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Original Research Article

The contribution of anaesthesia and surgery to global warming: A carbon footprinting study of operating theatres in three different surgical specialties—A prospective observational analysis

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Abstract

Background: Climate change is one of the most pressing global challenges, with significant consequences for public health. As healthcare services are major contributors to greenhouse gas (GHG) emissions, understanding their carbon footprint is critical in the fight against global warming. This study aimed to quantify the carbon footprint of operation theatres (OTs) in three different surgical specialties.

Materials and Methods: A prospective observational study was conducted over 8 weeks in three OTs, representing different surgical specialties: OT1 (Obstetrics) with regional anaesthesia (RA), OT2 (Surgical-Laparoscopy) with general anaesthesia (GA), and OT3 (Urology), which used both RA and GA as needed. Carbon emissions were measured across three scopes defined by the GHG protocol: Scope 1 (direct emissions from inhaled anaesthetics), Scope 2 (indirect emissions from electricity consumption), and Scope 3 (emissions from biomedical waste disposal). Emissions were reported as CO_2 equivalents (CO_2e).

Results: In OT1, no emissions were recorded for Scope 1, whereas OT2 generated 6904.78 kg of CO_2e from isoflurane and 325.39 kg from sevoflurane. OT3 produced 2861.1 kg of CO_2e from isoflurane and 157.76 kg from sevoflurane. Scope 2 emissions were 2957.05 kg for OT1, 1988.75 kg for OT2, and 2777.64 kg for OT3. Scope 3 emissions from biomedical waste disposal were similar across all OTs. Total CO_2e emissions were 4131.41 kg (20%) for OT1, 10273.96 kg (48%) for OT2, and 6840.82 kg (32%) for OT3. The emissions from OT1 were significantly lower than OT2 ($p<0.05$).

Conclusion: The study demonstrates that operating theatres are significant contributors to GHG emissions, with anaesthetic gases and energy consumption being the primary sources. Reducing these emissions should be a priority for healthcare sustainability efforts.

Keywords: Carbon footprint, Disposable plastics, General anaesthesia, Global warming, Medical waste.

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1. Introduction

Climate change is a major global public health priority. The delivery of health-care services generates considerable GHG emissions.[1] Operation theatres are a resource-intensive subsector of health care, with high energy demands, consumable load, and waste volumes. This study is the need of the era to obtain data and later adopt measures to reduce the greenhouse gas emissions from healthcare services. The carbon hotspots are single use plastics, inhalational volatile gases, intravenous drugs, air warmer and air conditioning.[2] These activities are generally accepted as necessary for the provision of quality care, but their environmental impact has not been examined in detail so far. In this study, the carbon footprint of 3 operation theatres has been estimated where surgeries of different surgical specialties were conducted over a period of 8 weeks.

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Chung JW in 2009, in a study to estimate the carbon footprint of the USA health care sector, concluded that "The health care sector, including upstream supply-chain activities, contributed an estimated total of 546 million metric tons of carbon dioxide equivalent ($MMTCO_2Eq$), of which 254 $MMTCO_2Eq$ (46%) was attributable to direct activities. The largest contributors were the hospital and prescription drug sectors (39% and 14%, respectively)." Approximately 80% of total global warming potential was due to carbon dioxide emissions.[2]

In a study in 2012, Mads P. Sulbaek Andersen, concluded that "Key criteria that will determine the global environmental impact of alternatives to halogenated anaesthetics and nitrous oxide are their atmospheric lifetime, Global Warming Potential (GWP), and Ozone Depleting Potential (ODP). These characteristics should be determined for existing anaesthetics, and for any new anaesthetic gases before widespread clinical use." It is agreed that before the large-scale use of any industrial compound, an assessment of the atmospheric chemistry, and thereafter environmental impact is a must. Using clinical knowledge of anaesthetic potency and resulting flow rate requirements, together with the 100-year GWP values, allows the anaesthesiology community to calculate the CO_2 emissions equivalent (i.e., future climate impact) of each anaesthetic procedure.[3]

