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Emerging Technology in Healthcare and the Associated Environmental Impacts

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Emerging Technology in Healthcare and the Associated Environmental Impacts

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1. Introduction

As sustainability efforts continue to grow, healthcare has become an area of environmental consideration. With healthcare reforms, people living longer, and the growing health sector, the healthcare system has begun looking into how it can keep up in the future. Hospitals are continually examining ways in which technology can be used to improve patient care and to stay competitive. As preventive healthcare becomes a more pressing concern, hospitals are becoming more concerned with the environmental impacts of the technology.

One of the most talked about advances in healthcare is robotic surgery. Even the New York Times reported on the hype concerning the increase in the use of the daVinci robot in surgeries (Kolata 2010). The daVinci robot is used in many surgical procedures, including procedures in gynecology, cardiac, colorectal, general, head and neck, thoracic, and urology (da Vinci Surgical 2013). Intuitive Surgical designed the daVinci robot, but there are also three other companies designing robots for surgery procedures: MAKO Surgical, Accuray, and Hansen Medical. MAKO focuses on knee and hip procedures, Accuray is a radiation oncology company, and Hansen focuses on intravascular robotics (Clement 2013).

With the health community becoming more concerned with the environmental impacts of patient care, the impacts of robotic surgery should be known. A collaborative research team worked to quantify the environmental impacts specifically for hysterectomy surgeries performed at the Magee Women's Hospital (Magee) of the University of Pittsburgh Medical Center. One of the methods of hysterectomy included the use of the daVinci robot. The research team included a professor, two Ph.D. candidates, and two undergraduate students from the University of Pittsburgh, doctors and hospital personnel at Magee, and an undergraduate student from the University of Arkansas. This thesis will further analyze the results of the hysterectomy project to identify the most harmful pieces of the robotic method.

1.1 Background and Motivation

Through the Mascaro Center for Sustainable Innovations, the Swanson School of Engineering at the University of Pittsburgh has worked on sustainability efforts in many different areas. Dr. Melissa Bilec was the leading professor on the research team and is the Assistant Director of Education and Outreach for the Mascaro Center and an assistant professor in the Civil and Environmental Engineering department. Her area of research is in sustainable healthcare and green design and construction. The Ph.D. candidates who worked on the research team were Scott Shrake and Cassie Thiel. Shrake's dissertation focused on the environmental impacts of professional services and healthcare as part of the service sector, and Thiel's focus was on using Life Cycle Analysis (LCA) and Evidence Based Design to quantify the environmental impacts of birthing options, hysterectomy surgeries, and green building design. The team's findings on hysterectomies will be described along with further analysis of the results.

There were 498,000 hysterectomies performed in the US in 2010 (CENTERS FOR DISEASE CONTROL AND PREVENTION 2010). A hysterectomy is the removal of a woman's uterus through surgery. The four methods of hysterectomies analyzed at Magee were abdominal, vaginal, laparoscopic, and robotic. Abdominal is the traditional form of surgery where the surgeon makes a large incision across the belly.

In order to offer a better surgery experience to the patients, new surgery techniques have been developed. Vaginal surgery allows the surgeon to complete the hysterectomy through the vagina leaving no visible scars. Laparoscopic and robotic are two types of "minimally invasive" surgery; these methods of surgery allow for much smaller incisions than abdominal and use special tools to assist with removing the uterus (Todd 2012). The robotic platform used at Magee was the daVinci Surgical System by Intuitive Surgical.

Figure 1: daVinci Robotic Platform (daVinciSurgery.com 2013)

The daVinci robot is currently the only robot approved by the FDA for use in hysterectomy surgery. There are three pieces to the robotic platform that set it apart from the other forms of surgery: the console, the robot, and the 3D viewing. These are pictured in Figure 1. The console allows the surgeon to be seated while controlling the robotic arms, has remote capabilities, and contains the 3D viewing. The controls use hand movements similar to traditional, open surgery movements. The robotic arms are inserted into the patient through small incisions and have seven degrees of freedom. The robot allows for error controlling (da Vinci Surgery 2013). These three aspects of robotic surgery overcome some challenges of the laparoscopic method. The laparoscopic tools have poor ergonomics; they are controlled by the surgeon bedside using gun-like hand movements and have five degrees of freedom. Laparoscopic surgery also does not utilize 3D viewing (Rassweiler 2010).

1.2 Problem Statement

Robotic surgery has been rapidly adopted at many hospitals throughout the United States, but little data exists to measure the sustainability of robotic surgery technologies. To truly consider the sustainability of surgeries, all three of the foundations of sustainability should be explored: economic, social, and environmental impacts.

One study analyzed data from the Perspective database (Premier) on hysterectomies as a result of benign gynecologic disease. More than 260,000 hysterectomies from 441 hospitals from 2007 to the first quarter of 2010 were identified. The use of the robot increased from 0.5% in 2007 to 9.5% in 2010.

Laparoscopic also increased while abdominal and vaginal decreased (Wright, et al. 2013). The quick adoption can be explained by numerous reasons. The robot has innovative technology like the 3D viewing and the robotic arms, which gives the potential for better clinical outcomes. In addition, there has been aggressive marketing of the robot to doctors, hospitals, and patients.

The fixed and variable costs of the robot are more expensive than the other methods of hysterectomy surgery. The daVinci robotic platform has a fixed cost of about $2 million (Pasic, et al. 2010; Soto, et al. 2011; Weinstein, et al. 2009). The research team at Magee found the disposable robotic materials per surgery to cost about $900 more than laparoscopic, which is about twice as much. From analyzing the Premier database, Wright, et al. (2013) found the cost per hysterectomy surgery performed with the robot to be over $2000 more than laparoscopic and abdominal methods.

