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Quantification of the Cost and Potential Environmental Effects of Unused Pharmaceutical Products in Cataract Surgery

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**IMPORTANCE** Pharmaceutical products, including unused portions, may contribute to financial and environmental costs in the United States. Because cataract surgery is performed millions of times each year in the United States and throughout the rest of the world, understanding these financial and environmental costs associated with cataract surgery is warranted.

**OBJECTIVE** To investigate the financial and environmental costs of unused pharmaceutical products after phacoemulsification surgery.

**DESIGN, SETTING, AND PARTICIPANTS** This descriptive qualitative study included 4 surgical sites in the northeastern United States (a private ambulatory care center, private tertiary care center, private outpatient center, and federally run medical center for veterans). Prices and data for use of services and pharmaceuticals were obtained for the tertiary care and outpatient centers from January 1 through April 30, 2016; for the ambulatory care center from June 1, 2017, through March 31, 2018; and the federal medical center from November 1, 2017, through February 28, 2018. Data were collected from routine phacoemulsification surgical procedures without vitreous loss or other complications. Volume or weight of medications remaining after surgery was measured. Total and mean costs of medications per case and month were calculated. Environmental effects were estimated using economic input-output life cycle assessment methods. Data were analyzed from December 1, 2017, through June 30, 2018.

**MAIN OUTCOMES AND MEASURES** Cost of unused pharmaceutical products (in US dollars) and kilogram equivalents of carbon emissions (carbon dioxide [CO₂-e]), air pollution (fine particulate matter emissions of ≤10 μm in diameter [PM₁₀-e]), and eutrophication potential (nitrogen [N-e]).

**RESULTS** A total of 116 unique drugs were surveyed among the 4 centers. Assuming unmeasured medications had no materials left unused, a cumulative mean 83 070 of 183 304 mL per month (45.3%) of pharmaceuticals were unused by weight or volume across all sites. Annual unused product cost estimates reached approximately $195 200 per site. A larger percentage of eyedrops (65.7% by volume) were unused compared with injections (24.8%) or systemic medications (59.9%). Monthly unused quantities at the ambulatory care center (65.9% by volume [54 971 of 83 440 mL]), tertiary care center (21.3% [17 143 of 80 344 mL]), federal medical center (38.5% [265 of 689 mL]), and outpatient center (56.8% [10 691 of 18 832 mL]) resulted in unnecessary potential emissions at each center of 2135, 2498, 418, and 711 kg CO₂-e/mo, respectively. Unnecessary potential air pollution between sites varied from 0.8 to 4.5 kg PM₁₀-e/mo, and unnecessary eutrophication potential between sites varied from 0.07 to 0.42 kg N-e/mo.

**CONCLUSIONS AND RELEVANCE** This study suggests that unused pharmaceutical products during phacoemulsification result in relatively high financial and environmental costs. If these findings can be substantiated and shown to be generalizable in the United States or elsewhere, reducing these costs may be of value.

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The health care sector is a large contributor to financial waste, environmental waste, and climate change, with 1 study indicating that health care is responsible for 10% of United States greenhouse gas emissions. Because cataract surgery is performed millions of times every year in the United States and globally, this surgery provides an excellent model organism for studying the financial and environmental effects of our health care system and, in turn, for helping to derive ways to reduce the financial and environmental consequences of surgery.

Most of the environmental and financial effects of surgery are believed to be from procurement-related activities, including production and disposal of pharmaceuticals. A 2013 study in the United Kingdom found that more than 50% of carbon emissions in standard phacoemulsification surgery are associated with procurement. Further, the financial effects of pharmaceuticals in health care cannot be understated. In 2017, national health care expenditures in the United States reached $3.5 trillion, representing 17.9% of the nation’s gross domestic product ($19.39 trillion). Prescription drugs account for about 10% of the nation’s total health spending, amounting to $333.4 billion annually and being among the largest contributors to financial waste, environmental waste, and greenhouse gas (GHG) emissions. The goal of this study is to quantify the financial and environmental effects of unused pharmaceuticals in standard phacoemulsification cataract surgery to identify prospects for cost savings, waste reduction, and decreasing GHG emissions.

