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ORIGINAL ARTICLE

An Audit on the Consumption of Inhalational Anaesthetic Agents at Mater Dei Hospital

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Background

nhalational anaesthetic agents carry a considerable cost, both economic and environmental. Consumption of such medications is related to the fresh gas flow, which is controlled by the attending anaesthetic team.

Method

Data was collected over a period of twelve weeks with intermittent, random observations of fresh gas flow rate and anaesthetic agent concentration performed by an investigator not being actively involved in the anaesthesia delivery. The type of procedure performed, time from induction, age of the patient and the type of airway device used were also collected.

Results

A total of three hundred and thirty-eight visits were made. The median FGF observed was 2L/min. Sevoflurane was the commonest anaesthetic gas used at a median MAC of 1.25.

Conclusion

A more economical use of anaesthetic agents is possible, with a potential reduction of FGF from 2L/min to 1L/min or less.

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Since the first successful demonstration of an anaesthetic agent in 1846.[1], anaesthesia is one of the few fields in medical care that utilizes therapeutic agents in a gaseous form. Indeed, the anaesthetic workstation has been developed with the aim of safely delivering anaesthetic gases together with oxygen to a patient during surgical procedures.

A carrier gas, known as fresh gas flow, is passed through dedicated vaporizers (Figure 1). The resulting gas mixture is then delivered to the patient during ventilation. The concentration of the anaesthetic gas is adjusted by the vaporizer setting, as a percentage volume of the total fresh gas flow.

The current anaesthetic practice uses isoflurane, sevoflurane and desflurane. These have different properties that influence anaesthetic choice (Table 1, Table 2). Isoflurane is cheaper but has a slower recovery. Desflurane is expensive but offers the fastest recovery. Sevoflurane is sweet-smelling and is the best choice for a gaseous induction, such as in paediatric anaesthesia. Minimum alveolar concentration (MAC) is the minimum concentration of an inhalational anaesthetic agent, that is the end-tidal concentration, required to prevent muscle movement in response to a surgical stimulus in 50% of patients, at room temperature and pressure. MAC is expressed as a percentage of the inspired gas mixture and is a measure of the potency of the inhaled agent. An agent with a higher MAC value will have a lower potency as it means that a higher concentration of the agent is required to achieve the desired effect [2]

The cost of an inhalational agent is dependent on the choice of agent and on the fresh gas flow. Since the vaporizer will deliver an amount of anaesthetic agent as a percentage volume of the fresh gas flow, the consumption of anaesthetic agent is directly proportional to the fresh gas flow. Modern anaesthetic systems with a circle breathing system allow reusing of exhaled gas, but any excess is vented to atmospheric air. Indeed, anaesthesia accounts for 0.1% of the total daily output of greenhouse gases.[3] This may seem negligible, but such reasoning does not consider the longevity of some anaesthetic gases compared to CO_2.[4] Furthermore, it is possible to reduce this amount by changing anaesthetic practices.

The aim of low-flow anaesthesia is to replenish the consumed gases with as little fresh gas as possible whilst ensuring carbon dioxide is removed from the circuit to avoid rebreathing. This will reduce the amount of volatile agents escaping into the environment, therefore saving costs.[5] For this to be

Table 1 *Physical properties of common currently used volatile anaesthetic agents*

	Sevoflurane	Isoflurane	Desflurane
MAC (%)	1.8	1.18	6
Oil/Gas Solubility	53	97	19
Blood/Gas Solubility	0.6	1.4	0.42
Boiling point (°C)	58	48	23.5
% Metabolism	3	0.2	0.02
Vapour Pressure at 20°C (mmHg)	157	238	669

Table 2 *Advantages and disadvantages of each inhalational anaesthetic agent*

	Sevoflurane	Isoflurane	Desflurane
Stability in light	+++	+++	+
Pleasant smell	+++	-	-
Flammable	-	-	+
Stability with soda lime	+	+++	+++
Cost	++	+	+++
Metabolism	+++	++	+
Potency	++	+++	+
Recovery	++	+	+++
Ease of administration	++	++	-
Bronchodilation	+++	+	+
Cardiovascular stability	+++	+	+

