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Abstract

Covid-19 has led to an increase in the use of PPE, gowns, masks, sanitizers, air circulators, and much more, all contributing to an increase in medical waste (1). Waste generation is one issue. Emissions are another. The two are linked because waste and emissions are both indicators of consumption. However, waste is not the biggest driver of environmental emissions for healthcare. It is the production medical equipment, particularly disposables that have the bigger impact (2). Energy use during care, including heating and cooling our facilities, is another. Environmental emissions like Greenhouse Gases may not correlate with waste generation, especially if the waste is plastic. Carbon is stored in plastic. Unless you're burning plastic, you're not emitting carbon.
Healthcare has a waste issue and healthcare has an emissions issue. They are not necessarily the same thing, however the strategies to mitigate each overlap. Life cycle analysis quantifies emissions from the creation to disposal of medical supplies (3). This allows the medical community to make informed choices with respect to the methods and materials that are used in providing care. As other specialties take the lead in reducing their environmental footprint, so too, must orthopedic surgery (4,5,6).
Life Cycle Assessment

Life cycle assessment (LCA) is a tool used to estimate the environmental emissions of a product or process. Life cycle assessment has been used in healthcare and can give providers insight into those activities, such as, in an operating room that contribute the most to environmental emissions. (3, 7). According to the International Standards Organization (ISO) series 14040, has divided the life cycle assessment process into four phases (8).

Phase I. The researcher provides the reason for analysis, the tools for analysis, life cycle for each specific tool in question, boundaries for assessment, and an appropriate functional unit. A functional unit can be defined by a product’s performance over some defined reference point. For instance, a surgical instrument’s functional unit may be defined by how many patients it serves from its first to final use (3). Creating a flow chart provides a visual map that defines stages of the life cycle while simultaneously organizing project boundaries (7).

Phase II. Inventory analysis uses databases like Ecoinvent to evaluate the inputs and outputs of an object's life cycle. This includes the energy required for creation of product and the emissions that are expelled from the production of the product. This collection step is used to gather all of the data needed to make appropriate calculations based on the original purpose of the study (7).

Phase III. Impact assessment, uses impact categories such as, human toxicity, and global warming potential to calculate equivalents that are relevant to the study. These calculations are used to create a quantitative representation of the collected data in phase two (7).

Phase IV. The interpretation phase is the point at which data is compiled and analysed to draw conclusions. This stage is particularly important as it is the point at which variability and uncertainty are assessed via sensitivity analyses. This can provide a statistically supported assessment of which products are better than others, if you've done a comparative LCA. It also shows how hot spots in your system might change if certain input variables change (3, 7). This process can be tedious, strenuous, and expensive to obtain the most accurate data needed to give a thorough and accepted assessment. When data is accessible from prior research, it can be used to assess impacts of interest without having to fully conduct LCA.

Case Study: Steroid Injections

In our Hand and Upper Extremity practice, we employed LCA to examine the cost and carbon emissions associated with using a tissue, paper towels, or 4x4 gauze for steroid injections.
Common practice includes sterile preparation of the site with alcohol wipes, administering the injection, pressure applied with a cotton gauze, and application of an adhesive bandage.

We analysed the cost and applied data from prior Life Cycle Assessments for tissue, paper towels and cotton gauze. All of the items were assessed using process-based LCA, meaning all measurements were based on the inputs and outputs of each product's full life cycle (9, 10, 11). For the paper towel and cotton gauze, the original study analysed the financial and environmental costs of reusable and single-use plastic anesthetic drug trays, measuring the environmental impacts of both in grams of carbon dioxide. This study used Ecoinvent v2.1, Swiss Centre for Life Cycle Inventories, Zurich, Switzerland, an internationally recognized LCA database, to obtain the necessary data to measure the impact of both paper towels and cotton gauze provided on a single-use drug tray (10). For the tissue analysis, the original study discussed the environmental impacts of disposable facial tissues versus a reusable cotton handkerchief measuring the data in kilograms of carbon dioxide. This study used Ecoinvent 2.2 to obtain the necessary data required to measure the impact of tissues, to later compare it to the impact of handkerchiefs (11).