### Methods

In this preliminary study, we analyzed the unused quantities of pharmaceuticals after routine phacoemulsification cataract surgery at the following 4 facilities in the northeastern United States: a private faculty ambulatory care center, a private tertiary care center, a private outpatient center, and a federal medical center for veterans (Table 1). We measured the quantities of unused drugs, determined their monetary costs, and then calculated the environmental effects of these unused pharmaceuticals. To measure the quantities of pharmaceuticals left unused after each case, a member of the study team (C.L.T. for the tertiary care and outpatient centers; J.T., I.C., D.K., and M.R. for the ambulatory care and federal medical center) attended at least 10 routine cataract procedures at each institution. Surgery was considered routine if phacoemulsification was used and an artificial intraocular lens was implanted without any vitreous loss or other complications. At the end of each case, direct observation and digital scales (accurate to 0.1 g) were used to measure the remaining volume (in milliliters) or weight (in kilograms) of each available medication, excluding the packaging weight. Data were collected at the tertiary care and outpatient centers from January 1 through April 30, 2016; the ambulatory care center from June 1, 2017, through March 31, 2018; and the federal medical center from November 1, 2017, through February 28, 2018. Any drugs we could not measure (for example, drugs used in only 1 or 2 cases in a month) were assumed to be completely used in surgery, meaning we conservatively underestimated the amount of unused pharmaceuticals at each location. All sites’ institutional review boards granted exemption because this research was deemed not to involve human participants.

Drugs were categorized into 1 of the following 3 groups based on their pharmacologic use in cataract surgery: eye drops, ocular injection, or systemic medication. Eye drops included all medications with a topical ocular route of delivery, such as proparacaine hydrochloride, tropicamide, and phenylephrine hydrochloride. At the 4 centers, vials of eyedrops were single use only, and owing to facility policies, physicians were not permitted to send them home with patients after surgery. Ocular injections included any substances administered directly into the anterior chamber or globe, including balanced salt solution, sodium hyaluronate, and lidocaine hydrochloride. Systemic medications included those that may be

### Table 1. Cases and Drug Use at 4 Case Sites

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Ambulatory Care Center</th>
<th>Tertiary Care Center</th>
<th>Outpatient Center</th>
<th>Federal Medical Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean No. of cases per month</td>
<td>73</td>
<td>102</td>
<td>112</td>
<td>21</td>
</tr>
<tr>
<td>Mean No. of drugs used per month</td>
<td>1689</td>
<td>2037</td>
<td>1967</td>
<td>NA</td>
</tr>
<tr>
<td>Drugs surveyed, No. (%)</td>
<td>981 (58.1)</td>
<td>1128 (55.4)</td>
<td>1212 (61.6)</td>
<td>NA</td>
</tr>
<tr>
<td>No. of unique drugs per month</td>
<td>46</td>
<td>60</td>
<td>53</td>
<td>23</td>
</tr>
<tr>
<td>Unique drugs surveyed, No. (%)</td>
<td>20 (43.5)</td>
<td>42 (70.0)</td>
<td>44 (8.03)</td>
<td>10 (43.5)</td>
</tr>
</tbody>
</table>

Abbreviation: NA, not applicable.
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Being intravenously or orally and are frequently dosed by anesthesiologists, including succinylcholine chloride, fentanyl, dextrose, and ibuprofen.

Using the institutions’ financial records, we recorded the use of each pharmaceutical in a 1-month period and the price paid by the facility for each in US dollars. These data for the tertiary care and outpatient centers were from April 2014, and for the ambulatory care center were from June 2017. Because the federal medical center does not bill patients individually, its monthly use and financial records could not be obtained at an individual case level. Instead, we recorded which drugs we observed being used in individual cases, and the pharmacy reported the prices paid for those drugs. These prices were reported in December 2017.

We used descriptive statistics to determine the mean unused quantity of each pharmaceutical; however, because of the limited data points for several drugs at each facility, we do not report confidence intervals on the aggregated estimates of unused pharmaceuticals. The costs of unused drugs were determined by multiplying the percentage of each unused drug by its cost. This result assumes that the total value of the drug is in the drug itself and not, for example, in its packaging. We did not include the costs of drug disposal for this particular study.

