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Environmental Impact of Minimally Invasive Surgery in the United States: An Estimate of the Carbon Dioxide Footprint

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Abstract

Purpose: To attempt to quantitate the carbon footprint of minimally invasive surgery (MIS) through approximated scope 1 to 3 CO_2 emissions to identify its potential role in global warming.
Patients and Methods: To estimate national usage, we determined the number of inpatient and outpatient MIS procedures using International Classification of Diseases, ninth revision-clinical modification codes for all MIS procedures in a 2009 sample collected in national databases. Need for surgery was considered essential, and therefore traditional open surgery was used as the comparator. Scope 1 (direct) CO_2 emissions resulting from CO_2 gas used for insufflation were based on both escaping procedural CO_2 and metabolic CO_2 eliminated via respiration. Scopes 2 and 3 (indirect) emissions related to capture, compression, and transportation of CO_2 to hospitals and the disposal of single-use equipment not used in open surgery were calculated.
Results: The total CO_2 emissions were calculated to be 355,924 tonnes/year. For perspective, if MIS in the United States was considered a country, it would rank 189th on the United Nations 2008 list of countries' carbon emissions per year. Limitations include the inability to account for uncertainty using the various models and tools for approximating CO_2 emissions.
Conclusion: CO_2 emission of MIS in the United States may have a significant environmental impact. This is the first attempt to quantify CO_2 emissions related to MIS in the United States. Strategies for reduction, while maintaining high quality medical care, should be considered.

Introduction

Laparoscopic surgical techniques and indications have expanded dramatically over the past 30 years since the inception of laparoscopy in medical practice. Because of recent advances in robot-assisted surgery, the number of laparoscopic robot-assisted procedures is exponentially rising as well. For example, in urology, more than half of radical prostatectomies are currently performed robotically. In 2009, an estimated 65% to 85% of all prostatectomies were completed using a robot-assisted laparoscopic approach.[1,2] This is remarkable considering the technology only received approval from the U.S. Food and Drug Administration in 2000. The collateral effects of minimally invasive technology are controversial and are currently being debated.[3] The environmental collateral effects of minimally invasive surgery (MIS) have not been considered.

Carbon dioxide is the principle gas used in MIS for insufflation. CO_2 contributes 9% to 26% of the greenhouse effect, mostly from fossil fuel use, implicating it in the current global warming trend since the industrial revolution of the 20th century.[4] The burning of fossil fuel has produced three quarters of CO_2 emissions globally with the remaining amount secondary to deforestation, land utilization, and other factors.[4] The levels of CO_2 emission are projected to be 90% to 250% increased in the year 2100 compared with baseline levels in 1750 if current trends continue unmitigated.[4] This has prompted urgent warnings from the scientific community regarding the dire consequences of the resulting global warming. It follows that major consumers of fossil fuel have started to consider alternatives in an attempt to abate this undesired trend.

The environmental impact of healthcare in the United States, the second highest producer of CO_2 emission in the world and the 19.91% overall global contributor, has only recently been estimated in a research letter in the *Journal of the American Medical Association* by Chung and colleagues.[5] They estimated that the healthcare sector contributes 7% of the entire U.S. CO_2 emission. There has been no published

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literature known to the authors assessing the impact that MIS use of CO_2 has on this figure in the United States.

The aim of this analysis is an attempt to quantitate the carbon footprint of MIS through approximated scope 1 to 3 greenhouse gas (GHG) emissions, as defined by the GHG protocol,[6] to identify its potential role in global warming.

Patients and Methods

The need for surgery was considered as essential and, therefore, the analysis used traditional open surgery as the comparator. Other components of the overall carbon footprint common to surgery in general (ie, operating theater, electricity use, patient travel, paper products used) were considered equivalent. Only additional aspects unique to MIS were considered in the analysis. Other GHGs, as inventoried in the Kyoto protocol,[7] were not considered, but the authors recognize that a complete accounting of the environmental impact of MIS would include this. CO_2 was considered alone because it is used for insufflation in MIS and it is the only GHG additionally unique to the procedure. Essentially, our calculation addresses the additional carbon emissions of performing procedures via MIS rather than open surgery.