Both robotic and laparoscopic methods are considered minimally invasive surgeries and have advantages over open surgery (Weinstein, et al. 2009; Yu, et al. 2012). However, there exists a debate over whether robotic surgery has better clinical quality over the laparoscopic method. Schroek, et al. (2013) found that patients go into robotic surgery with high expectations of the clinical outcomes, even though these expectations are not being fully realized. Patients expected a quicker return to physical activity after a radical prostatectomy if the robot was used than if performed laparoscopic, but the study found no difference in return to physical activity (Schroek, et al. 2011). Wright, et al. (2013) found laparoscopic and robotic surgeries had similar perioperative outcomes; the only difference was laparoscopic surgeries resulted in more hospitalizations lasting longer than two days. In 2009, daVinci Surgical System implemented a dual-console approach for gynecologic procedures; this allowed for a surgeon and a fellow to operate at the same time. Smith, et al. (2012) compared the effects of using the dual console in robotic surgery with laparoscopic surgery. During the robotic surgeries, the surgeon was at one console while the fellow was at the other, and the laparoscopic surgeries were completed by the surgeon with the fellow as the co-surgeon. 106 laparoscopic and 116 robotic cases were identified at Magee-Women's Hospital of UPMC. Most of the operative results and complications were similar between the two groups except total surgical time was shorter and the estimated blood loss was less for the robotic surgeries (Smith, et al. 2012). Many others found robotic and laparoscopic methods to have similar outcomes (Pasic, et al. 2010).

Currently, few studies exist on the environmental outcomes of surgeries. Some information is available on individual surgery items, such as whether to use disposable or reusable hospital gowns (Overcash 2012) and masks (Eckelman, et al. 2012), but very little exists on the surgery as a whole. Even though the cost is high for robotic surgery and the benefits of robotic over laparoscopic are being debated, the use of the robot keeps increasing. Using the robot in the most sustainable way could add a competitive advantage.

In order to quantify the average environmental impacts of the four methods of hysterectomies, the research team used Life Cycle Analysis (LCA). LCA is a method to report the environmental impacts of a process through its life cycle. It uses a database of emissions, materials, and energy use from a variety of industries from acquisition to disposal of a material. It then outputs the amount of environmental impact for ten impact categories for the particular process being analyzed (Thiel, C. 2011).

The research team conducted a waste audit of single-use items, a reusable material analysis, and an energy collection for each hysterectomy method. There were 15 vaginal, abdominal, and robotic hysterectomies and 16 laparoscopic hysterectomies included in the study. These included only hysterectomies being performed for non-cancerous reasons. The average weight of materials used in surgery and the average energy usage were calculated for each method and used as the inputs into the LCA (Thiel, et al. 2013). The environmental impacts could then be outputted into the ten impact categories, such as the amount of global warming and the amount of smog.

The laparoscopic and robotic tools were too complex to be broken down into individual materials, so the team used Economic Input-Output (EIO)-LCA to determine the environmental impacts of these items. The EIO-LCA matches the environmental data within the correct industry sector with the cost of tools. It is an online tool created by Carnegie Mellon University Green Design Institute (2013) and outputs impacts for six of the ten impact categories. The four categories not included in the EIO-LCA are acidification, respiratory effects, eutrophication, and smog. The research team provided an overview of the surgeries, the material decomposition, and the environmental impacts for each method of hysterectomy.

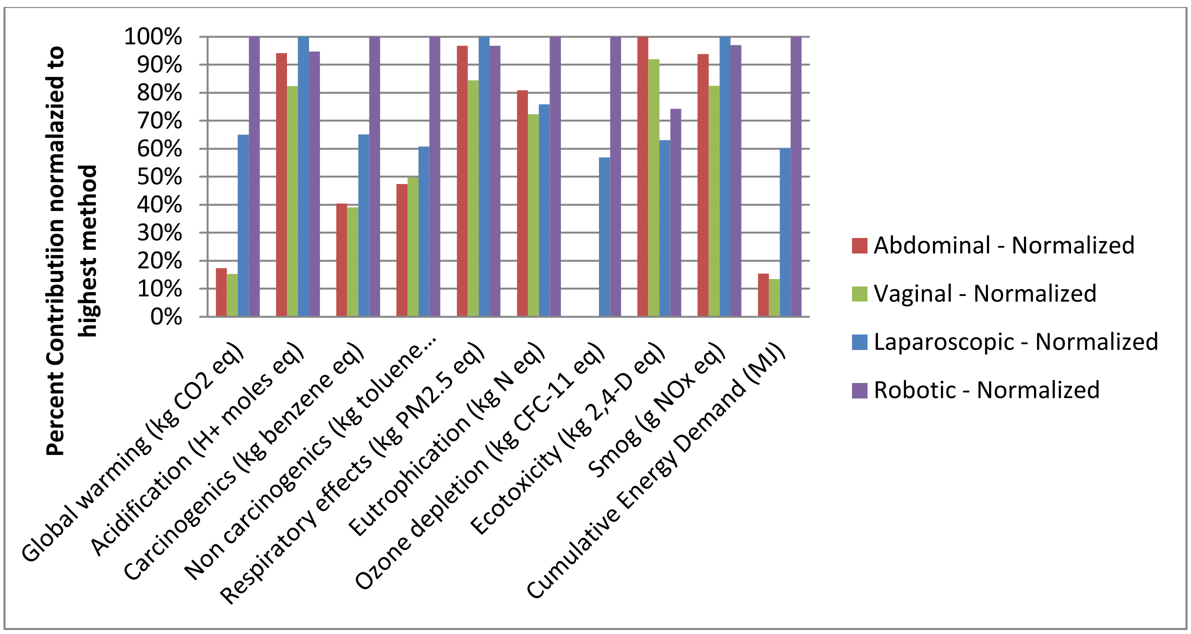

Figure 2: Total LCA Results for Average Hysterectomy by Surgery Method; normalized to highest method (Thiel, et al. 2013)