Environmental emissions from pharmaceutical production were estimated using the economic input-output life cycle assessment (EIO-LCA) model and a free online EIO-LCA tool from Carnegie Mellon University, Pittsburgh, Pennsylvania.9 Life cycle assessment is used to calculate the environmental emissions of a product or process throughout its life cycle from raw material extraction, manufacturing, use, and end of life. Its use is regulated by the International Organization for Standardization standard 14040:2006.10 Whereas process-based LCA uses the quantity of material to estimate environmental emissions from its life cycle, EIO-LCA uses economic input-output tables to assign environmental emissions (such as carbon emissions) to the dollar spent in specific economic sectors. The EIO-LCA model was chosen for this study because process-based LCA databases do not contain estimates of emissions for most pharmaceutical manufacturing. Because all pharmaceutical manufacturing is in a single economic sector, the EIO-LCA model limits our abilities to compare individual drugs but gives us a general estimate of the overall emissions created when any particular drug is manufactured. This method has been used in previous studies assessing the environmental footprint of medical systems.2,6,11-14

Because we collected the pharmaceutical prices paid by each institution, we used the purchaser price model in the EIO-LCA tool. The North American Industry Classification System sector 325412, pharmaceutical preparation manufacturing, was used,15 and all 2017 US dollar amounts were deflated to 2002 dollars, the year of the most recent US model in the EIO-LCA tool.9 This deflation used the US Bureau of Labor Services Producer Price Index tables.14,16

The US Environmental Protection Agency’s tool for the reduction and assessment of chemical and other environmental impacts (TRACI; version 2.1) was used for the impact assessment phase of this LCA, which sorts and combines environmental emissions into specific effects categories, such as global warming.17 Herein we report the emissions created from the manufacturing of unused pharmaceuticals. We report potential emissions contributing to climate change (also known as GHG emissions), criteria air pollutants, and eutrophication, although other important environmental emissions such as toxicity can also be calculated using the EIO-LCA model. Units for GHG emissions are kilogram equivalents of carbon dioxide (CO₂-e), signifying the equivalent global warming effect of carbon dioxide on a 100-year time scale. Air pollutants are reported in terms of kilogram equivalents of fine particulate matter emissions with a diameter of 10 μm or less (kg PM₁₀-e) and eutrophication, in kilogram equivalents of nitrogen (kg N-e).

We chose to consider unused pharmaceutical potential emissions in terms of CO₂-e, PM₁₀-e, and N-e because years of research have demonstrated that these measures can represent direct effects to global and individual health.18-44 Although the effects of these particular emissions have not been strongly associated with eye diseases, health care professionals are increasingly concerned about environmental pollutants, given the clear association with human health and the sizable footprint of the US health care sector.8,45,46 Because cataract surgery is one of the most frequently performed surgical procedures in the world, ophthalmologists are well situated to model efficient and environmentally conscientious surgical care.47,48

Results

Among the 4 centers included in the study, the ambulatory care center performed a mean of 73 cases/mo; the tertiary care center, 102 cases per month; the outpatient center, 112 cases per month; and the federal medical center, 21 cases/mo. Unused quantities of surveyed drugs ranged from 21.3% to 65.8% at all 4 centers. Owing to the financial records system of the federal medical center, we do not know how many individual doses were administered monthly or the monthly expenditures on pharmaceuticals; however, we found the costs of 23 unique drugs used during the surveillance period. Data about cases and drugs at each center are given in Table 1.

Quantity and Cost of Unused Pharmaceuticals

Assuming unmatched drugs were used completely, the money spent on unused drugs as a percentage of the total spent on all pharmaceuticals in cataract surgery ranged greatly across facilities from 16.0% to 60.2% (Table 2), and a cumulative mean of 83 070 of 183 304 mL per month (45.3%) of pharmaceuticals were unused by weight or volume across all sites. Of a total monthly cataract surgery pharmaceutical cost of $26 354, the ambulatory care center disposed of 65.8% (54 971 of 83 440 mL) of cataract surgical drugs by weight or volume during the surveillance period, representing $15 859 of unused pharmaceuticals, or $217 per case and approximately $190 300 per year. The tertiary care center disposed of 21.3% (17 143 of 80 344 mL) of drugs by weight, representing $16 268 (42.3%) of unused pharmaceuticals of $38 447 spent on cataract surgical drugs monthly, equating to $159 per case or approximately $195 200
per year. At the outpatient center, 56.8% (10 691 of 18 832 mL) of drugs by weight were thrown away after surgery, amounting to $4627 of the $28 992 (16.0%) spent on drugs monthly, or $41 per case and approximately $55 500 per year. At the federal medical center, 38.5% (265 of 689 mL) of cataract drugs were unused each month. The combined price (assuming 1 per case and 21 cases per month) was $15721 with $3079 (19.6%) being thrown away after surgery. This represents $148 per case or approximately $36 900 per year.