To determine an estimate of CO_2 emission related to MIS, the first step was to separate the contributing components into scopes of emission. Scope 1, as defined by the GHG protocol, involves direct GHG emissions from sources that are owned or controlled by the entity. Scope 2 involves indirect GHG emissions resulting from the generation of electricity, heating and cooling, or steam generated off site but purchased by the entity, and the transmission and distribution. Scope 3 involves indirect GHG emissions from sources not owned or directly controlled by the entity but related to the entity's activities.[6]

Scope 1 CO_2 emissions were considered as gas that was used during MIS for insufflation. CO_2 escapes into the atmosphere via two processes during MIS. Directly, CO_2 escapes via leaks at port sites, decompression of insufflation at the end of surgery, or inadvertently because of the CO_2 tubing valve open. Indirectly, patients will absorb CO_2 across intra-abdominal viscera, eventually diffusing into the bloodstream. This absorbed CO_2 is ultimately eliminated via respiration into the atmosphere. The amount may be calculated using the equation proposed by Christopher and Wolf and depends on end-tidal CO_2, tidal volume, respiratory rate, atmospheric pressure, partial pressure of water vapor, and the weight of the patient.[8] This absorbed CO_2 is such a minute amount after calculation that it was not included in the analysis.

A typical CO_2 cylinder used in our institution's operating room contains 65 liters of compressed USP grade gas. Using the Ideal Gas Law, 1 mole of any gas occupies 22.4 liters at 1 atmosphere of pressure.[9] Because 1 mole of CO_2 weighs 44 g, calculations reveal there are 0.00015 metric tonnes of CO_2 in one cylinder. To estimate the operative time/cylinder, we used our institution's procedure numbers, operative times, and overall CO_2 use for the year 2009. The calculated time/cylinder was 1.6 L/hour of laparoscopy based on 2387 procedures. The above calculations were introduced in an initial general surgery analysis by Gilliam and associates[10] at the University of Liverpool, United Kingdom.

Data regarding the number of MIS procedures performed both for inpatient and outpatient settings in the United States were identified in national databases. Inpatient common MIS procedures (Table 1) were identified using International Classification of Diseases, ninth revision-clinical modification codes in the Nationwide Inpatient Sample collected by the Healthcare Cost and Utilization Project.[11–13] These data were cross referenced with inpatient and ambulatory statistics compiled by the U.S. Department of Health and Human Services and the Centers for Disease Control and Prevention.[14] Outpatient MIS procedures were extracted from this dataset. Intuitive Surgical's robot-assisted procedure data were obtained from a publicly available online investor presentation from their website.[15] Average operative times for each procedure were estimated using data from our institution, and we supplemented procedure data not currently performed at our institution with average procedure times from published series.[16–21] The number of cylinders and CO_2 emissions were calculated from these data.

Table 1. Total Scope 1 Carbon Emissions for Minimally Invasive Surgery

	Total number of procedures		
	Inpatient	*Outpatient*	*Total hours*
Gastrointestinal			
Cholecystectomy	374,485	348,000	722,485
Appendectomy	218,558	227,000	277,850
Bariatric surgery	126,850	151,000	445,558
Colon	77,108		
Gynecologic			
Hysterectomy	91,835	84,000	527,505
Salpingo-oophorectomy/ tubal ligation	389,288	91,000	240,144
Urology			
Prostatectomy	90,000		360,000
Nephrectomy (partial/radical/ nephro-U)	34,022		102,066
Miscellaneous			
Laparoscopy NOS	64,569	59,000	123,569
Robot-assisted procedures NOS	93,508	280,524	374,032
Total hours		3,233,917	Hours
Total # CO_2 cylinders		2,021,298	Cylinders
Total CO_2 emission		303.0	Tonnes

NOS = natural orifice surgery.

Contributions to scope 2 and 3 CO_2 emissions were identified as all other processes involved before and after the actual MIS procedure. Calculable processes before surgery were broadly categorized as CO_2 capture/compression and transportation (delivery) of CO_2 to hospitals. Postprocedure CO_2 emissions were calculated relating to single use equipment unique to MIS and their requirement of incineration as biomedical waste. All other indirect emissions were considered to be equivalent to open surgery for purposes of comparison.