The total LCA results include the environmental impacts from the LCA and the EIO-LCA. The units of the impact categories are set to equivalents (eq) of different measurements and cannot be compared directly; this is why the total LCA results are in Figure 2 are normalized to the surgical method with the highest contribution in each impact category. The robotic method is the highest method in six of the ten impact categories while laparoscopic is highest in three categories and abdominal is highest in one category. In the six categories with robotic as the highest impact, the other methods are only 80% or less of the robotic impact.

The goal of this thesis is to identify the aspects of robotic hysterectomy that cause the high environmental impacts for future improvement of the robot and hysterectomy surgery. The three objectives are to 1) analyze the waste streams, 2) identify waste causing high impacts within robotic hysterectomy, and 3) compare robotic waste to the other hysterectomy methods.

2. Methods

Further analysis of the Life Cycle Assessment (LCA) results for the robotic method of hysterectomy allowed for identification of the most environmentally harmful inputs. The waste streams included in the LCA were mapped then analyzed for the stream with the highest impact in the robotic method. That waste stream was then broken down into finer components. The contribution of these waste components to the robotic method LCA results was determined. Then the robotic waste and impacts were compared to the other hysterectomy methods. The use of simple statistics allowed for identification of large differences in the waste components between the four methods of hysterectomy.

3. Results

3.1 Waste Stream Analysis

The scope of the hysterectomy study included the items and energy used during surgery. Figure 3 depicts the breakdown of the energy sources and the items used. The energy usage during the surgeries was related to both facilities and equipment. The scope of this thesis focuses on the items because the items can be improved upon more easily than changing the facility or the equipment.

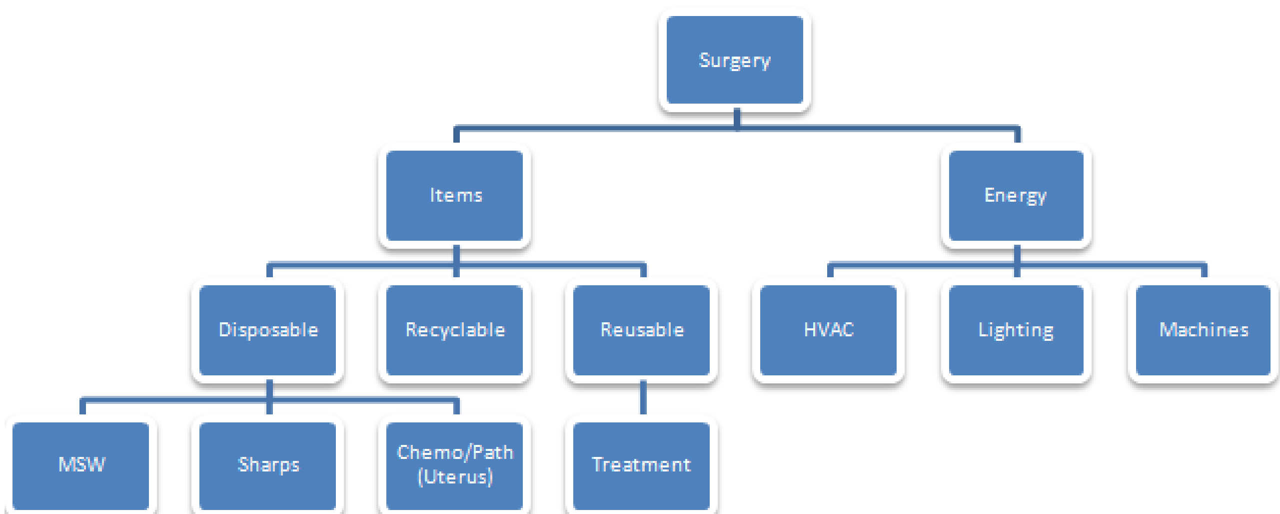

Figure 3: Aspects of Hysterectomy included in Total LCA

Magee separated the items according the type of waste stream the item would enter. The items were classified as disposable, recyclable, or reusable. Within disposable, the items were further described as Municipal Solid Waste (MSW), sharps, or the uterus. The MSW is the actual trash and included single-use items like gloves and gowns, while needles were disposed as sharps.

