GYNECOLOGY

A comparative carbon footprint analysis of disposable and reusable vaginal specula

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BACKGROUND: Healthcare systems in the United States have increasingly turned toward the use of disposable medical equipment in an attempt to save time, lower costs, and reduce the transmission of infections. However, the use of disposable instruments is associated with increased solid waste production and may have negative impacts on the environment, such as increased greenhouse gas emissions.

OBJECTIVE: The purpose of this study was to inform this discussion; we applied life cycle assessment methods to evaluate the carbon footprints of 3 vaginal specula: a single-use acrylic model and 2 reusable stainless steel models.

STUDY DESIGN: The functional unit of the study was defined as the completion of 20 gynecologic examinations by either type of speculum. The greenhouse gas emissions (eg, carbon dioxide, methane, nitrous oxide) across all life cycle stages, which includes material production and manufacturing, transportation, use and reprocessing, and end-of-life, were analyzed with the use of SimaPro life cycle assessment software and converted into carbon dioxide equivalents.

RESULTS: The reusable stainless steel grade 304 speculum was found to have a lesser carbon footprint over multiple model scenarios (different reprocessing techniques, autoclave loading/efficiency, and number of uses) than either the reusable stainless steel grade 316 or the disposable acrylic specula. The material production and manufacturing phase contributed most heavily to the total life cycle carbon footprint of the acrylic speculum, whereas the use and reprocessing phase contributed most to the carbon footprints of both stainless steel specula.

CONCLUSION: The use of disposable vaginal specula is associated with increased greenhouse gas equivalents compared with reusable alternatives with no significant difference in clinical utility. These findings can be used to inform decision-making by healthcare systems, because they weigh a wide range of considerations in making final purchase decisions; similar analytic methods can and should be applied to other components of health systems' waste streams.

Key words: carbon footprint, disposable, life cycle assessment, reprocessing, reusable, speculum, sterilization

Healthcare in the United States represents a substantial portion of our economy, valued at $2570 billion in 2015[1] and is associated with 655 megatons of CO_2 equivalents (CO_{2e}; 9.8% of the United States total) in 2013.[2] In addition to climbing costs, healthcare facilities are facing the monumental challenge of controlling rising levels of multidrug–resistant infections. To address increased costs and infections, many facilities have increased their use of disposable materials, which typically have decreased upfront costs compared with their reusable alternatives.[3] This shift has further contributed to growing waste production; in 2007, the US healthcare sector produced 4 billion pounds of waste.[4] The factors that contribute to the selection of medical devices include patient safety, clinical efficacy, ease of use, and cost. However, accounting for the environmental impacts of the device across its life cycle (such as increased greenhouse gas emissions, air and water pollution, and solid waste production) should also be included in these decisions, because they represent hidden or externality costs that impact the natural environment and public health.

The vaginal speculum is a ubiquitous instrument in healthcare that is used in primary care and obstetrics/gynecology settings for general examinations and surgical and diagnostic procedures. It is unique among medical devices in that, depending on the clinical situation, it can be reprocessed with either high-level disinfectants (such as hydrogen peroxide and glutaraldehyde) or steam sterilization.[5] Disposable and reusable specula differ in production requirements, materials, and need for reprocessing; these differences result in variations in carbon footprint over their lifetime.

Life cycle assessment (LCA) can be used to analyze the environmental and human health impacts of a product across its life cycle with the use of a "cradle to grave" approach.[6] Although still relatively uncommon, the use of LCA is increasing in health-related research,[7–11] providing valuable information regarding the impacts of healthcare practices beyond the clinic setting. This study applied a LCA framework and approach to evaluate the carbon footprints of reusable stainless steel vaginal specula and single-use acrylic vaginal specula by quantifying the materials, energy, and the associated greenhouse gas emissions at each stage of the speculum life cycle: production, transportation, use, reprocessing, and disposal.

Materials and Methods

We completed a carbon footprint analysis of 3 speculum models that were chosen from a convenience sample of specula currently in use at the Michigan Medicine hospitals and clinics. The specific specula that were studied included the Welch Allyn KleenSpec Disposable Vaginal Specula (Welch Allyn, Skaneateles Falls, NY), the Sklar Merit stainless steel grade 304 Graves

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AJOG at a Glance

Why was this study conducted?