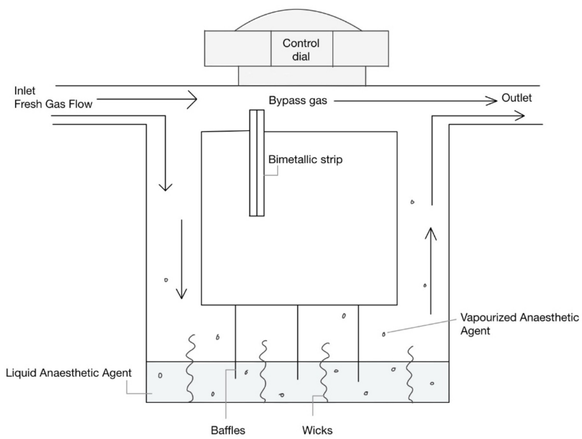

Figure 1 *Diagram of a simplified variable bypass vaporizer used for Sevoflurane and Isoflurane*

effective, at least 50% of the exhaled gas volume must be returned to the patient after removing carbon dioxide. With modern anaesthetic machines, this could be achieved using flows between 1-2 L/min.[6] Low flow anaesthesia is described to be less than 1 L/min by Foldes in 1954 and minimal flow anaesthesia to be 0.5 L/min by Virtue in 1974.[7]

This observational study aims to highlight the consumption of inhalational anaesthetic agents in daily use at Mater Dei Hospital. This is done by investigating the fresh gas flow and corresponding agent concentration during anaesthesia after ten minutes have elapsed from the start of anaesthesia.

METHOD

The study was an observational study carried out prospectively in one centre. Permission to carry out the study was granted by the relevant authorities, including Data Protection. Ethical approval was not sought since this study did not involve any subjects.

The primary outcome was the use of fresh gas flow during maintenance, and the use of volatile anaesthetic agent. Secondary outcomes included oxygen concentration used in anaesthesia, the relationship between airway device and anaesthesia concentrations, and the cost of anaesthetic agents, as discussed below.

Data was collected over twelve weeks. Intermittent, random observations of fresh gas flow rate and anaesthetic agent concentration were performed by an investigator not involved in the anaesthetic care. This was done by randomly dividing time slots between investigators when to visit theatres. The individuals responsible for setting the fresh gas flows were higher specialist trainees and above including resident specialists and consultants. However, the level of seniority was not noted, and thus ad-hoc observations were made. Data on the type of procedure performed, time from induction and the type of airway device used was also collected.

Procedures performed under general anaesthesia with a volatile anaesthetic were included in this study. This included emergency, urgent, and elective cases. No data was collected if no volatile anaesthetic agent was used, such as if surgery was performed under local or regional anaesthesia, or if total intravenous anaesthesia was used. The data was collected at least ten minutes after induction of anaesthesia. Any visits made before ten minutes were excluded.

Table 3 *Cost of Inhalational Anaesthetic Agents*

	Sevoflurane	Isoflurane	Desflurane
Volume in Bottle (mL)	250	250	240
Cost per Bottle (€)	74.85	24.21	85.15
Cost per mL (€)	0.299	0.097	0.341

All data was gathered into an Excel® sheet (version 2202, Microsoft, California, US). Statistical analysis was performed with R (version 4.2.2), using R Studio (version 2023.03.0+386). Univariate analysis was performed with non-parametric tests where appropriate. Data was first checked for normality and skewness using visual methods. Testing for normality was done using the Shapiro-Wilk test. When appropriate, t-tests, Mann-Whitney U tests, Kruskal-Wallis test and chi-squared tests were used for univariate analysis. Most results reported showed skewness, so median values are reported, rather than means. With a p-value of 0.05 or less, the result was taken to be significant.

Finally, an estimate of the cost of volatile agent use in Mater Dei Hospital was calculated. The cost of each anaesthetic agent was obtained from hospital sources (Table 3). The median gas flow and median concentration for each gas were multiplied to obtain the median consumption of each gas. This was translated into the consumption of liquid agent as described by Biro et al[8] and the cost per hour was then calculated.

RESULTS

In total, there were 383 visits spread over 35 days, of which 244 visits were done during maintenance of anaesthesia with a volatile agent (Figure 2). The median time of visit from the start of induction was 49 min (IQR: 20 – 90 min).