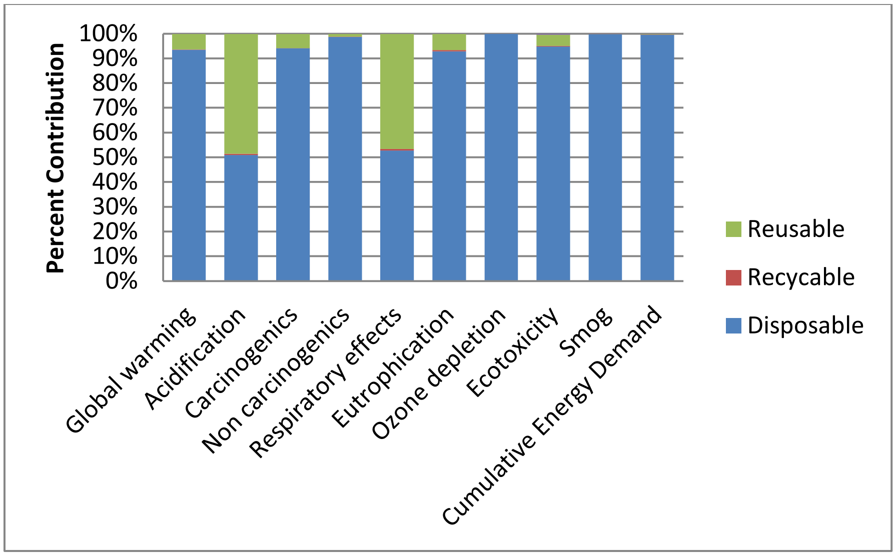

Figure 4: Distribution of Impacts by Item Classification for the Robotic Method (Thiel, et al. 2013)

Figure 4 compares the LCA results of the different item classifications for the robotic method. It shows the percent contribution in each impact category of the item classifications. The disposable items represented most of the environmental impact. Out of the disposable items, sharps and the uterus were very small percentages of the total disposable waste. MSW represented the majority of the disposable waste.

Method	Average MSW Weight (kg)	Min Weight	Max Weight
Abdominal	9.2	5.9	13.9
Vaginal	8.5	5.9	11.3
Laparoscopic	10.6	6.6	13.6
Robotic	13.7	9.3	16.8

Table 1: Average, Minimum, and Maximum weight of MSW for each surgery method

The research team also weighed the total MSW after each hysterectomy. The average, minimum, and maximum MSW weight in kilograms is given in Table 1 for each method. The robotic method had the largest amount of total MSW with an average of 13.7 kg per hysterectomy.

3.2 Robotic Method Waste

MSW was the main cause to the robotic hysterectomy having higher environmental impacts than the other methods, and the robotic method consisted of the largest amount of MSW. The MSW items are the focus of further analysis. To be used as inputs into the LCA, the MSW items had to be broken down into individual materials.

Material	Average Weight per Robotic Surgery (kg)	% of Total Robotic Weight	Example Items
Cotton	0.709	5.2%	Towels, swabs
Plastics	6.400	46.7%	IV bags, trays, tool parts, hard plastic, soft plastic, arm ties
SMS gowns	2.981	21.8%	Gowns, drapes
Metal	0.089	0.6%	Tool parts
Gloves	0.454	3.3%	Tan, purple, green gloves
Paper	2.466	18.0%	Packaging, labels
Other	0.248	1.8%	Vials, jars, tongue depressors
Complex materials	--	--	Robotic arms and disposable instruments

Table 2: Material Information for the Robotic Method

Table 2 shows the breakdown of the MSW materials for the robotic method of hysterectomy. The materials are listed along with their average weights in kilograms, their percentage of total MSW weight, and example items. Plastics had the largest average weight, and SMS gowns and paper also represented large portions of the total robotic MSW weight. The average weights were used to calculate the environmental impacts for the robotic method of hysterectomy. A weight was not given for the complex materials because the EIO-LCA used the price of the robotic tools to calculate the impacts.

		MSW Materials							
Impact category	Unit	Cotton	Plastics	SMS gowns	Metals	Gloves	Paper	Other	Complex
Global warming	kg CO2 eq	3.0%	2.3%	0.4%	0.0%	0.2%	1.0%	0.0%	93.0%
Acidification	H+ moles eq	52.7%	14.9%	22.3%	0.6%	2.2%	6.8%	0.6%	n/a
Carcinogenics	kg benzene eq	10.2%	18.3%	3.7%	0.1%	11.7%	11.6%	0.1%	44.3%
Non carcinogenics	kg toluene eq	5.1%	37.2%	8.1%	0.2%	23.8%	20.2%	0.1%	5.3%
Respiratory effects	kg PM2.5 eq	54.6%	13.3%	21.5%	0.5%	2.2%	7.3%	0.5%	n/a
Eutrophication	kg N eq	27.8%	37.7%	15.3%	0.0%	4.0%	15.0%	0.2%	n/a
Ozone depletion	kg CFC-11 eq	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Ecotoxicity	kg 2,4-D eq	24.8%	6.5%	2.3%	43.4%	1.4%	21.5%	0.1%	0.0%
Smog	g NOx eq	51.5%	26.4%	4.2%	0.5%	2.0%	14.7%	0.8%	n/a
Cumulative Energy Demand	MJ	2.1%	4.3%	5.0%	0.0%	0.4%	1.9%	0.0%	86.3%

Table 3: Robotic LCA Results for each Material with complex materials

Table 3 shows how each material contributed to the environmental impacts for the robotic method. For each impact category, the percentage of impact is given for each material instead of the actual values because the impact categories have different units. No results were given for complex materials in four of the impact categories because the EIO-LCA gives results for six of the ten categories. The pink cells represent high contribution to the impact. Within the six categories that include complex materials, the complex materials have high values in four, and plastics and metals each have a high value in one category. Within the impact categories that do not include complex materials, cotton has high values in all four and plastics have high values in two categories.

The complex materials represent a large portion of the impact for the robotic method. To determine how the other MSW materials affect the degree of impact for the robotic method, the LCA results without the complex materials are analyzed.