The Environment Input-Output Life-Cycle Assessment (EIOLCA) model developed by Carnegie Mellon University Design Green Institute (US 2002 version) was used to estimate CO_2 emission involved in CO_2 capture/compression.[22] The theory was originally conceived by Wassily Leontief, and his work on input-output life-cycles won him the Nobel Prize in economics in 1973. Industrial CO_2 is produced in numerous ways, mostly as a by-product of other processes, such as hydrogen energy production plants converting methane to CO_2. Medical or USP grade CO_2 requires high standards of purity and therefore is often mined from natural CO_2 springs, where it is produced by acidified water acting on dolomite or limestone.[4] Our institution's supplier confirmed our CO_2 is mined from a natural source in Delaware City, DE. The Carnegie Mellon EIOLCA tool was used by inputting the estimate of economic sector activity for the largest medical CO_2 supplier in the United States, specifically for industrial gas manufacturing. This was estimated using the supplier's 2009 annual corporate report and their published breakdown of sales by economic sector.[23] To specifically target the MIS procedural use of CO_2, only the United States (52% of all sales), medical (8%) and packaged gas (31%) portions of 2009 annual sales were used for the EIOLCA model. Not all packaged medical CO_2 delivered is used for MIS, however, and therefore we attempted to correct for this by using our institution's 2009 data as an index case: 6102 L of CO_2 were delivered, but only 2604 L (43%) of CO_2 were directly used for MIS procedures. In a similar attempt to focus on MIS in the model, only industrial gas categories of manufacturing, power generation/supply for mining, and gas extraction output CO_2 emissions were included in the final total.

Transportation of CO_2 to healthcare facilities was estimated also by using our institution as an index case. The number of miles/CO_2 cylinder was calculated for CO_2 emission estimation. We used a standard CO_2 semitruck transport with an approximate 6 miles/gallon fuel efficiency and estimated based on a 16 tonne payload (weight of CO_2 gas alone) and an 18 tonne base freight weight in the model.[24] The total distance from the source mine in Delaware City, DE, to our institution in New York City is 140 miles. A carbon footprint calculator based on U.S. Department of Transportation (US DOT) fuel efficiency data and Greenhouse Gas Protocol Initiative (GHGPI) mobile guides were used to estimate the carbon emissions for transportation.[25] Calculations revealed that every CO_2 cylinder used requires 2 miles of semitruck transport time.

Data for the number of disposable instruments, specifically laparoscopic trocars, were obtained from U.S. market engineering research as of 2004,[26] because this was the only published data available nationally. The average weight of a laparoscopic trocar was approximated. Robot-assisted procedures, which usually need three to four disposable instruments, were estimated based on Intuitive Surgical's procedure numbers, instrument catalogue unloaded weights,[27] and using a general rule of 10 uses before disposal. The incineration of the instrument biomedical waste was estimated based on a common carbon footprint calculation with the assumption that incinerating 1 kg of plastic produces approximately 6 kg of CO_2.[28]

Results

There were 2,520,223 MIS procedures included for 2009. The total operative time was estimated at 3,233,917 hours that translated into 2,021,198 CO_2 cylinders. The total CO_2 scope 1 emissions were 303 tonnes (Table 1).

Scope 2 and 3 CO_2 emissions from CO_2 capture/compression were calculated using the EIOLCA model and inputting $69 million of economic sector activity specific to the United States, medical, packaged gas (with Memorial Sloan-Kettering Cancer Center index case correction factor). The subtotal of CO_2 emissions for industrial gas manufacturing, power generation and supply, and gas extraction were calculated as 351,400 tonnes. For CO_2 transportation, the US DOT/GHPI calculation for 4,042,396 miles traveled to deliver CO_2 revealed 2970 tonnes of CO_2 emissions. Finally, to incinerate 208,441 kg of plastic biomedical waste from disposable trocar and robotic instrument use, 1251 tonnes of CO_2 emissions

Table 2. Total Scope 2 and 3 Carbon Emissions for Minimally Invasive Surgery

CO_2 capture/compression		*$USD (millions)*	
U.S. CO_2 supplier	Total global sales (adjusted for inflation) 2009	9102	
	U.S. sales (52%)	4733	
	Medical sector (11%)	521	
	Packaged gas (31%)	161	
	MSKCC MIS correction (43%)	69	
		CO_2 emissions	
EIOLCA calculation	Industrial gas manufacturing	251 000	
	Power generation and supply	83 700	
	Gas extraction	16 700	
	Subtotal CO_2 emissions	351,400	Tonnes
CO_2 transportation	Number of CO_2 cylinders	2,021,198	Cylinders
	Total miles/all cylinders	4,042,396	Miles
US DOT/GHGPI calculation	Subtotal CO_2 emissions	2970	Tonnes
Incineration of biomedical waste			
U.S. laparoscopic trocar data 2004	Number of disposable laparoscopic trocars	6,200,000	Trocars
	Average weight of trocar	30	Grams
	Total weight plastic	186,000	kg
U.S. robotic instrument data 2009	0.8 kg/unloaded instruments/10 uses		
	Total weight plastic	22,441	kg
	Subtotal CO_2 emissions	1251	Tonnes
	Total scope 2–3 CO_2 emissions	355,621	tonnes

USD = United States dollars; MSKCC = Memorial Sloan-Kettering Cancer Center; MIS = minimally invasive surgery; EIOLCA = Environment Input-Output Life-Cycle Assessment; US DOT = United States Department of Transportation; GHGPI = Greenhouse Gas Protocol Initiative.

were generated. The total indirect CO_2 emissions were 355,621 tonnes (Table 2).

