to the materials used in the system being modeled, using basic material inputs to that system (unit processes). This study's LCI was created by matching the collected data points, described with unit processes from the ecoinvent 3.3 LCI database, with an allocation at the point of substitution (APOS) system model,[47] using SimaPro PhD version 8.5.2.3 software from Pré Consultants. Ecoinvent is one of the most comprehensive LCI databases in the world and is commonly used to estimate environmental emissions from specific units of a system. For chemicals and reagents not found in this database, the Chemical Life Cycle Collaborative (CLiCC; University of California, Santa Barbara) LCIA Estimate tool was used.[48] It should be noted that using 2 different LCI databases may lead to inconsistencies due to differences in modeling structures, methods of allocation, and assumed system boundaries. However, detailed LCI and unit process descriptors for our study can be found in Supplemental Table 2.

LCI GHG emissions data were then aggregated into units of kilograms of carbon dioxide equivalents (kg CO_2e) using the life cycle impact assessment tool TRACI (Tool for the Reduction and Assessment of Chemicals and Other Environmental Impacts) 2.1 version 1.04 from the US Environmental Protection Agency.[49] This is a US-based impact assessment method commonly used in LCA studies of all types.

Sensitivity Analyses

To test the effect of our model's allocation method and improve generalizability, sensitivity analyses were conducted. For supply and reagent production, the same average weekly consumption measured in this study was compared against the range in the number of cases that the laboratory typically handles each working day. Based on the weekly range of biopsy cassettes processed in this laboratory, the average or baseline scenario assumes 988 cassettes are processed daily, with a range of 850 (low) to 1,100 (high) cassettes per day. For staff travel, the mode and the travel distance were also modified to a "maximum" scenario, in which all staff traveled by car at double the assumed roundtrip distance (50 km instead of 25 km). Finally, to account for variation in waste-disposal management practices between health care organizations, a "worst case scenario" was estimated in which all laboratory wastes were incinerated without energy recovery.

Results

Biopsy processing involved 11 steps conducted by 5 laboratory staff (Figure 1). GI biopsy processing is estimated to emit 0.28 kg CO_2e when 1 jar is used (scenario 1) and 0.79 kg CO_2e (or 2.8 times more) when 3 jars are used (scenario 2), shown in **Table 1**. These GHG emissions are equivalent to driving a typical passenger vehicle 0.7 mile and 2.0 miles, respectively.[50] Differences are appreciated when considering specific categories of emissions sources.

Production of supplies was the largest contributor to GHG emissions, at 0.11 kg CO_2e (39% of total emissions) in scenario 1 and 0.28 kg CO_2e (36% of total emissions) in scenario 2 (2.5 times more than scenario 1). Production of chemicals and reagents was the second largest contributor, at 0.08 kg CO_2e (26% of total

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Table 1
Greenhouse Gas Emissions of Gastrointestinal Biopsy for a Single Patient, by 2 Approaches in kg CO_2e (% of Scenario Total)

Scenario[a]	Supply Production	Chemicals/ Reagent Production	Waste Treatment	Staff Travel	Energy	Total
Scenario 1	0.11 (38)	0.08 (26)	0.05 (19)	0.04 (13)	0.01 (4)	0.29 (100)
Scenario 2	0.28 (36)	0.23 (29)	0.12 (16)	0.12 (15)	0.04 (5)	0.79 (100)

[a]Scenario 1 is 3 biopsy samples in 1 jar. Scenario 2 is 3 biopsy samples in 3 jars.

emissions) in scenario 1 and 0.23 kg CO_2e (29% of total emissions) in scenario 2 (2.9 times more than scenario 1). Electrical energy required for the laboratory equipment was the smallest contributor, at 0.01 kg CO_2e (4% of total emissions) in scenario 1 and 0.04 kg CO_2e (5% of total emissions) in scenario 2 (4 times more than scenario 1). Scenario 2 also generated 2.4 times more emissions from waste treatment than scenario 1 and 3 times more from staff travel because having to handle more cassettes per case decreases the total number of cases for which staff travel emissions can be allocated, resulting in higher per-case emissions.

Breaking down results for each scenario by specific activity **Figure 2** showed that step 3, processing the cassette(s) on the tissue processor (Leica ASP 300S), resulted in the largest proportion, 36% of total emissions, (0.10 kg CO_2e for scenario 1 and 0.28 kg CO_2e for scenario 2). This result was largely attributable to production of reagents used (22% of total emissions and 60% of step 3 emissions). Step 1, receiving and accessioning the case in the laboratory, is the second largest fraction of overall emissions at 17% of scenario 1 (0.15 kg CO_2e) and 19% of scenario 2 (0.15 kg CO_2e), mostly stemming from the production of single-use disposable jar(s). Step 6 (block cutting to make slides) and Step 7 (staining the slides) are the next biggest emitters, together accounting for 31% (0.09 kg CO_2e) and 30% (0.24 kg CO_2e) of GHGs, respectively, in both scenarios.