Jodi Sherman, in 2012 conducted a study and concluded that for all inhaled anaesthetics, GHG impacts are dominated by atmospheric anaesthetic gas waste emission. They used life cycle assessment to examine the climate change impacts of 5 anaesthetic drugs: sevoflurane, desflurane, isoflurane, nitrous oxide, and propofol. Desflurane accounts for the largest life cycle GHG emissions amongst the anaesthetic drugs considered here, both in terms of waste anaesthetic gas and other life cycle stages. Life cycle GHG emissions of desflurane are 15 times that of isoflurane and 20 times that of sevoflurane as per Minimum Alveolar Concentration (MAC) per hour basis when administered in an O_2/air admixture. GHG emissions increase significantly for all drugs when administered in an N_2O/O_2 admixture. GHG impacts of propofol are comparatively quite small. Unlike the inhaled drugs, the GHG impacts of propofol primarily stem from the energy needed to operate the syringe pump and not from environmental releases of the drug.[4]

Not many studies have been conducted in India determining the contribution of anaesthesia to global warming and hence, keeping the above facts as a framework, this study was conducted, which will be an important milestone towards achieving a greener environment.

The primary objective of this study was to calculate the carbon dioxide CO_2e from gas emissions, energy consumed and waste generated in 3 different specialty OTs' in a tertiary care hospital. The secondary objective was to determine whether there was a difference in the above parameters between different surgical specialties and anaesthetic techniques employed.

2. Materials and Methods

This prospective cross-sectional study was conducted after obtaining ethical clearance from the institutional ethical committee (RRMCH-IEC/40/2023) and registering with the Clinical Trials Registry of India (CTRI/2023/06/053583). The study was carried out at a tertiary care hospital over a period of 8 weeks. Data were collected from three strategically selected operation theatres (OTs) where various anaesthesia techniques were employed for all elective cases conducted between 8:00 AM and 7:00 PM. OT-1 was dedicated to obstetric cases under regional anaesthesia (RA), OT-2 was used for surgical laparoscopic cases under general anaesthesia (GA), and OT-3 handled urological cases, using either RA or GA, depending on the patient and surgical requirements.

GA was administered according to institutional protocols. Prior to surgery, patients were confirmed to be nil per os (NPO), and standard ASA monitors were attached. Pre-medication included intravenous Inj. Midazolam (0.02 mg/kg) and Inj. Glycopyrrolate (0.01 mg/kg). Preoxygenation was performed with 100% oxygen, followed by induction with Inj. Fentanyl (1-2 µg/kg) and Inj. Propofol (1-2 mg/kg). Intubation was facilitated using Inj. Vecuronium (0.1 mg/kg), with an oral cuffed endotracheal tube and cuff inflation done with air. Following confirmation of end-tidal carbon dioxide and bilateral equal air entry, the tube was secured. Maintenance anaesthesia was provided with a 1:1 mixture of oxygen and air (flow rates: 3-4 L/min) along with inhaled anaesthetics such as isoflurane or sevoflurane (MAC 1 to 1.5), and intermittent doses of Inj. Vecuronium as needed. Bispectral index (BIS) values were maintained between 40-60. RA included subarachnoid block, epidural anaesthesia, or combined spinal epidural anaesthesia, depending on the patient and surgical requirement.

The carbon footprint was calculated based on the Greenhouse Gas (GHG) Protocol, a unit of the World Resources Institute (WRI), which defines three scopes of emissions for accounting and reporting.[5] For Scope 1, direct emissions from volatile anaesthetics used in each OT were determined by the weekly volumes of isoflurane and sevoflurane administered. Since these volatile anaesthetics undergo minimal in-vivo metabolism, the administered volume approximates the waste anaesthetic gas volume.[6]

GWP is the measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of CO_2. Emissions in CO_2 equivalents (kg CO_2e) was calculated using GWP values from the work of Sulbaek Andersen and colleagues, which is a measure of the contribution of a greenhouse gas to climate change over a 100-year time horizon. Carbon dioxide equivalents (CO2e) were calculated using the Global Warming Potential (GWP) values of isoflurane (GWP = 510) and sevoflurane (GWP = 130). The formula used for calculation was: CO_2e (kg) = (Density × Volume in ml × GWP) / 1000. The GWP of isoflurane and sevoflurane are 510 and 130 respectively. Density of isoflurane and sevoflurane are 1.496 and 1.517.