		MSW Materials						
Impact category	Unit	Cotton	Plastics	SMS Gowns	Metals	Gloves	Paper	Other
Global warming	kg CO2 eq	42.85%	33.31%	6.35%	0.57%	2.48%	13.94%	0.49%
Acidification	H+ moles eq	52.70%	14.93%	22.27%	0.59%	2.19%	6.77%	0.55%
Carcinogenics	kg benzene eq	18.07%	32.61%	6.65%	0.21%	20.88%	21.36%	0.21%
Non carcinogenics	kg toluene eq	5.31%	38.94%	8.44%	0.21%	24.93%	22.08%	0.10%
Respiratory effects	kg PM2.5 eq	54.58%	13.28%	21.53%	0.49%	2.24%	7.34%	0.53%
Eutrophication	kg N eq	27.66%	37.60%	15.28%	0.01%	3.98%	15.27%	0.20%
Ozone depletion	kg CFC-11 eq	33.50%	8.81%	0.77%	0.03%	17.99%	36.82%	2.07%
Ecotoxicity	kg 2,4-D eq	24.61%	6.43%	2.28%	42.96%	1.41%	22.20%	0.11%
Smog	g NOx eq	51.45%	26.40%	4.18%	0.48%	1.99%	14.75%	0.75%
Cumulative Energy Demand	MJ	15.49%	31.56%	36.14%	0.25%	2.73%	13.55%	0.28%

Table 4: Robotic LCA Results for each MSW material without complex materials

The MSW LCA results for the robotic method without complex materials are given in Table 4. The pink highlighted cells represent large contributors to the high robotic impact. By taking out the complex materials, cotton and plastics represent most of the impact. Gowns, metals, and paper each have high values in one category.

3.3 Compare Methods

The other methods have the same list of MSW materials but with different amounts of MSW and different degrees of environmental impact. To help determine which aspects of the robotic hysterectomy to improve, the impacts are compared among the methods.

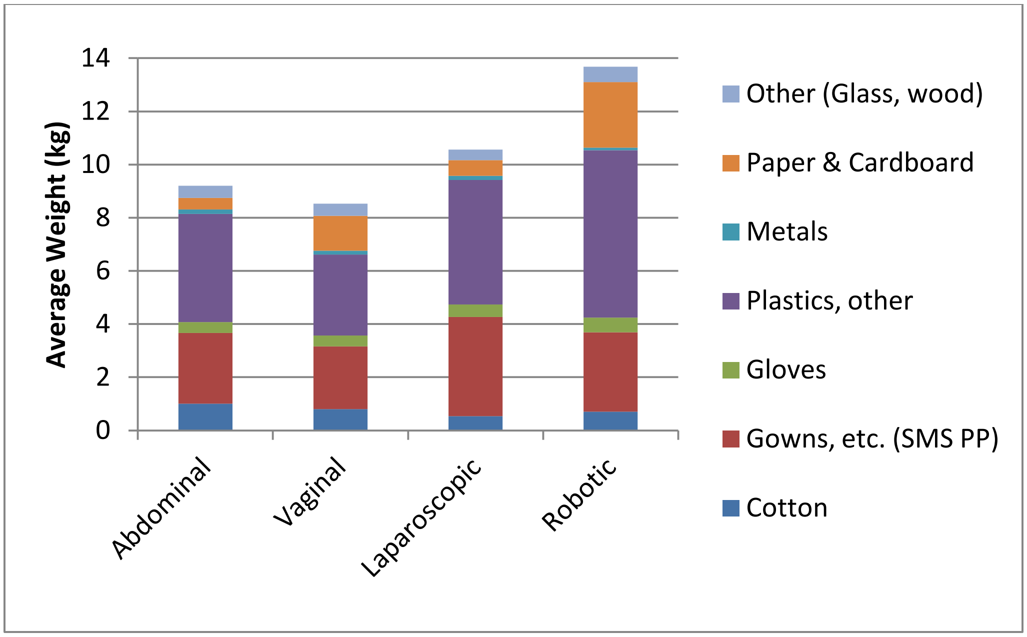

Figure 5: MSW Weights for each Hysterectomy Method (Thiel, et al. 2013)

Figure 5 provides a visual representation of the differences in the average weight of MSW materials between the methods. From the graph, plastics are obviously a large portion of the total weight and metals are a small portion of the total weight for all the methods. The average amounts of paper and cotton vary between the methods.

MSW Materials	Surgery Method	Average Weight (kg)	% Difference from Robotic	% of Total Weight
Cotton:	Lap	0.540	-27.1%	5.1%
	Abd	1.009	34.9%	11.0%
	Vag	0.807	12.9%	9.5%
	Rob	0.709	-	5.2%
Paper:	Lap	0.594	-122.4%	5.6%
	Abd	0.431	-140.5%	4.7%
	Vag	1.308	-61.4%	15.4%
	Rob	2.466	-	18.0%
Plastic:	Lap	4.732	-30.0%	44.6%
	Abd	4.120	-43.3%	44.8%
	Vag	3.094	-69.6%	36.4%
	Rob	6.400	-	46.7%
SMS Gowns:	Lap	3.726	22.2%	35.2%
	Abd	2.653	-11.6%	28.8%
	Vag	2.355	-23.5%	27.7%
	Rob	2.981	-	21.8%
Gloves:	Lap	0.420	-7.8%	4.0%
	Abd	0.366	-21.5%	4.0%
	Vag	0.357	-23.9%	4.2%
	Rob	0.454	-	3.3%
Metals:	Lap	0.157	55.3%	1.5%
	Abd	0.170	62.5%	1.8%
	Vag	0.152	52.3%	1.8%
	Rob	0.089	-	0.6%
Other:	Lap	0.160	-43.1%	1.5%
	Abd	0.146	-51.8%	1.6%
	Vag	0.230	-7.5%	2.7%
	Rob	0.248	-	1.8%

Table 5: Comparing MSW Materials across the Methods

The pink cells in Table 5 represent large differences between the robotic and the corresponding method for the specified MSW material. Cotton, paper, and metals show large differences in the percentage of the total weight of a method compared to robotic. The other materials make up the same portion of the total weight for all four methods. Plastics and gowns represent a large percentage of the total weight for all methods. Metal and paper both have large differences in the weight of the material among the methods. Further investigations are needed to understand these large differences in material weight.