The purpose of this study was to determine the CO_2 emissions that are associated with the production, use, and disposal of 3 types of vaginal specula that are used commonly in practice.

Key findings

Reusable stainless steel specula have a lesser carbon footprint compared with their disposable plastic alternatives.

What does this add to what is known?

This study lends support to the supposition that disposable medical equipment items have a more negative impact on the environment than reusable alternatives.

and Pederson vaginal specula (Sklar Surgical Instruments, West Chester, PA), and a surgical grade (stainless steel grade 316) specula comparable with the Sklar model.[12] The grade 316 stainless steel contains a higher percentage of molybdenum, which makes it more resistant to corrosion and thus likely to last for a longer period of time than grade 304 steel, although there are no current recommendations regarding the appropriate service life. No coatings or other grades of stainless steel were considered. The scope of our analysis (Figure 1) includes extraction of material and energy resources, manufacturing, transport between various sites in the production process and to the hospital, reprocessing, and disposal at end of life. Possible reprocessing options included autoclaving for sterilization or high-level disinfection with hydrogen peroxide.[11] There were no life cycle data available on other high-level disinfectants, such as glutaraldehyde or ortho-phthalaldehyde, so these were excluded from the scope of this study.

In the life cycle assessment, the basis of comparison is called the "functional unit." For this study, the functional unit of both disposable and reusable specula was defined as the completion of 20 gynecologic examinations by each type of instrument. The LCA software package (SimaPro 8.5.2; PRé Sustainability, Amersfoort, The Netherlands) was used to conduct the majority of the analysis.[13] The databases used include Ecoinvent 2.2,[14] IDEMAT,[15] GREET,[16] and WARM.[17] Total carbon footprint was assessed as kilograms of CO_{2e} released, which is a common measure of global warming potential impact.[18]

Modeling

Production phase

Manufacturer data were obtained regarding speculum and packaging composition and weight (Table 1). If the material was unknown, assumptions were made based on relevant literature[7]; more detailed information from suppliers would allow for a more accurate analysis. Materials that were excluded from the analysis were inks, bulk packaging, autoclave production, illumination pack for plastic specula, and lubrication; these were expected to have minimal impacts on the final results. No specific data were available from manufacturers regarding production of the specula; injection molding was assumed for the acrylic specula and a combination of hot extrusion, milling/turning, deformation, and heat treatment was assumed for the stainless steel specula, based on relevant literature.[19]

Transportation

Based on manufacturer and general industry data,[20] the acrylic resin that is required to make the disposable specula was assumed to be made in China, from where it was likely to be transported by container ship to Los Angeles, CA, and from there by truck to Skaneateles Falls, NY, where it would be processed to form specula. These specula were then likely shipped from New York to Ann Arbor, MI, by truck, given that 70% of shipments in United States are made by truck,[21] The stainless steel specula were manufactured in Germany with iron that was mined in France, Belgium, and Italy.[22] All transportation within Europe was assumed to be by rail.[22] The finished specula were assumed to be transported via container ship to Philadelphia, PA, then driven by truck to the distribution center in West Chester, PA, and from there to Ann Arbor, MI. Transport of other materials (sterilization packs, high-level disinfectants, or autoclaves) was not included in this analysis.

Use phase/disposal

Reusable and disposable specula were assumed to have equal clinical efficacy. When the disposable specula were entered into use at Michigan Medicine ambulatory clinics, they were removed from original packaging, used for a gynecologic examination or procedure, and then were disposed of, along with packaging, in general waste. Reusable specula were removed from original packaging, sterilization pack, or nonsterile container (depending on clinical need), used for an examination or procedure, and put aside for reprocessing with either high-level disinfectants or sterilization via autoclave; any associated packaging was discarded in general waste.