Scope 2 emissions, representing indirect emissions from electricity consumption, were calculated by assessing the total electricity consumed by various equipment in the OT, such as the HVAC system, cautery, lights, monitors, workstations, and suction devices.[7] Energy consumption was measured in kilowatt-hours (KWh) using separate electrical meters in each OT, and CO_2e emissions were calculated using grid intensities provided by the local electricity utility (Karnataka Electricity Board). In addition, energy consumed for laundry (including gowns, drape sheets, and linen) and for autoclaving instruments was measured, and the corresponding emissions were calculated using a conversion factor of 0.85 kg CO_2e per KWh.

For Scope 3 emissions, the total weight of biomedical waste generated in each OT was measured. Waste was processed by a biomedical waste management company (Maridi Eco Industries), with whom the hospital had a Memorandum of Understanding (MOU).8 The waste processing involved shredding, autoclaving, and incineration, all of which consumed electricity. The CO_2e released was calculated based on the energy required to power these processes, and emissions were calculated accordingly. Waste was collected on regular basis and stored at their facility after which it got processed on a daily basis. All single use plastics underwent shredding in a 200kg/hr shredder, reusable waste underwent autoclaving in a 3000litre/hr capacity autoclave. The disposables, tissues and infectious waste were incinerated using a 450kg/hr capacity incinerator. The electricity needed to power these modalities were calculated in KWH and CO_2 Equivalents released accordingly.

Data collected for each scope across the three OTs were entered into a Microsoft Excel spreadsheet daily for 8 weeks. A complete enumeration of all cases conducted in the three OTs between 8:00 AM and 7:00 PM during the study period was considered for analysis. As the study aimed to analyze all cases within the specified time frame, a specific sample size was not predefined. Therefore, the entire population of surgeries conducted during the study period was included, eliminating the need for a sample size calculation. Descriptive statistics were used to present the data as numbers and percentages. For inferential analysis, a Z-test was applied to determine the statistical significance of the data. A p-value of less than 0.05 was considered statistically significant.

3. Results

Over the course of eight weeks, total operating room (OT) utilization was recorded as 315.7, 258.1, and 256 hours for OT 1, OT 2, and OT 3, respectively (**Table 1**). The average weekly OT utilization was 39.46 hours for OT 1, 32.26 hours for OT 2, and 32 hours for OT 3 (Table 1). Additionally, the average number of cases conducted per week were 16.37 for OT 1, 13.62 for OT 2, and 10 for OT 3 (**Table 2**).

Table 1: Duration of anesthesia administered in the respective OTs over 8 weeks

Duration of Anesthesia	**OT 1 (Hours)**	**OT 2 (Hours)**	**OT 3 (Hours)**
Week 1	42.5	36.5	38.5
Week 2	40.6	30.4	36.6
Week 3	45.4	34.6	30.4
Week 4	36.6	30.4	30.8
Week 5	40.3	28.6	32.2
Week 6	38.4	32.8	26.5
Week 7	41.3	36.1	32.2
Week 8	30.6	28.7	28.8
Total duration of anesthesia in hours	315.7	258.1	256
Average duration of anesthesia in hours in a week	39.46	32.26	32

Carbon dioxide equivalents (CO_2e) released from each OT, with respect to the usage of anaesthetic gases—specifically isoflurane and sevoflurane—were compared (**Figure 1**). OT 1, which is an obstetric OT, did not administer general anaesthesia (GA) during the study period, and thus no anaesthetic gases were used. In contrast, OT 2 (surgical laparoscopy) produced a total of 6904.78 kg of CO_2e, with 325.39 kg attributed to isoflurane and sevoflurane, while OT 3 (urology) produced 2861.1 kg of CO_2e, with 157.768 kg from the same gases.