Unused quantities, expressed as a percentage of the total initial weight or volume of pharmaceuticals (not including containers), also varied by the type of drug, ranging from 24.8% for injections to 59.9% for systemic medications and 65.7% for eyedrops (Figure 1). When broken down by drug category, the greatest percentages of unused pharmaceuticals at the ambulatory care, tertiary care, and outpatient centers were in eyedrops (range, 42.5% to 78.8%), whereas the federal medical center left more injections unused (48.0%).

The Potential Carbon Footprint of Unused Pharmaceuticals

Potential emissions causing global warming (CO₂-e), air pollution (PM₁₀-e), and water eutrophication (N-e) were calculated at each center using financial data and unused pharmaceutical percentages (Table 3). Unnecessary potential GHG emissions from unused drugs varied from 418 kg CO₂-e/mo at the federal medical center to 711 kg CO₂-e/mo at the outpatient center, 2135 kg CO₂-e/mo at the ambulatory care center, and 2498 kg CO₂-e/mo at the tertiary care center (Figure 2). Unnecessary potential air pollutant emissions varied from 0.8 to 4.5 kg PM₁₀-e/mo, whereas water-polluting potential eutrophication emissions from unused drugs varied from 0.07 to 0.42 kg N-e/mo at each site. The largest absolute quantity of potential emissions in all 3 environmental categories originated from the tertiary care center because the potential emissions values are correlated with drug spending (Table 2).

These potential GHG emissions are equivalent to driving 1025 to 6120 miles in an average passenger vehicle or burning 47 to
281 gallons of gasoline every month. On a per-case basis, emissions from the production of unused drugs range from 6 to almost 30 kg CO₂-e. Considering the most recent 2011 US cataract surgery prevalence estimates of 1100 per 100 000 residents, we can estimate these emissions contributing a potential additional 23 000 to 105 000 metric tons of CO₂-e toward climate change. This quantity of emissions is equivalent to driving a car from Anchorage, Alaska, to Miami, Florida, 4600 to 51 400 times every year.

Discussion

This study evaluates the financial costs and potential environmental effects of unused pharmaceuticals in routine phacoemulsification cataract surgery. Across 4 US surgical centers, no less than $36 900 per year was spent on unused pharmaceuticals, and at 2 sites more than $190 000 in drugs were thrown out in 1 year. Given that the mean cost of cataract surgery is $3600 per eye, these expenses could theoretically have covered an additional 53 surgical procedures at each of the latter 2 locations.

Eyedrops accounted for most of the proportion of unused pharmaceuticals by volume at 3 sites in our study. This result is not surprising given that most eyedrop bottles used held 5 to 15 mL, only a few drops were used from each bottle, and a new bottle of each medication was opened for every patient. In contrast, ophthalmologists in the United Kingdom typically use drugs packaged in single-dose, disposable containers of 1 mL or less. Resizing to smaller containers could reduce the quantities of pharmaceutical solution unused, although it may also increase the percentage of packaging per drug and thus may not always decrease the price per patient (or vial) of the drug itself.

Instead, considering multidose packages for some agents, such as dilating drops, could be cost-effective and environmentally efficient. The American Society of Cataract and Refractive Surgery supports using multidose drops for multiple patients as long as appropriate safety protocols are followed. Many health care professionals, however, might be hesitant to entertain multidosing because of concern for cross-contamination between patients, despite growing evidence to the contrary. Jensen and colleagues reported saving hundreds of dollars per cataract surgical procedure by using multidose vials without adverse outcomes. In a study on endophthalmitis at Aravind Eye Care System in southern India, infection rates were comparable to previously published data in developed countries, even with the use of multidose eyedrops. As an additional alternative, a surgical facility’s pharmacy could purchase bulk units of certain medications and resize them in a sterile fashion for individual surgical procedures. Some centers have attempted to reduce costs and waste by combining multiple drugs into a single bottle in a compounded fashion, although this approach is relatively new and requires further study.