Sensitivity Analyses

Compared with the baseline of 988 cassettes processed daily, lowering the volume to 850 cassettes increased per-case emissions by 9% (0.30 kg CO_2e for scenario 1 and 0.86 kg CO_2e for scenario 2) while raising the volume to 1,100 decreased per-case emissions by 15% (0.24 kg CO_2e for scenario 1 and 0.67 kg CO_2e for scenario 2). The supply impact represents the largest share of potential savings from increased throughput **Figure 3**.

Incinerating all waste, as opposed to the baseline treatment of autoclaving and landfill, would increase per-case GHG emissions by 25% (0.08 kg CO_2e for scenario 1 and 0.19 kg CO_2e for scenario 2). Doubling staff commuting distances to 50 km by car would increase per-case emissions by 20% (0.06 kg CO_2e for scenario 1, and 0.16 kg CO_2e for scenario 2).

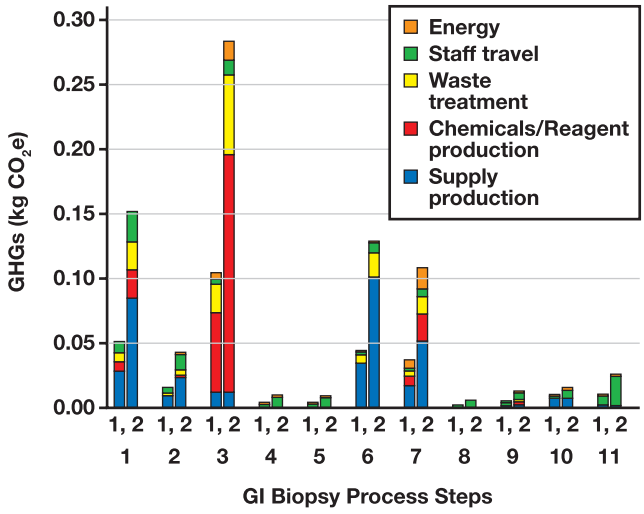

Figure 2 Greenhouse gas (GHG) emissions from gastrointestinal (GI) biopsy by process step (1-11) and by 2 approaches. Scenario 1 uses one biopsy jar; scenario 2 uses 3 biopsy jars.

Discussion

The surgical pathology laboratory is a complex environment that utilizes a variety of supplies, reagents, and equipment. This study mapped the biopsy process, logged resources used (inputs) and their end-of-life processes (outputs), and quantified the life cycle GHGs for 2 scenarios. Processing a single GI biopsy, whether in a single jar or in 3 jars, generated a relatively small amount of CO_2e. However, given that 20 million biopsies are performed in US clinical laboratories annually,[42] if all were processed in a manner similar to those at this study's location, they would generate nearly 5,600 metric tons of CO_2e in scenario 1 or 15,750 metric tons of CO_2e in scenario 2. These amounts are equivalent to 1,200 and 3,400 passenger cars on the road each year, respectively.[50] Given these results, we outline options for improving the environmental performance of clinical biopsies based on the principles of reduce, reuse, and recycle.

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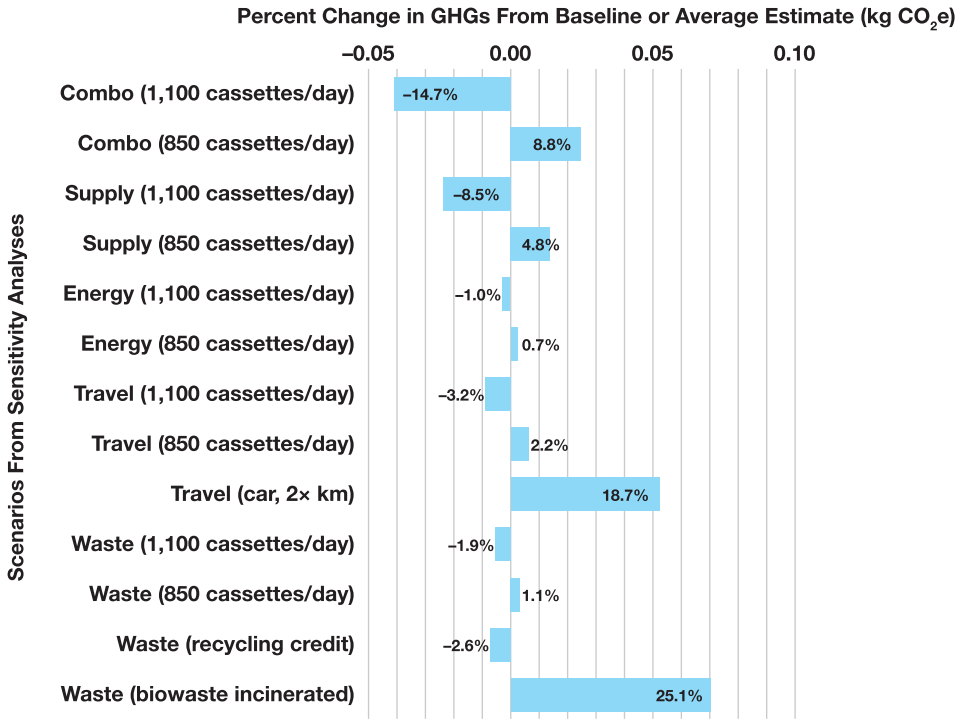