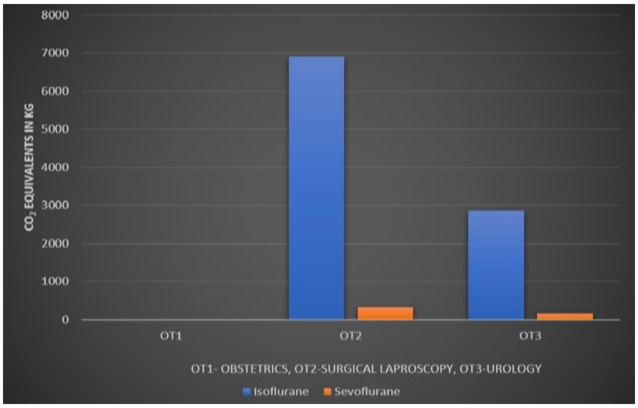

Figure 1: CO_2 equivalents from anaesthetic gases

Power consumption for each OT was also analyzed, with the CO2 equivalents calculated based on the power consumed (**Figure 2**). OT 1 emitted 2957.05 kg, OT 2 emitted 1988.75 kg, and OT 3 emitted 2777.64 kg of CO_2 equivalents.

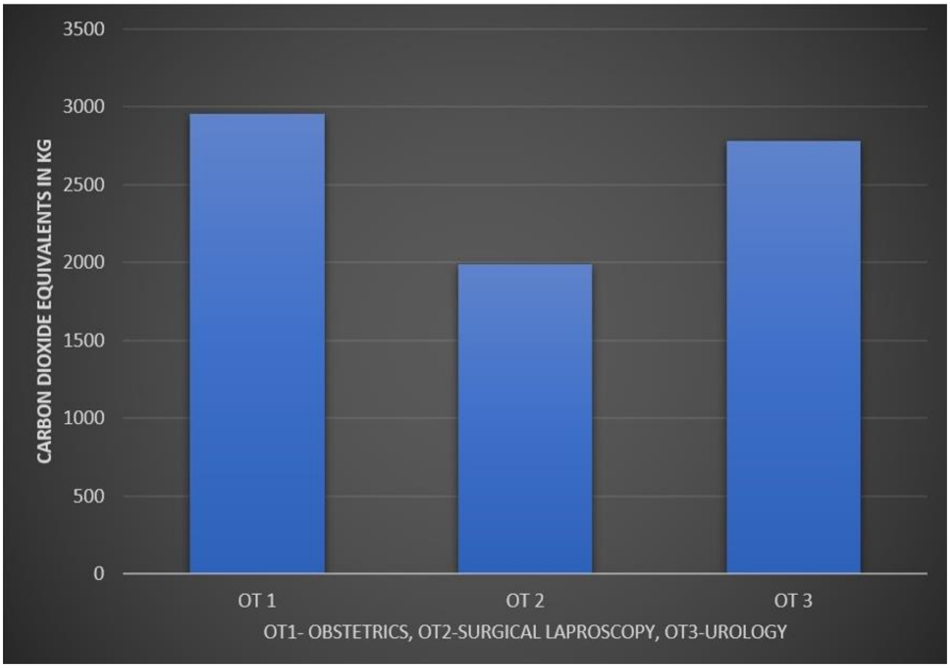

Figure 2: CO_2 equivalents from power consumption

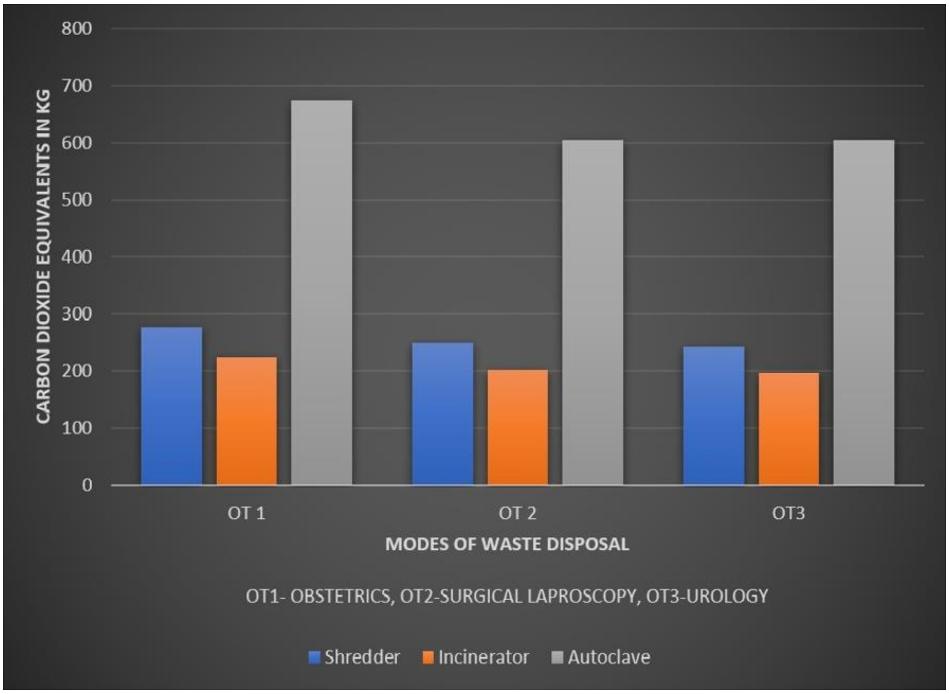

Figure 3: CO_2 equivalents from biomedical waste management

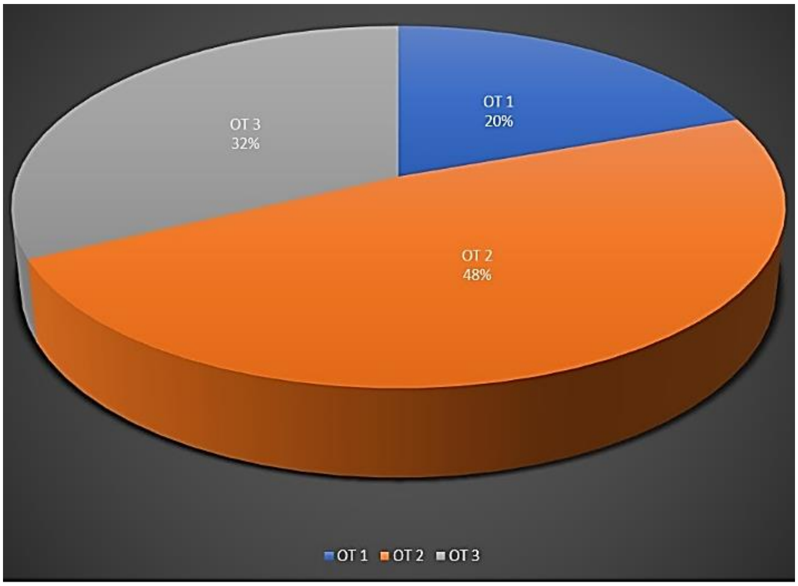

Figure 4: Overall contribution of CO_2 equivalents in Kg from each OT

Further analysis was conducted on the CO_2 emissions resulting from the disposal of biomedical waste through various modalities, including shredding, autoclaving, and incineration, with the data obtained from MARIDI Private Limited (**Figure 3**). The power consumption for each modality was summed in kilowatt-hours (kWh), with the autoclaving process consuming the most energy due to its need for sustained heat and high pressure. These power values were converted into CO_2 equivalents using an emission factor of 0.85 kg per kWh. The emissions from biomedical waste disposal were as follows: OT 1 produced 1174.36 kg, OT 2 produced 1055.44 kg, and OT 3 produced 1044.22 kg of CO_2 equivalents.