Similarly, multiuse eyedrops, wherein medications are reused for the same patient, could offer savings in costs and potential emissions. For example, topical antibiotic eyedrops are commonly used before, during, and after cataract surgery. At our test sites, surgeons were not permitted to send a bottle of antibiotic eyedrops home with a patient although that bottle had only been used for that patient on that day. These antibiotics were disposed of after only a few drops were used (80%-100% unused by weight at 2 of our study sites). The patient may have been required to repurchase the same medication at his or her local pharmacy, creating cost increases as well as efficiency decreases.

Variable state and local regulations, institutional regulations, and surgeon preferences lead to inconsistency among surgical sites surrounding multidose and multiuse eyedrops. Well-designed studies that reduce the concern of cross-contamination, as well as sensible government and institutional regulations, could increase consistency and allow for safe and proper use of multidose and multiuse eyedrops.

Furthermore, cataract surgery is unique in that most patients undergo bilateral sequential surgery, with the second surgery often occurring within short sequence of the first. Currently, some surgeons may decrease unused pharmaceuticals by directing patients to save the remaining eyedrops for the second procedure. This practice of preplanned resource allocation, however, is inconsistent and specific to institutional and surgeon preferences.

Notably, antibiotics were the most expensive eyedrops in our study. Thus, a reasonable starting point to reduce costs is...
to consider multiuse and multidose use for antibiotics. For most surgeons, preoperative and/or postoperative topical antibiotics are considered standard of care in cataract surgery, despite lack of a large randomized clinical trial that demonstrates effectiveness in preventing endophthalmitis. At many centers, surgeons have transitioned to using intracameral antibiotics in addition to or in lieu of topical antibiotics. Although intracameral antibiotics may help to decrease costs and unused quantities of topical antibiotics, their use should be designed to minimize costs and potential environmental emissions from the outset.

Limitations
This is a preliminary study with wide variance in site results, so although conclusions are difficult to draw, the results may provide useful estimates for future study. This study was designed to capture a baseline estimate of the unused portion of cataract surgery drugs and thus does not account for variability in drug use between individual physicians and surgical teams. In this study, our sample size included only 4 facilities, of which 3 were private practices. Other centers may reflect different patient cohorts and unique payment structures; thus, our findings may not generalize to all facilities. Notably, none of these 4 centers were high-volume cataract surgery sites, which may theoretically operate more efficiently. In addition, any form of LCA comes with assumptions and uncertainty. In this case, the prices used to estimate emissions were reported by the facilities for each drug, and these prices can vary drastically between surgical facilities. The emissions mapping in an EIO-LCA aggregates emissions across all pharmaceutical manufacturing, which may lead to an overestimate or underestimate of emissions from the specific pharmaceuticals included in this study. Industry data and manufacturer participation are needed to create a more accurate estimate of emissions from cataract surgery pharmaceuticals manufacturing.

We were also not able to measure all unused pharmaceuticals in a month; instead, we extrapolated unused quantities from observed cases. Because we do not have a record of all the drugs used by the federal medical center in a 1-month period and only surveyed 10 cases, we are likely to be missing some pharmaceuticals in our estimates. In addition, although we observed only phacoemulsification cases, we could not ensure exact uniformity in surgical procedure and technique across all surgical procedures. Surgeon experience ranged from novice residents to experienced surgeons, which may account for variable rates of materials used.

Finally, although surgeons and operating room staff were not involved in data reporting and analysis, they were aware of the nature of the study being performed and therefore may have been influenced to alter their use of materials while being observed. If this change occurred to a meaningful extent, we may have underestimated unused pharmaceuticals.

Conclusions
Discarded pharmaceuticals during ubiquitous cataract phacoemulsification surgical procedures appear to result in measurable financial and environmental costs. Future studies to substantiate our findings could include more large-scale, multicenter studies to help further quantify the extent and variation of unused pharmaceuticals from center to center as well as evaluate the use of multidose and multiuse pharmaceuticals in cataract surgery. Such studies may indicate the value of reducing these costs.

REFERENCES