The overall CO_2 emissions from MIS were estimated at 355,924 tonnes/year.

Discussion

Sustainable healthcare has only recently entered into the medical lexicon. This first and only attempt by researchers in the United States to quantify the environmental impact of healthcare was published this past year by Chung and colleagues.[5] Their report, using the same EIOLCA tool as the present study, estimated that healthcare contributes to 7% of total U.S. CO_2 emissions per year. They suggested that measuring and then reducing healthcare environmental impact should be considered as an extension of improving healthcare quality overall. Indeed, the National Health Service in England has organized and initiated a Carbon Emission Reduction program as part of their overall sustainable healthcare agenda.[29] Our analysis is an attempt to quantify the carbon footprint of MIS and identify major sources of CO_2 emission to propose mitigating factors in the United States.

A previous small study from the University of Liverpool in 2008 attempted to calculate the carbon footprint of general surgery from 2005 to 2007 at their center.[10] They concluded that laparoscopy contributes a negligible total amount of CO_2 emission to global warming. This claim was unfortunately shortsighted. Their analysis only included direct CO_2 emissions. Similar to our study, the scope 1 CO_2 emissions of MIS are exceedingly small when comparing it on a national and global scale. This narrow thinking is similar to measuring the CO_2 released while drinking an artificially carbonated beverage and concluding that it has no environmental impact because the number is so minute. All processes involved in manufacturing and delivering the beverage, as well as disposal, need to be considered. Thus, the GHG Protocol initiative requires all three scopes to be calculated when performing industry carbon accounting.[30]

There have been a number of unsuccessful attempts to replace CO_2 use in laparoscopy. These efforts have centered on mitigating the potential adverse physiologic, oncologic, and immunologic consequences studied during capnoperitoneum.[31] Ranging from the use of other gaseous mediums such as helium or argon for insufflation, to completely gasless systems, non-CO_2 MIS has not gained widespread acceptance. Consideration of strategies such as these may be a potential approach in reducing the carbon footprint of MIS, although the practicality of this suggestion is at this time limited.

The total estimated CO_2 emission from MIS is 355,924 tonnes of CO_2/year in this study. To put this in perspective, it amounts to just 0.1% of the entire calculated U.S. healthcare carbon emission as evidenced by Chung and coworkers.[5] Another way to put this, however, is that it amounts to driving a medium sized car 80,000 times around the earth at the equator or 645,000 flights from New York City to London.[32] Still another way, MIS in the United States amounts to more CO_2 emission/year than yearly CO_2 emissions of 27 entire countries as listed by the United Nations from 2008 data.[33] It would rank 189th overall.

The monumental task of attempting to empirically quantitate CO_2 emissions according to a specific activity, such as MIS, needs to be emphasized. If measuring CO_2 emissions is the first crucial step in the process of eventually reducing a carbon footprint, more transparency and more statistics are needed by all players to identify mitigating factors.

The overwhelming majority of CO_2 emissions in this study were indirect. Therefore, it is incumbent on healthcare, as a consumer in the industrial market, to work with their suppliers to attempt to reduce the overall carbon footprint. Individuals performing MIS can do their part by reducing the amount of inadvertent CO_2 released during an operation by using the ALARA (as low as reasonably achievable) principle. When factoring in all of the indirect aspects, a small amount of CO_2 conserved can translate quickly into a meaningful impact. Also, using nondisposable items will significantly decrease the carbon footprint. This is of particular concern considering the rise of robotic surgery where there are appreciably more disposable items used than either traditional laparoscopic or open surgery.[2]