Figure 3 Greenhouse gas (GHG) emissions from alternative assumptions for the gastrointestinal biopsy process. "Low volume" assumes 850 cases handled daily, and "high volume" assumes 1,100 cases daily (with 3 jars and same daily average resource use for both). "Combo" aggregates all low-volume and high estimates.

Sampling Scenarios From Colonoscopic Surveillance Guidelines

The decision to place biopsy tissue into one or multiple jars depends on many factors and is not clearly defined for all types of biopsies. Even given a single jar of biopsy tissue, there are no broad guidelines as to how much tissue should go in each cassette—an aspect of biopsy processing that we did not address in this study. Our scenario 1 would be equivalent to putting all biopsy tissue in a single jar, which is processed into a single cassette and, subsequently, a single slide.

Our findings could have implications for the routine surveillance of chronic disease, such as dysplasia surveillance in patients with inflammatory bowel disease. Guidelines discuss the cost of performing random colon biopsies,[51] the number of biopsies, and the location interval (ie, 4 biopsies taken every 10 cm)[52] but do not discuss details about tissue placement into jars. An earlier technical review recommends placing biopsy tissue from each anatomic section of colon in separate jars so as to better localize incidental flat dysplasia.[53] At a patient's first surveillance colonoscopy, separate jars will help to determine the extent of disease, which has an impact on the prognostic risk of developing colorectal cancer.[52,53] In addition, at the initial and subsequent surveillance, determining whether a flat dysplasia is unifocal or multifocal would influence the decision to undergo colectomy, and isolating the anatomic sections in different jars is preferred over a single jar to localize disease. Multiple positive biopsy fragments in a single jar may represent multifocal disease or a larger affected single area, which is insufficient to guide clinical management.[52] Extrapolating our findings would indicate that placing biopsies into separate jars corresponding to anatomic segment (3-4 jars), rather than at 10-cm intervals (8-10 jars), would result in fewer GHG emissions while preserving the clinical utility and intent of inflammatory bowel disease surveillance.

These findings could also be applied to patients with multiple colonic polyps. The current surveillance guidelines do not discuss placement of polyp tissue into specimen jars.[54] Factors influencing whether any individual polyp is placed separately in its own jar include individual polyp size and total polyp burden. Based on the recommendations, it is reasonable that small polyps less than 10 mm, especially from the distal colon, can be placed together in a single jar, which would have fewer GHG emissions than using a separate jar for each one.

Responsible Laboratory Test Ordering

Clinicians should review policies and encourage appropriate ordering of laboratory testing. A 2014 survey of general internal medicine physicians found that 14.7% of

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the time that physicians order laboratory tests, they have uncertainty about the tests being ordered.[55] Respondents reported infrequent consultation with laboratory professionals regarding test ordering, but when interactions occurred, respondents reported that they provided value.[55] Consequently, laboratory professionals should engage with their clinical counterparts to encourage appropriate ordering of laboratory testing. In 2012, the American Board of Internal Medicine Foundation created the Choosing Wisely campaign, a partnership with more than 50 medical subspecialty societies, to identify overused tests and procedures that did not substantially improve the quality of a patient's care, with a consideration for responsible health care resource management.[56] However, responsible ordering of laboratory tests cannot be fully defined without an understanding of the environmental impacts, and there is presently an opportunity within Choosing Wisely to add recommendations to address environmental emissions, resource conservation, and environmentally and socially preferable practices.[57] Consideration should be given to specific recommendations regarding unnecessary biopsies and associated use of resources.