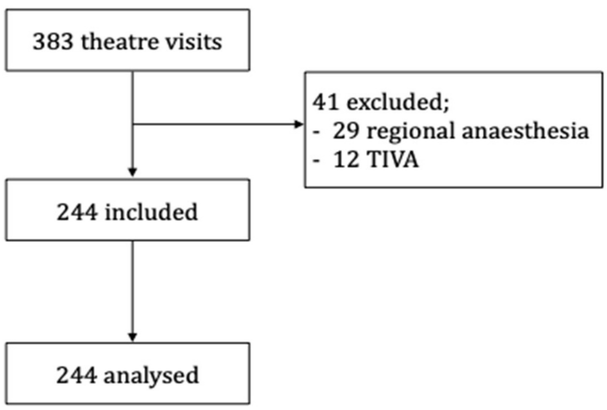

Figure 2 *Consort flow of results*

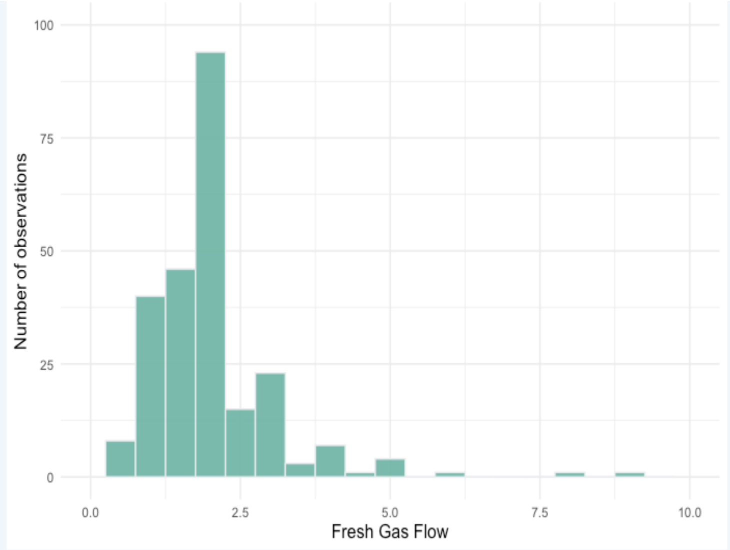

Figure 3 *Distribution of Fresh Gas Flow in L/min*

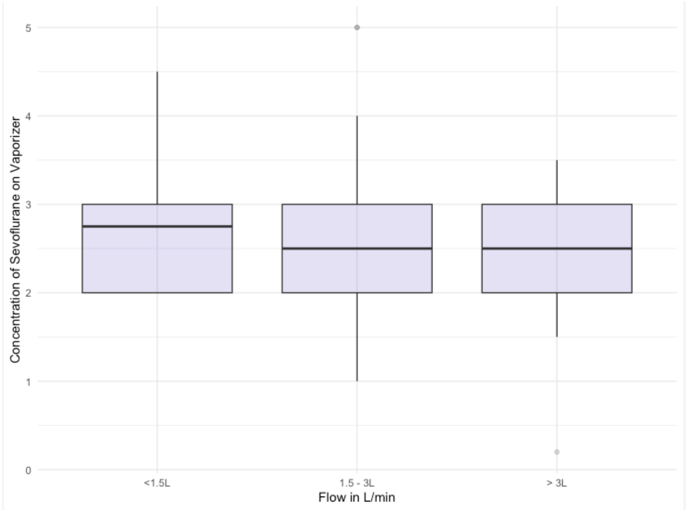

Figure 4 *Relationship between concentration of sevoflurane on vaporizer and flow in L/min*

The median Fresh Gas Flow (FGF) used at the time of the observation was 2L/min (IQR 1.5 – 2 L/min), with a maximum of 9 L/min in one case. This is shown in Figure 3.

The most used inhalational anaesthetic agent was Sevoflurane, used in 205 cases (84%), followed by Isoflurane in 32 cases (13%) and Desflurane in 7 cases (3%). The median FGF used for each gas was not statistically different (Sevoflurane: 2L/min, Isoflurane: 2L/min and Desflurane 1.2L/min, p=0.061).

The median consumption of each agent was calculated and used to calculate an estimated cost per hour using each anaesthetic agent, shown in Table 4.