Study limitations include the inability to account for uncertainty, particularly using the EIOLCA tool, which has been previously outlined.[5] The scope 2 and 3 carbon emissions relating to the initial CO_2 capture/compression far outweigh other factors calculated; therefore, the final number will reflect any inadequacies and errors intrinsic to the model itself. It is, however, the best estimation method we found for this type of analysis currently available. Interestingly, the major CO_2 supplier used as an index case in our model publishes a sustainability report and their company's complete carbon disclosure.[34] They have been recognized as a leader in corporate responsibility and sustainability, likely because of their commitment to such processes. Our estimate is surprisingly validated considering so many factors. For 2009, they report, in a statement of GHG emissions, that their scope 1 emissions categorized according to CO_2 as the source as 320,000 tonnes CO_2 emissions. Their scope 2 emissions were 9,317,000 tonnes, and scope 3 emissions were 226,000 tonnes. Again, using their annual report percentages for 2009 (52% U.S. sales, 11% medical sector, 31% packaged gas, 43% MIS correction factor), the total emissions are 75,203 tonnes of CO_2 emissions. This represents 21% of our calculated total; however, there are a number of other companies that supply medical gas to hospitals in the United States. Unfortunately, no other company has as rigorous carbon accounting as the index company and

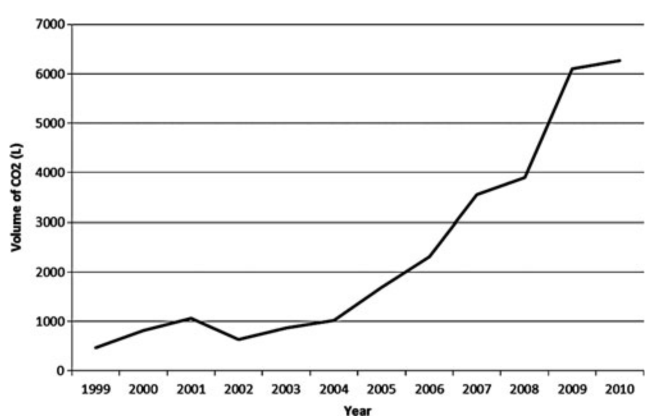

FIG. 1. Our institution's volume of carbon dioxide operating room use for minimally invasive surgery from 1999 to 2010.

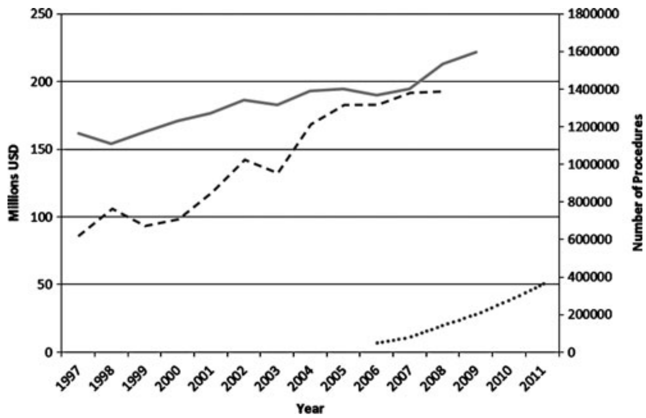

FIG. 2. Trends of United States yearly inpatient laparoscopic procedures (—), yearly robot- assisted procedures (.....), and carbon dioxide supplier's yearly U.S. medical packaged gas sales adjusted for inflation (- - - -).

therefore external validation of our estimate is not possible at this time.

We did, however, perform a number of analyses in an attempt to demonstrate an association between the increased use of MIS, increased CO_2 use, and, consequently, increased carbon footprint. Using our institution's operating room CO_2 use since 1999, a sharp increase is noted in 2005 when robot-assisted surgery use rose dramatically (Fig, 1). By combining our CO_2 supplier's yearly sales in medical packaged gas to the United States from1997 to 2008 (adjusted for inflation and just before the U.S. financial market crisis), total number of laparoscopic cases performed in the United States (from 1997–2009 in the Nationwide Inpatient Sample collected by the Healthcare Cost and Utilization Project dataset), and Intuitive Surgical's reported U.S. robot-assisted procedures (2006–2011), an apparent association becomes evident (Fig. 2). All indications from this analysis point to increasing use of CO_2 in operating theaters over time. Furthermore, if our CO_2 emissions estimate is correct and this trend continues, the carbon footprint of MIS may become a significant issue for sustainable healthcare in the future.

Conclusion

The CO_2 emissions of MIS in the United States, when considering both direct and indirect factors, have a significant environmental impact. This should be considered in larger strategies to reduce healthcare's carbon footprint while maximizing healthcare quality.

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Abbreviations Used

CO_2 = carbon dioxide
EIOLCA = Environment Input-Output Life-Cycle Assessment
GHG = greenhouse gas
GHGPI = Greenhouse Gas Protocol Initiative
MIS = minimally invasive surgery
U.S. = United States
US DOT = United States Department of Transportation