Before being reprocessed, reusable specula are rinsed or cleaned to remove gross debris. For high-level disinfection, specula were then completely submerged in a 7.25% hydrogen peroxide solution for at least 8 minutes and then rinsed with water before storage. For autoclave sterilization, specula were placed in a heat seal pouch, which is made made of polypropylene and kraft paper, then into the Midmark M11 autoclave (Midmark, Dayton, OH).[23] Manufacturer specifications for pouch setting indicate a maximum power consumption of 1425—1500 W for a 5-minute 270F steam sterilization plus a 30-minute drying cycle. Total kilowatt hours requirements per cycle were assumed to be 0.83125—0.875 kilowatt hours, although this is likely to be an overestimation because the sterilization, likely the most energy intensive step, only lasts 5 of the 35-minute total cycle. The autoclave typically was run with an assortment of pouched instruments, but loading varied significantly.[23] Both grade 304 and grade 316 specula were assumed to be reused over a range of uses (10−500), as tested by sensitivity analysis.

Waste management after disposal was modeled with the use of the EPA WARM model, which estimates the average greenhouse emissions that are associated with the disposal of various materials, such as plastics and metals, in the United States.[17]

Alternate assumptions

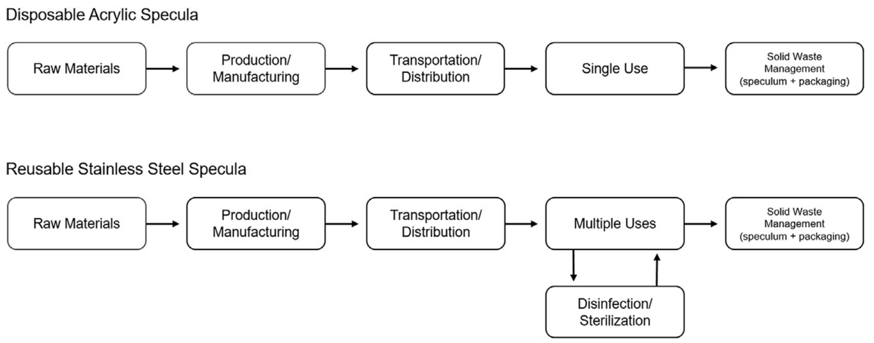
Sensitivity analyses were conducted to better elucidate the influence of key model parameters on the carbon footprints of these products. Alternative model parameters include changes in autoclave loading practices and the number of reuses of the surgical grade specula before disposal. Efficiency of autoclave sterilization was also modeled with the use of the GREET database (Argonne National Laboratory, Argonne, IL) on the carbon intensity of different electricity grids throughout the Untied States.[16]

Results

The CO_2 equivalent emissions of the disposable and reusable specula are shown in Table 2; the base case that is listed is 20 examinations that were completed by a stainless steel speculum that had been sterilized in a half-loaded autoclave run on the ReliabilityFirst Corporation grid (the grid of Michigan Medicine). Overall, both types of reusable specula had more favorable CO_2e emission profiles than the disposable acrylic speculum. As demonstrated in Figure 2, the grade 304 speculum produces fewer life cycle CO_2e emissions than the equivalent number of acrylic specula after 2 completed examinations (2.11 kg $CO_2e<2.63$); the grade 316, after 3 completed examinations (3.11 kg $CO_2e<3.51$). Because the grade 304 speculum is less carbon intensive to produce than the grade 316 speculum, its total life cycle CO_{2e} emissions remain less than that of the grade 316 speculum over a wide range of uses (Table 2), provided that the grade 304 speculum does not need to be replaced earlier than the grade 316 speculum to complete the same number of examinations. If the number of completed examinations extends to 500, the difference between the 3 speculum options becomes more apparent (316−107.52, 304−101.31, acrylic−438.55 kg CO_2e), with the difference between the grade 316 speculum and the equivalent acrylic specula becoming approximately equivalent to burning 37.97 gallons of gasoline.[24]

The stages within the speculum life cycle that contribute to these emissions differ between the disposable and reusable alternatives (Figure 3). The largest source of CO_2e emissions for the disposable acrylic speculum is material production and manufacturing (90.6%) followed by transportation (6.5%), and waste/end-of-life (2.9%). The largest source of CO_2e emissions for the grade 304 speculum is use/reprocessing (74.1%) followed by material production and manufacturing (24.9%) and transportation (0.46%). For the grade 316 speculum, use/reprocessing represented 65.2% of its total life cycle emissions with production and transportation representing 34.4% and 0.4%, respectively. Most of the life cycle impacts of the acrylic speculum are intrinsic to the material used, thus limiting opportunities to decrease the carbon footprint. For the steel specula,

FIGURE 1
Life cycle system boundaries



The diagram details the aspects of the speculum life cycle that is included in this analysis, which includes production, manufacturing, use, and disposal.