In the case of Sevoflurane, there was no relationship between the FGF and the vaporizer setting as shown in Figure 4. The mean concentration of Sevoflurane used on the vaporizer was not statistically different at different levels of FGF.

We observed that the majority (71%) of cases involved endotracheal intubation (ETT: 173 cases vs LMA: 70). There was no statistical difference between the choice of airway and FGF (both 2L/min, p = 0.099).

There was no relationship between the FGF employed and the time from induction when sevoflurane was used. Due to the low number of cases involving either isoflurane or desflurane, we did not perform a similar analysis for these anaesthetic gases.

The mean oxygen concentration observed in this observational study was 0.6 (SD: 0.085). There was no difference when the type of volatile agent was compared. There was also no relationship between FGF and oxygen concentration.

DISCUSSION

We have shown that in a single-centre operating theatre suite, the median fresh gas flow was 2L/min. This is consistent with data from other centres. Dexter et al found an average fresh gas flow of approximately 2L/min in a single centre in 2001, with a reduction to 1.27L/min [9] when re-assessed in 2006.

Table 4 *Consumption of each agent and cost per hour*

Anaesthetic Agent	Median FGF (L/min)	Concentration %	Consumption, Vapour (mL/min)	Conversion 1ml liquid agent to volatile (ml)	Consumption, Liquid (mL/min)	Cost per Hour (€)
Sevoflurane	2	2.5 [IQR: 2-3]	50	184	0.27	€4.88
Isoflurane	2	1.5 [IQR: 1.2-2]	30	195	0.15	€0.87
Desflurane	1.2	6 [IQR: 5.5-7]	72	210	1.34	€6.96

In another observational study carried out using information gathered from the anaesthetic machines databases over 2008 covering 11,700 cases, the mean FGF for Sevoflurane was 2.49L/min, for Isoflurane 1.89L/min and for Desflurane 1.87L/min [10] More recently, in 2018, an audit at Memorial Sloan Kettering Cancer Centre, USA found a mean FGF of 2.55L/min when using sevoflurane.[11] During the audit, potential bias could have arisen because participants might have been more cautious when setting their fresh gas flows if they were aware of the ongoing audit, even though the investigators were discrete.

Currently, no best practice guidelines exist on the use of fresh gas flows or the practice of low-flow anaesthesia. The Royal College of Anaesthetists, in their 2020 quality improvement compendium, recommend the use of low-flow anaesthesia by reducing initial rates during induction to 6L/min and then moving to 0.5L/min or less after intubation as an intervention to reduce carbon emissions.[12]

The manufacturer of sevoflurane recommends a flow rate of 1-2L/min to limit potential exposure to compound A. It is licensed for use of an exposure limited to 2 MAC hours at flow rates of 1-2L/min.[13] There are no recommendations for isoflurane and desflurane. According to R. Ross Kennedy et al, Sevoflurane has demonstrated safe usage at fresh gas flow rates below 1L/min, Furthermore, it has been established that Compound A, at concentrations encountered in anaesthesia, does not exhibit harmful effects on humans.[14]

In the current economic and environmental constraints, knowing the consumption of anaesthetic agents and optimising such use might be beneficial. Volatile anaesthetic agents, nitrous oxide and fluorinated agents such as sevoflurane, isoflurane and desflurane are greenhouse gases and ozone-depleting.[15], therefore exerting a negative environmental impact. The main concern is the contribution to climate change[16] The global warming potential (GWP) is used to compare the global warming impacts of different gases by comparing them to carbon dioxide. The GWP of halogenated volatile anaesthetics is up to 2000 times greater than carbon dioxide.[17] Through the anaesthetic gas scavenging system, the minimally metabolised volatile agents are vented to the atmosphere limiting exposure to personnel in theatre. However, waste gases may cause adverse effects with chronic exposure making it crucial to limit waste.[15] The use of low-flow anaesthesia is one way to achieve this, where a fresh gas flow rate of less than the minute volume is used. The European Union is proposing to ban Desflurane starting January 2026.[16] Isoflurane has the least environmental impact due to its relatively short atmospheric lifetime and its decreasing use. The 100-year horizon GWP for Desflurane is 20 times higher than Sevoflurane. In addition, it has a three times lower potency than sevoflurane (MAC is three times higher), making its environmental impact more pronounced.[17] explaining the proposal to restrict its use. This should not, however, be viewed as the solution for environmental sustainability in anaesthesia and other measures should still be taken such as using low-flow anaesthesia. In this audit, only 2.8% of the total cases used desflurane, whilst the majority, 84%, used sevoflurane and the remaining 13.2% isoflurane.