The total CO_2 equivalents from all sources were then calculated for each OT. OT 1 contributed 4131.41 kg (20%), OT 2 contributed 10273.96 kg (48%), and OT 3 contributed 6840.82 kg (32%) of the total CO_2 emissions over the 8-week period. A statistically significant difference in CO_2 emissions was observed between OT 1 and OT 2 ($p < 0.05$) (**Table 3**). Finally, the CO_2 equivalent per hour of OT utilization was extrapolated, yielding values of 13.08 kg for OT 1, 39.80 kg for OT 2, and 26.72 kg for OT 3 (**Table 4**).

Table 2: Number of cases conducted in the respective OTs over 8 weeks

Number of Surgeries	**OT 1**	**OT 2**	**OT 3**
Week 1	18	16	10
Week 2	16	14	12
Week 3	18	15	10
Week 4	14	14	10
Week 5	16	11	12
Week 6	17	15	8
Week 7	18	14	10
Week 8	14	10	8
Average number of surgeries in a week	**16.37**	**13.62**	**10**

Table 3: Comparison of CO_2 equivalents between the OTs

Description	**OT utilisation per week in Hours**	**CO_2 Equivalents in Percentage**	**p value**
OT 1 OT 2	39.46 32.26	20 48	**0.01174**
OT 2 OT 3	32.26 32	48 32	0.1902
OT 3 OT 1	32 39.46	32 20	0.246

Table 4: Carbon dioxide equivalents produced per hour of OT utilisation

OT'S	**OT1**	**OT2**	**OT3**
OT utilisation over 8 weeks in Hours	315.7	258.1	256
Total CO_2e in Kg	4131.41	10273.96	6840.828
CO_2e in Kg/hr	13.08651	39.80612	26.72198

4. Discussion

The healthcare sector, while essential for patient well-being, also contributes significantly to greenhouse gas (GHG) emissions, with anaesthesiology being a notable area of concern. Anaesthesiologists play a critical role in ensuring patient safety during surgical procedures, but the environmental footprint of anaesthesia practices is often overlooked. Given the increasing awareness surrounding climate change and its potential consequences, there has been a growing movement within the anaesthesiology community to reduce the environmental impact of their practices, specifically in terms of carbon emissions and biomedical waste management. Recent studies suggest that anaesthesiologists, as stewards of medical practice, can make meaningful contributions to the sustainability of healthcare systems by adopting greener protocols and technologies.[9]

Anaesthetic gases, in particular, are known to have substantial global warming potentials, with gases such as desflurane being up to 2,500 times more potent than carbon dioxide in terms of GHG emissions. This has prompted calls for minimizing their use where possible. Additionally, the widespread reliance on disposable surgical supplies, which contribute to significant waste generation, further exacerbates the environmental impact of anaesthesiology practices.[10,11]

From this study, it was observed that anaesthetic gases played a significant role in the production of CO_2 equivalents. In OT1, which used regional anaesthesia (RA), it contributed only 20% of the total CO_2 produced, despite having the longest OT utilization hours (315.7 hours). On the other hand, OT2, where general anaesthesia (GA) was administered exclusively, contributed 48% of the total CO_2 produced. This highlights the greater environmental impact of GA compared to RA.

In India, a typical passenger car emits 2.3035 and 2.68 kg of CO_2 equivalents per liter of petrol and diesel, respectively.[12] The CO_2 produced from a 5-hour surgical case using isoflurane and sevoflurane is equivalent to driving a typical diesel car with an average fuel efficiency of 15 km/l for 879.23 km and 227.30 km, respectively. Despite the increased number of cases in OT1 leading to higher power consumption, this did not result in a proportional increase in total CO_2e emissions, as the use of regional anesthesia offset the CO_2e increase caused by power consumption.

In OT3, which saw an increased use of endoablation in urology, power consumption was higher. However, no statistically significant difference was found in the carbon equivalents between OTs 1 and 3. An important factor contributing to power consumption in all OTs was laundry, which included gowns and draping sheets. This was particularly significant in Obstetrics. Furthermore, biomedical waste management was another crucial factor contributing to global warming. The biomedical waste generated was similar across all three OTs. Disposables were shredded, while reusables were autoclaved, both of which contributed to CO_2 production.