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TABLE 1
Speculum composition data

Material	Product	Weight, g
Acrylic	Disposable speculum	88.28
Stainless steel grade 304	Reusable speculum	145.2
Stainless steel grade 316	Reusable speculum	145.2
Kraft paper	Sterilization pack	4.18
Polypropylene	Sterilization pack	3.49
Polyvinyl-chloride	Packaging for disposable speculum	6.13
Hydrogen peroxide	High-level disinfectant	104.4

Weights of speculum body represent averages of 3 sizes (small, medium, large) and 2 styles (Graves and Pederson vaginal specula [Sklar Surgical Instruments, West Chester, PA]).

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TABLE 2
Results of sensitivity analysis

Assumption	Steel grade, kg CO_2 equivalents 316	304	Acrylic
Examinations completed			
1	2.48	1.69	0.88
10	4.39	3.60	8.77
20 (base case)	6.51	5.72	17.54
50	12.87	12.08	43.86
100	23.47	22.69	87.72
500	107.52	101.31	438.55
Autoclave loading practices			
4 Pouches (base case)	6.51	5.72	NA
1 Pouch	14.29	12.53	NA
8 Pouches (full load)	5.21	4.58	NA
Selected regional electricity grids			
ReliabilityFirst Corporation (base case)	6.51	5.72	NA
Hawaiian Islands Coordinating Council	7.96	7.17	NA
Northeast Power Coordinating Council	5.12	4.33	NA
Texas Regional Entity	6.34	5.56	NA
Western Electricity Coordinating Council	5.67	4.88	NA
Reprocessing method			
Autoclave (base case)	6.51	5.72	NA
H_2O_2 (7.25%)	7.28	6.49	NA

Base case: 20 examinations that were completed by a stainless steel speculum that had been sterilized in a half-loaded autoclave run on the ReliabilityFirst Corporation grid, which includes Michigan, Wisconsin, Illinois, Indiana, Ohio, West Virginia, Pennsylvania, Maryland, Delaware, and New Jersey. The Hawaiian Islands Coordinating Council grid includes Hawaii. The Northeast Power Coordinating Council grid includes New York, Massachusetts, Rhode Island, Connecticut, New Hampshire, Vermont, and Maine. Texas Regional Entity grid includes parts of Texas. Western Electricity Coordinating Council grid includes Washington, Oregon, California, Idaho, Nevada, Montana, Colorado, Utah, New Mexico, and Wyoming.

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where the electricity that is needed to power autoclaves makes up the majority of the footprint, there is the opportunity to reduce emissions with increased electricity efficiency and transition of the local electric grid to more renewable energy sources.

Table 2 also shows the results for our sensitivity analysis. The impact of changes in the autoclave loading practice was significant when shifting to individually sterilizing the specula (an increase in 189—219% above the base case); however, the impact was not as great between a half-full and completely loaded autoclave (20—39% decrease in greenhouse gas emissions). The carbon intensity of the local electricity grid also did not have a substantial effect on overall emissions over 20 reuses of a speculum; the difference between the most carbon intensive grid (NPCC) and least carbon intensive grid (HICC) resulted only in a 33—36% reduction in total CO_2e emissions. Regardless of the grid, the life cycle greenhouse gas emissions of either steel option were lower than the equivalent acrylic specula. The use of a high-level disinfectant, such hydrogen peroxide instead of autoclave sterilization, resulted in a 11—12% increase in greenhouse gas emissions.

Comment

Principal findings and results

The results of this study suggest that the reusable speculum, regardless of steel grade, has a lower total life cycle carbon footprint in comparison with the disposable acrylic speculum. This result remains robust across multiple different clinical and reprocessing scenarios.