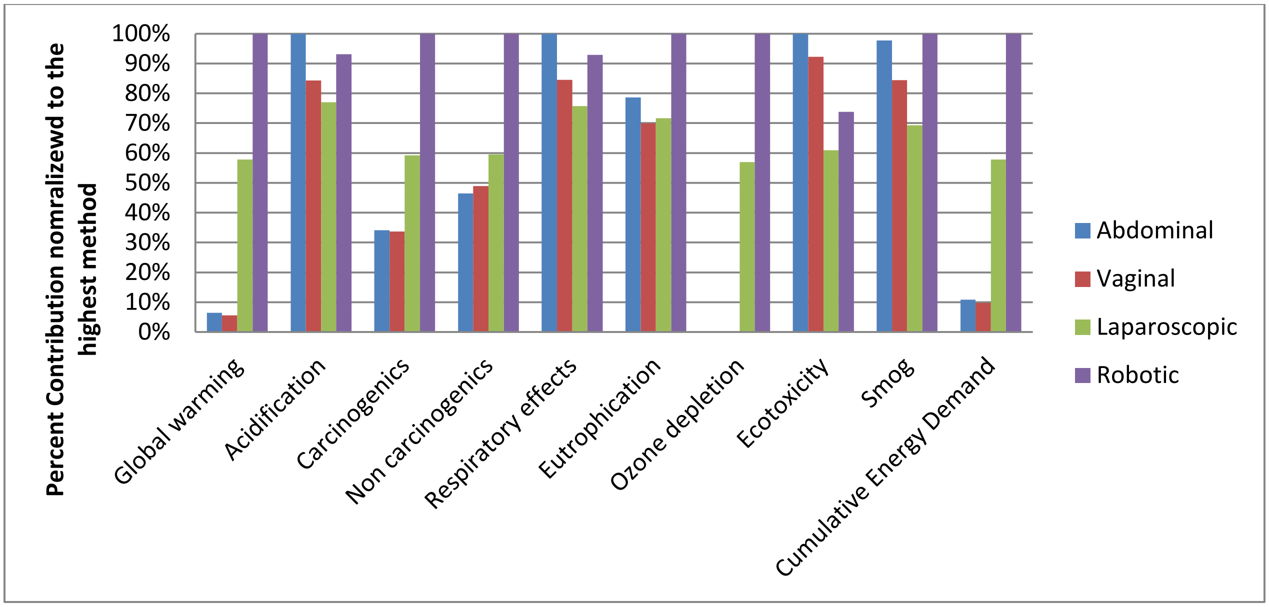

Figure 6: MSW LCA Results normalized to highest method (including complex materials)

The MSW materials were identified as leading to the high robotic impacts; Figure 6 compares the LCA results of the MSW among the methods. This figure includes the impacts due to complex materials in the laparoscopic and robotic methods. Robotic was the highest method for seven of the ten categories, and abdominal was highest in the other three categories.

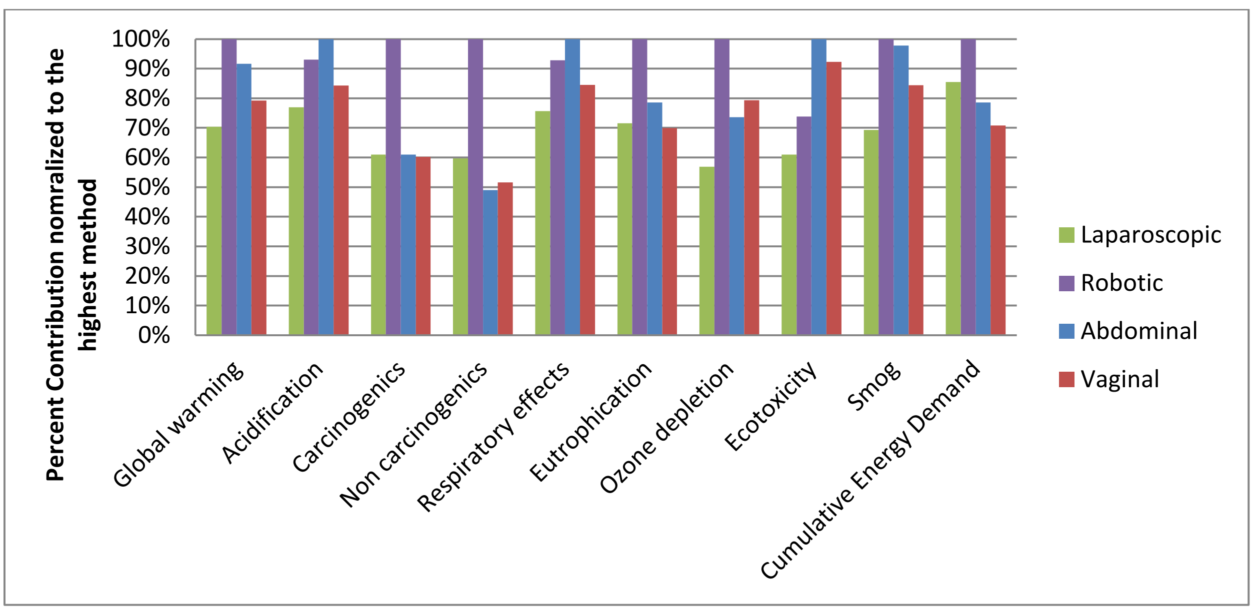

Figure 7: MSW LCA Results normalized to highest method (not including complex materials)

Figure 7 shows the MSW LCA results but excludes the impact due to complex materials because abdominal and vaginal do not use complex materials. By taking out those impacts, robotic was still the highest impact method in the same seven categories while abdominal was highest for the other three.