A narrative review by Mishra et al. examined 51 articles using the keywords anesthesia, environment, and pollution. They concluded that inhaled anaesthetics had significant greenhouse gas (GHG) effects and suggested that adopting regional anesthesia, low-flow anesthesia techniques, and the use of adjuvants during general anesthesia (GA) and total intravenous anesthesia (TIVA) could reduce environmental impacts and emissions.[13] Additionally, Upadya et al., in their review article on low-flow anesthesia techniques, highlighted that low-flow anesthesia is the most sustainable approach in modern-day practices.[14]

In 2019, Aanandaswamy et al. conducted a study on the assessment of knowledge, attitude, and practices regarding biomedical waste (BMW) management among OT personnel in a tertiary care center. They identified several deficiencies in knowledge and practices in BMW management, along with a lack of training among various categories of operating room personnel. They highlighted the need to reorient and train OT personnel for BMW disposal.[15] In the present study, BMW was segregated efficiently, and techniques were standardized for all OTs.

Andrea McNeill et al., in 2017, compared the carbon footprint of three different hospitals in the US, Canada, and the UK by using the GHG protocol in their operating theatres. All patients were administered GA. They estimated the total carbon equivalents in each hospital and concluded that the avoidance of desflurane significantly reduced the carbon footprint.[5] In the present study, one OT was dedicated to regional anesthesia, another to laparoscopic surgery with GA using sevoflurane/isoflurane, and desflurane was not used. In the third OT, either GA or regional anesthesia was administered as per patient requirements. The carbon equivalent by type of anesthesia could thus be determined.

Chantelle Rizan et al., in their 2020 systematic review on calculating the carbon footprint of surgical operations, found that major carbon hotspots within the examined operating theatres were electricity use and procurement of consumables.[16]

The present study provided concrete data to convince surgical colleagues to adopt environmentally friendly anaesthetic techniques. The anesthesia protocol was modified to use regional anesthesia wherever possible, and a consensus was reached to practice total intravenous anesthesia (TIVA) and regional anesthesia (RA) in thoracic segments for major surgeries with the concurrence of surgeons. To familiarize juniors and students with these techniques, TIVA workshops were conducted. These efforts contributed to better acceptance and awareness of the environmental impact of anesthesia practices.

However, the study has several limitations. It was conducted in a single hospital, and the findings may not be generalizable to other healthcare settings with different surgical practices, anesthesia protocols, or available resources. The waste generated during the manufacture of anaesthetic gases was not taken into account. Consumption of gases and power could have varied with the duration, type of surgery and the expertise of the surgeon.

Recommendations include the implementation of mandatory Green OT certification across healthcare facilities, which could promote sustainability in the operating theatre. Minimizing general anesthesia (GA) and opting for regional anesthesia whenever possible would help reduce environmental footprints. When GA is necessary, prioritizing total intravenous anesthesia (TIVA) over inhalational techniques would further reduce emissions. The practice of administering low-flow anesthesia during inhalational procedures should be encouraged to lower CO_2 output. Additionally, optimizing ventilation, heating, and cooling systems in operating rooms can significantly reduce CO_2 emissions. Regular audits on waste management practices and the reduction of biomedical waste and single-use disposables are essential steps toward a more sustainable healthcare environment. Reutilizing equipment without compromising safety standards would also be a key factor in minimizing environmental impact.

5. Conclusion

The study highlights the potential for reducing the carbon footprint of operating theatres through strategic modifications in anesthesia practices. With the successful modification of protocols, adoption of sustainable techniques, and proper training, the environmental impact of surgical operations can be significantly mitigated. Despite the challenges in implementation, the findings create a strong foundation for future efforts in sustainable healthcare practices and contribution to stop global warming, making the world a cleaner place for future generations.

6. Source of Funding

None.

7. Conflict of Interest

None.

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