The consumption of volatile anaesthetic agents is a significant cost in hospitals. The carrier gases, oxygen and air should also be given importance to limit waste [18] The cost of these agents depends on their potencies and the fresh gas flow rate (besides market price). By reducing FGF accordingly, the amount of drug delivered to the circuit is reduced without changing the amount entering the patient. Using isoflurane, the most economical volatile agent, could offer advantages for maintaining anaesthesia lasting less than three hours. It may be reasonable to use Sevoflurane or Desflurane for longer procedures as their poor solubility allows for better use of low-flow anaesthesia and leads to a more rapid recovery.[19] The mean Sevoflurane use was 51ml/min meaning that approximately 4.88 euro every hour was spent when using sevoflurane at the recorded fresh gas flow rates.

In this audit, we looked at the FGFs during the maintenance of anaesthesia and ignored the first ten minutes from induction which would be considered as the wash-in period. The wash-in time refers to the time it takes to saturate the circle system with the desired concentration of the volatile agent. Factors which influence the wash-in-period include the concentration of the anaesthetic agent (as set on the vaporizer), patient factors and fresh gas flow. From a clinical perspective, it is preferable to have an initial high-flow to thoroughly saturate the circle system during the wash-in period quickly. Leijonhufvud F, et al have shown that using a FGF of more than 6L/min will not increase speed for the wash-in period. The longest time it took to reach the desired concentration using low flows was 431.3 seconds using low flows.[20] Thus, we deemed it appropriate to assume that after ten minutes after induction of anaesthesia, the fresh gas flows should have been set for what would be used during maintenance. Arslan et al showed that low-flow anaesthesia can be performed safely and efficiently without the initial high fresh gas flow phase. When compared to 4L/min, a FGF of 1L/min after intubation required more time to achieve a target MAC value of 0.7 (2.7 minutes vs 4.8 minutes), but lower consumption of anaesthetic agent.[21] This practice would further help to reduce waste and pollution.

In our practice, the median oxygen concentration used in the FGF was 0.61. Patients are at a higher risk of absorption atelectasis with a higher oxygen concentration during induction and maintenance of anaesthesia.[22] During induction, due to potential emergencies, the risk-benefit of a high inspired fraction of oxygen justifies the use of preoxygenation. However, in most cases during maintenance of anaesthesia, lower oxygen concentrations of 0.3-0.4 may be used which would be beneficial for the patient in addition to other economic and environmental advantages. There is conflicting data on whether higher oxygen concentrations prevent surgical site infection or postoperative nausea and vomiting.[23]

We propose that a concerted effort should be made to reduce wastage and costs. An educational campaign targeting anaesthetists may be prepared, together with visual cues to remind anaesthetists to lower the fresh gas flows.

Reducing a fresh gas flow from 2L/min to 1L/min in our study would have meant reducing the consumption of Sevoflurane from a median of 50mL/min to just 27.5mL/min. This would mean reducing Sevoflurane costs by €1.30 per hour, a savings of 45%. One centre had carried out monthly stop audits to assess fresh gas flow rates and shared the information relating to cost of the volatile agents via a 'low-flow board'. By doing so each month they had seen a trend towards the use of low-flow anaesthesia.[24]

However, education alone may not be enough, and ultimately, more centres are opting for automated systems that adjust the fresh gas flow during a procedure.

Pioneered in the 1980s, such systems became commercially available in 2003. They are now widely available and used. There is a capital expenditure since such systems require the use of dedicated electronic vaporizers, but Kalmar et al have shown that the consumption of Sevoflurane decreased by an average of 40% after the introduction of anaesthetic machines capable of such automated gas flows[25-26]

CONCLUSION

The recorded fresh gas flows from Mater Dei Hospital show responsible use of anaesthetic agents and are comparable to other centres. However, improvement can be made by employing minimal-flow methods. It would be worthwhile to conduct a follow-up audit in the future to assess the effect of these findings on fresh gas flow usage.

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