Without the complex materials included, the LCA results of the MSW materials can be better compared between the robotic and the abdominal and vaginal methods.

		MSW Materials						
Impact category	Unit	Cotton	Plastics	SMS Gowns	Metals	Gloves	Paper	Other
Global warming	kg CO2 eq	34.94%	-53.03%	-11.64%	60.22%	-24.60%	-142.13%	-51.89%
Acidification	H+ moles eq	34.94%	-59.03%	-11.64%	63.78%	-15.07%	-142.04%	-51.89%
Carcinogenics	kg benzene eq	34.94%	-111.58%	-11.64%	63.08%	-27.93%	-140.29%	-51.92%
Non carcinogenics	kg toluene eq	34.94%	-113.25%	-11.64%	70.32%	-27.94%	-140.24%	-51.93%
Respiratory effects	kg PM2.5 eq	34.94%	-69.40%	-11.64%	64.71%	-16.80%	-141.56%	-51.90%
Eutrophication	kg N eq	34.94%	-61.79%	-11.64%	56.22%	-28.15%	-141.31%	-51.92%
Ozone depletion	kg CFC-11 eq	34.94%	-63.47%	-11.64%	66.43%	-29.15%	-143.90%	-51.93%
Ecotoxicity	kg 2,4-D eq	34.94%	-62.69%	-11.64%	70.80%	-27.97%	-140.58%	-51.93%
Smog	g NOx eq	34.94%	-52.64%	-11.64%	58.93%	-22.86%	-142.34%	-51.87%
Cumulative Energy Demand	MJ	34.94%	-48.47%	-11.64%	65.22%	-22.23%	-141.75%	-51.90%

Table 6: Percent Difference in LCA Results from Abdominal to Robotic

The pink highlighted cells in Table 6 represent a large percentage of difference between the robotic and abdominal environmental impacts. Abdominal had a smaller impact from plastics, paper, and other, but a larger impact from metals.

		MSW Materials						
Impact category	Unit	Cotton	Plastics	SMS Gowns	Metals	Gloves	Paper	Other
Global warming	kg CO2 eq	12.91%	-77.76%	-23.47%	49.88%	-22.54%	-61.32%	-7.27%
Acidification	H+ moles eq	12.91%	-82.45%	-23.47%	53.22%	-28.85%	-61.32%	-7.27%
Carcinogenics	kg benzene eq	12.91%	-129.15%	-23.47%	52.56%	-29.33%	-61.38%	-7.20%
Non carcinogenics	kg toluene eq	12.91%	-130.40%	-23.47%	59.41%	-29.53%	-61.38%	-7.19%
Respiratory effects	kg PM2.5 eq	12.91%	-91.18%	-23.47%	54.09%	-27.55%	-61.34%	-7.25%
Eutrophication	kg N eq	12.91%	-85.62%	-23.47%	46.15%	-26.85%	-61.35%	-7.20%
Ozone depletion	kg CFC-11 eq	12.91%	-70.72%	-23.47%	55.71%	-19.37%	-61.25%	-7.19%
Ecotoxicity	kg 2,4-D eq	12.91%	-86.20%	-23.47%	59.87%	-25.78%	-61.37%	-7.19%
Smog	g NOx eq	12.91%	-77.67%	-23.47%	48.67%	-23.55%	-61.31%	-7.31%
Cumulative Energy Demand	MJ	12.91%	-73.64%	-23.47%	54.57%	-23.74%	-61.33%	-7.25%

Table 7: Percentage Difference in LCA Results from Vaginal to Robotic

The pink highlighted cells in Table 7 represent a large percentage of difference in the environmental impact between the robotic and vaginal methods. Vaginal had a smaller impact due to plastics and paper, but a larger impact due to metals.

		MSW Materials							
Impact category	Unit	Cotton	Plastics	SMS Gowns	Metals	Gloves	Paper	Other	Complex
Global warming	kg CO2 eq	-27.06%	-36.44%	22.22%	60.35%	-8.13%	-127.24%	-43.17%	-54.93%
Acidification	H+ moles eq	-27.06%	-40.76%	22.22%	48.60%	-7.82%	-126.98%	-43.17%	n/a
Carcinogenics	kg benzene eq	-27.06%	-71.07%	22.22%	51.13%	-16.23%	-121.74%	-43.17%	-54.93%
Non carcinogenics	kg toluene eq	-27.06%	-72.44%	22.22%	18.35%	-16.42%	-121.58%	-43.18%	-54.93%
Respiratory effects	kg PM2.5 eq	-27.06%	-47.84%	22.22%	45.09%	-7.81%	-125.53%	-43.17%	n/a
Eutrophicatio n	kg N eq	-27.06%	-43.02%	22.22%	71.01%	-14.12%	-124.79%	-43.18%	n/a
Ozone depletion	kg CFC-11 eq	-27.06%	-57.31%	22.22%	38.01%	-7.85%	-132.65%	-43.18%	-54.93%
Ecotoxicity	kg 2,4-D eq	-27.06%	-42.36%	22.22%	15.48%	-13.03%	-122.61%	-43.18%	-54.93%
Smog	g NOx eq	-27.06%	-35.70%	22.22%	64.05%	-8.01%	-127.88%	-43.16%	n/a
Cumulative Energy Demand	MJ	-27.06%	-34.12%	22.22%	43.08%	-7.81%	-126.09%	-43.17%	-60.72%

Table 8: Percentage Difference in LCA Results from Laparoscopic to Robotic

The pink highlighted cells in Table 8 represent a large percentage of difference in the environmental impact between the robotic and laparoscopic methods. Laparoscopic had a smaller impact due to paper and complex materials. Laparoscopic had greater impact due to metals in four categories and less impact due to plastics in three categories.