Strengths and limitations

To complete this analysis, multiple assumptions regarding the production and reprocessing of the specula were made. Although manufacturers were able to provide general information regarding the composition and site of manufacture of their products, exact details of the production process often had to be supplemented by other sources.[7,20,22] When assumptions had to be made, the authors tended to choose a more carbon-intensive approach to the steel specula and a less carbon-intensive approach to the acrylic to ensure that any difference shown between them would be robust. Such potential inaccuracies could be ameliorated by working more closely with manufacturers to discover the details that are unique specifically to the process of making and transporting specula. Of note, there is no standard for surgical stainless steel; this term can be applied to any corrosion-resistant steel, although grades 316 and 420 are the most commonly used alloys for this application.[12,25,26] Our study was further limited by the lack of specific life cycle data on common high-level disinfectants such as glutaraldehyde, ortho-phthalaldehyde, and peracetic acid.

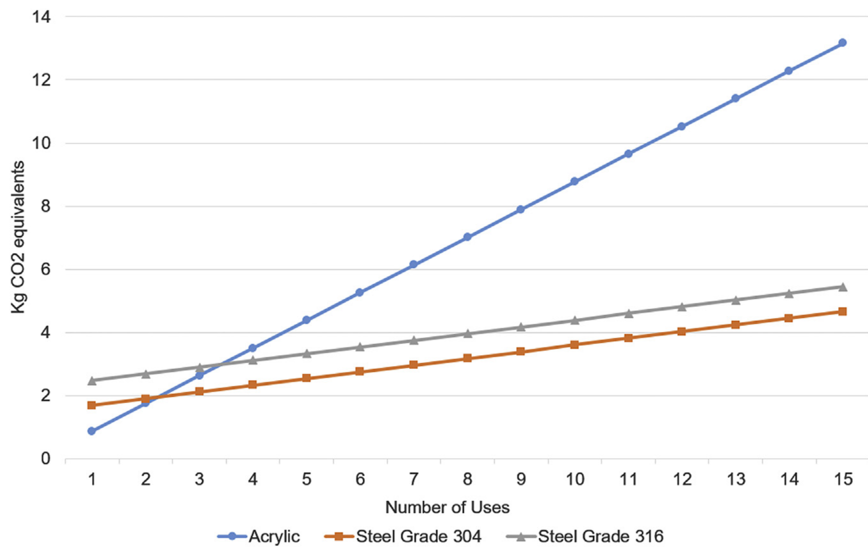
Research implications

Because our study was limited in scope to 3 models, many variations in the make of specula could also be analyzed. For example, many steel specula are made more corrosion resistant by the addition of a protective chemical coating, and most acrylic specula are produced either with an internal LED light source built in or with the option of a reusable LED light pack that can be inserted as needed. All of these alterations would be expected to change the total life cycle carbon footprint of these products, thus more research should be done on this issue to be able to make more generalized comparisons between all vaginal specula. Although an economic input-output LCA approach[27] could be used to estimate the impacts of products with the use of purchaser price data, this approach is designed to examine carbon footprint of the scale of economic subsectors and thus would be less accurate when attributed to a single compound. Further LCA studies within medicine should include high-level disinfectants such as glutaraldehyde, ortho-phthalaldehyde, and hydrogen peroxide, which already have been associated with acute eye and upper airway irritation, dermatitis, bronchitis, and worsening asthma.[28–31] Additionally, most healthcare systems use and reprocess metal tools, including specula, indefinitely until there are signs of wear or damage and do not track how often a tool is used before it is retired. Future studies could investigate how often specula are used before disposal to determine if the additional corrosion resistance of the grade 316 speculum confers any advantage over the grade 304 speculum in regards to reusability and thus total life cycle CO_2e emissions.