The calculated price per tissue, based on our established vendor $0.01 (Table 1). The price per paper towel was $0.03 (Table 1). The price for 4x4 gauze was $0.11 (Table 1).

Grams of carbon dioxide generated during the life cycle of each item were used as an equivalent unit in this study to observe the environmental impact of each item. One tissue generates 2.55 grams of CO2 (11). The amount of carbon dioxide produced by a paper towel is 5 grams (10). The grams of carbon dioxide generated by 1 4 X 4 gauze was 95.95 grams (10) (Table 1).

We examined the injection practices of two orthopedic hand surgeons for one month. Both surgeons used, at a minimum, an adhesive bandage in all instances. For every injection recorded, both surgeons documented whether they used a tissue, paper towel, 4x4 gauze, or band aid only. We multiplied both the price and grams of carbon dioxide of each item by the number of times each surgeon used them. We then summed the individual amounts for each item used to determine the total amount of money spent and grams of carbon dioxide expelled by each surgeon.
Results
Surgeon one used 4x4 gauze for 1.1% of the injections, a tissue for 12.5%, a paper towel for 3.4% of the injections, and an adhesive bandage only for 83.0% of injections. Surgeon one’s estimated annualized spending for pressure and dressing materials for each injection totaled $3.51. Carbon dioxide emission is estimated to be a total of 1,668 grams released into the environment (Table 2).
Surgeon two used 4x4 gauze for 96% of injections and an adhesive bandage alone in 4%.
Surgeon two spent 17.79 times more than surgeon one, with disposable costs of $62.44. Those same disposables cost the environment 33.13 times more than surgeon one by releasing 55,267.2 grams of carbon dioxide per year into the environment (Table 2).

Discussion
The estimated number of injections done by all orthopedic surgeons in our Healthcare system in Pittsburgh is 153,039 injections per year. If all surgeons followed the protocol of surgeon one, the hospital would spend a total of $509.28 per year on pressure dressing disposables for injections. This would be 31.27 times less than if injections were done using more traditional practices, such as those employed by surgeon two. The savings to the system would be over $15,000 and would conserve over 8,000,000 grams of carbon dioxide per year (Table 3). The cost savings both environmentally and economically reaches substantial levels when broadened regionally, nationally, and internationally. This study exposes the significant cost and environmental impact of a simple, widely applied clinical procedure while simultaneously offering a reasonable and safe alternative.

Summary
Life cycle assessment is a powerful tool that gives us the data necessary to compare different options of how we conduct ourselves while providing care. Understanding and implementing this can help conserve financial resources and minimize the impact of our work on the environment.
Declaration of Competing Interest
No disclosures relevant to the context of this article.
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Table 1: Analysis of cost and environmental impact per unit tissue, paper towel, and gauze.

|               | Cost (in dollars) | Impact (in Grams of CO2) |
|---------------|-------------------|--------------------------|
| Tissues       | $0.01             | 2.55                     |
| Paper Towels  | $0.03             | 5                        |
| 4x4 Gauze     | $0.11             | 95.95                    |
Table 2: Comparison of the two surgeons cost per year and impact per year from the compiled research done.

| Surgeon   | Cost per Year (in dollars) | Impact per Year (in Grams of CO2) |
|-----------|----------------------------|-----------------------------------|
| Surgeon 1 | $3.51                      | 1,668                             |
| Surgeon 2 | $62.44                     | 55,267.2                          |
Table 3: The predicted values if all orthopedic surgeons in our system mimicked surgeon one versus surgeon two in the injection procedure.

|                      | Cost per Year (in dollars) | Impact per Year (in Grams of CO2) |
|----------------------|----------------------------|------------------------------------|
| Mimic Surgeon 1      | $509.28                    | 255,269,052                        |
| Mimic Surgeon 2      | $15,925.85                 | 8,458,037,020.8                    |