Greening Lab Processes: Equipment, Supplies, and Reagents

Although technological alternatives may exist, such as light-sheet microscopy,[58-60] traditional laboratory processing of biopsies will continue to be necessary for the foreseeable future. Efforts should be made to increase current laboratory resource efficiency, such as through the application of basic principles already familiar to laboratories, including the Deming cycle of plan-do-check-act and other continuous improvement processes.[61,62] Laboratories may consider pursuing certification in the ISO 14000 Environmental Standard to systematically approach identification and mitigation of the environmental impacts of their processes.[63] From an operational perspective, clinical laboratories are similar to research laboratories, in that they have a similarly energy-intensive equipment load, use chemicals and reagents, use disposable products, and generate hazardous and/or biohazardous waste. The sustainable laboratory movement is being led by nonprofit organizations such as the International Institute for Sustainable Laboratories and My Green Lab (MGL). Many activities promoted for research laboratories can be adapted for clinical laboratories, although this concept is emerging.[64] Although a comprehensive discussion of sustainability solutions is beyond the scope of this paper, MGL offers comprehensive laboratory sustainability solutions in addition to those described.

McAlister et al[41] performed an LCA of the carbon footprint of 5 routine clinical pathology blood tests and found that emissions stemming from reagent use and single-use items involved in receiving and collecting the specimen are the largest contributors to per-test GHG emissions, similar to our findings for biopsies. Whereas purchasing environmentally friendly products for an office setting is a fairly established practice, finding suitable products in the laboratory setting has been a challenge for those hospitals and laboratories that have begun to adopt green purchasing practices. In 2017, MGL launched the Accountability, Consistency, Transparency (ACT) label, an independently verified environmental nutrition label suitable for all products and equipment used in laboratories.[65] Adoption of the ACT label will be a key driver to fundamentally change the way laboratory products and equipment contribute to a laboratory's environmental impact.

Energy

Ni et al[40] reported on modeling the carbon footprint from a clinical laboratory in the United Kingdom. At the building level, they found that the HVAC and lighting systems were major contributors to electricity consumption. They also found that turning off an amino acid analyzer instrument when not in use results in a savings of 30% of the CO_2 equivalents. Consequently, because the CO_2 equivalent is strongly related to electricity consumption, the authors identified that at both the building and instrument levels, reducing electricity consumption had the greatest impact on the carbon footprint of their laboratory.[40] Similar findings were reported in other health care settings.[66,67] In our study, energy was not a major contributor to per-case GHGs. This may be because we were unable to measure primary space heating, the sources of energy have different carbon factors,[68] or our scope was a single biopsy rather than the entire laboratory, which could change the relative contributions of energy inputs compared with the use of reagents and supplies. Regardless, energy efficiency and decarbonizing electric grids are promoted as effective methods to reduce the overall footprint of medical activities.[11,57,69]

Recycling

There is much interest in recycling in laboratories and in the health care sector in general.[70] The Healthcare Plastics Recycling Council, a technical coalition supporting the broader adoption of clinical plastics recycling programs, is an example of establishing communication and collaboration between health care organizations and health care product manufacturers to address barriers to and opportunities for recycling of clinical plastics.

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Recycling requires transportation and processing energy, and with recent changes in trade agreements, many products diverted for recycling are ultimately sent to landfills. In LCAs, to complete the closed loop of recycling, it is best practice to assign the credit to the entity using recycled content in their product rather than the entity diverting the product into the recycling stream. Indeed, the corollary would be that laboratories should aim to purchase products with recycled content, which typically is allowed only in packaging of products used in the patient care setting.[71] Given the reality of marginal gains from recycling, health care institutions should consider prioritizing reduction, reuse, and remanufacturing while supporting recycling programs as a strong employee-engagement tool.

Study Limitations

This study was conducted at a high-volume surgical pathology laboratory, and some of the process steps may not be applicable in smaller settings. Staining and coverslipping of slides, for example, may be done by hand rather than on a slide stainer and a separate coverslipping machine. Specific equipment with variations in energy consumption and reagent volumes and specific tools and supplies used throughout the process may vary across laboratories. In addition, many components of the process are not standardized and are left to the preference of the histotechnologist or laboratory manager, such as frequency of changing water baths or quantity of ice used to set the block on to prepare for cutting. Adjustments in these areas would result in different per-case amounts of staff time, powered equipment time, and reagent quantities, which would affect the estimated GHGs. As with most clinical spaces, the laboratory's energy use is not submetered. The energy allocation utilized in this study is our best attempt to assign the laboratory's annual energy consumption to a single biopsy. Submetering of the laboratory's HVAC system and electricity consumption would improve accuracy.

Conclusions

Understanding the quantities and sources of GHG emissions stemming from tissue biopsy processing can help identify and prioritize opportunities for reducing laboratory pollution. Emissions were relatively small on a per-case scale; however, collectively, they may be significant and should not be ignored. Future research should seek to clarify optimal utilization of resources. Reducing the carbon footprint of a pathology laboratory is a multifaceted process that can be achieved.

Corresponding Author: Ilyssa O. Gordon, MD, PhD; gordoni@ccf.org.

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