Clinical implications

Although reusable specula present the more environmentally sound choice of instrument, there are potential risks associated with reusing instruments with different patients, namely that of infection transmission. To date, there has been no report of iatrogenic infection from a contaminated speculum. However, a recent study has shown that, even after steam sterilization, multiple discarded stainless steel surgical instruments retained microscopic soil and biofilms, despite testing culture negative; a stainless steel grade for these instruments was not reported.[32] Other studies have shown that alternative reprocessing practices (soaking in water rather than alcohol before sterilization, thermal cycling of high risk instruments) may reduce this risk.[33,34] A major concern for the retention of proteinaceous compounds on instruments is the risk of transmitting human papillomavirus, which is a major cause of cervical neoplasia worldwide. Recent studies have shown that human papillomavirus serotypes 16 and 18 were resistant to some commonly used high-level disinfectants, specifically glutaraldehyde and ortho-phthalaldehyde, when used on endocavitary ultrasound probes.[35] However, disinfection with

FIGURE 2
Total life cycle carbon footprint by speculum type



For data for the stainless steel specula, we assume sterilization in a half-loaded autoclave run on the ReliabilityFirst Corporation grid.

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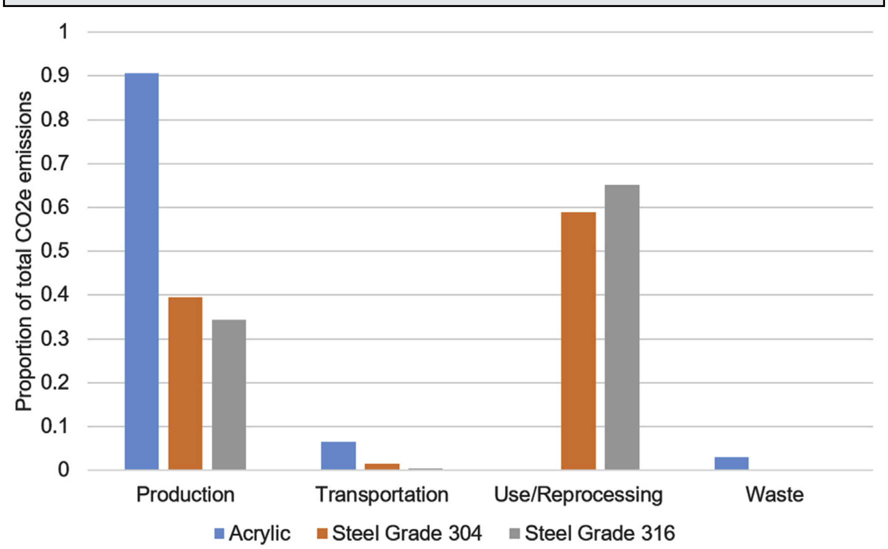
FIGURE 3
Life cycle stage impacts by speculum type



The results are based on functional unit of 20 examinations that were completed by each speculum type.

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hydrogen peroxide and sterilization by autoclave or ultraviolet C radiation were both found to be effective in reducing the amount of human papillomavirus on instruments to undetectable levels.[36–38]

Given the results of this study, strategies for the improvement for health systems that seek to reduce the carbon footprint of their specula include (1) adopting more reusable alternatives in clinical situations in which the risk of infection transmission, despite sterilization, is low, especially alternatives made of corrosion resistant grades such as 316; (2) sourcing lower carbon electricity to further reduce the impact of the reprocessing stage of the reusable specula, and (3) opting to sterilize instruments via autoclave rather than disinfection via chemicals such as hydrogen peroxide. Hospitals may also consider partnering with manufacturers to develop practices for the safe recycling of stainless steel instruments. Steel is an exceptionally recyclable material; however, there are few systems currently in place for recycling steel medical instruments. Manufacturers of acrylic specula may also consider developing reusable models to reduce the carbon footprint of their product.

Conclusions

Over a period of 1 year, Michigan Medicine used 5875 disposable acrylic specula, which produced emissions of 5153 kg CO_{2e} and 5462 kg of solid waste. If steel grade 304 or grade 316 specula (100 uses average) had been used to complete the same number of examinations, the greenhouse gas emissions would have been decreased by 75% and 74%, respectively, with a significant decline in end-of-life solid waste generation as well (both 64.43 kg). As more institutions consider moving toward carbon neutrality, it is important to consider the energy costs that are hidden in the tools of our trade in addition to what is shown on our energy bills. To address the burden of plastic waste pollution and climate change, health systems might consider environmental impact in addition to cost and clinical efficacy when choosing medical instruments. ■

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