4. Conclusions and Discussion

Although researchers found the daVinci robot to have a high cost, similar clinical outcomes to laparoscopic, and higher environmental impacts than the other methods of surgery, the robot technology appears to have taken off. Robotic surgery keeps expanding due to the innovative technology of the robots and due to aggressive marketing. However, the use of the robot in surgical procedures must become cost effective and provide better clinical outcomes than the other methods of surgery for the daVinci to continue expanding.

Further analysis of the robotic waste streams and environmental impacts lead to the aspects of robotic hysterectomies that are most harmful. First, the waste streams of the robotic hysterectomy were analyzed. The energy waste streams were out of scope for this thesis. The items were classified as disposable, recyclable, or reusable. The disposable items caused the most environment impact. MSW represented most of the disposable items, and the robotic hysterectomy had the largest average, minimum, and maximum amount of MSW.

Next, the waste causing the high environmental impacts within the robotic method were identified. Plastics, SMS gowns, and paper made up the majority of the total MSW. It was clear that the complex materials led to large portions of the environmental impacts of robotic hysterectomy. The complex materials were composed of the robotic tools. Without including the complex materials, cotton and plastics created the majority of the impacts related to the MSW materials.

The amount of waste and the impacts due to the waste were compared among the hysterectomy methods. With or without complex materials, the robotic method had higher overall environmental impact due to MSW compared to the other methods. Plastics and gowns represented high percentages of the total amount of MSW materials in all methods. The amounts of some materials and the amounts of environmental impact due to those materials varied between robotic and the other methods. Abdominal had much less paper and other and more metals than robotic. The harmful environmental impacts were greater for abdominal due to metals and were less due to paper, other, and plastics. Vaginal had less paper and plastics and more metals than robotic which corresponded to the impacts being less due to paper and plastics and more due to metals. Laparoscopic had less paper and more metals than robotic, and the laparoscopic tools cost less than the robotic tools. The laparoscopic impacts were less due to paper in all ten categories, less due to plastics in three categories, less due to complex in six categories, and more due to metals in four categories.

This thesis found which materials lead to the high environmental impacts for robotic hysterectomy. There are many different ways to decrease the impact due to those materials. One review of green surgical practices for hospitals found these leading operating room recommendations: waste reduction and segregation, reprocessing and recycling of disposable devices, purchase of eco-friendly products, energy consumption management, and pharmaceutical waste management (Kwakye, et al. 2011). Also, a common sustainability practice is to reduce, reuse, and recycle. The reduction, segregation, reprocessing, and recycling of waste and the purchase of eco-friendly products could all help reduce the environmental impacts associated with the MSW.

The robotic tools (complex materials) used were the leading source of environmental impact for the robotic method. Since the use of the robot is increasing, reducing the amount of robotic tools used is probably not likely. The reuse of the tools is not possible because of the risk of transmitting infections to other patients. However, the robotic tools could be reprocessed which would cut down on the cost of the items and reduce the environmental impacts.

Cotton created much of the impact for robotic, even though cotton represented a small portion of the total MSW weight. Paper did not create much of the impact for robotic, but there were differences between robotic and the other methods in the amount of paper and the impacts due to paper. Plastic represented the largest percentage of the total MSW weight for all methods and created much of the impact for robotic when excluding the complex materials. There were differences in the impacts due to plastics between robotic and the other methods. SMS gowns were a large portion of the total MSW weight for all methods. Gloves were a small percentage of the total MSW weight and a small portion of the impacts. Metals represented a small percentage of the impacts for robotic, but the other methods had larger amounts of metals and larger impacts due to metals. The other materials made up a small portion of the total MSW weight and impacts for all the methods, and abdominal had even less other materials than robotic.

All the MSW materials could be improved upon by following the common “greening” techniques. The amount of plastics and SMS gowns could be reduced to help decrease the total amount of waste. Cotton causes much of the environmental impact even though it represents a small portion of the total MSW weight. The amount of cotton could be reduced or could be replaced with other materials with fewer impacts. Now that the harmful materials have been identified, the health community can try to reduce the overall environmental impacts.

5. Future Work

This thesis was only a very small portion of the analysis that could be completed on robotic surgery. The conclusions drawn were based on relative significance, not statistical significance due to a small sample size of material data. The items used and procedure information for each hysterectomy studied and the average MSW material weights for each method were available, but the weight of each MSW material for each surgery performed was not available. This information plus a larger sample size are needed to determine what factors caused the material weights to vary.

The field of robotics is expanding throughout healthcare. Hysterectomy surgery is not the only surgery that has a robotic method. Many other surgical procedures use the daVinci robot or one of the other robots available. Studying the environmental impacts of these surgeries would allow for a better understanding of the sustainability of robots across all uses in healthcare. It is important for the technology in healthcare to advance to better serve patients, but the healthcare sector should also be aware of the environmental impacts of these technologies.

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