A COMPARISON OF THE COST OF INHALATIONAL ANAESTHESIA USING VARIOUS BREATHING SYSTEMS: IMPLICATIONS FOR THE DEVELOPNG WORLD

MATTHEW DRAKE, SPECIALITY REGISTRAR, GLOUCESTERSHIRE ROYAL HOSPITAL

INTRODUCTION

The provision of safe anaesthesia in the adverse conditions found in many parts of the developing world poses great challenges within limited resources.

When considering the cost of a technique for inhalational anaesthesia, the choice of breathing system is very important. It determines the fresh gas flow required and consequently the quantity of volatile agent used during the administration of an anaesthetic. It also determines the degree of monitoring required, the extent of the cleaning and sterilisation of equipment between patients and the need for additional items such as soda lime.

In this paper the cost of these factors is compared for a variety of breathing systems. No attempt has been made to include the cost of factors which are unrelated to the choice of breathing system, such as intravenous agents which are common to all systems.

METHOD

This is a three-part theoretical study with no direct patient involvement:

1. The fresh gas flows recommended[1,2] for use with a number of different breathing systems were used to determine the cost of supplying these gases.
2. The volume of volatile anaesthetic agent required to produce equivalent expired concentrations with each of the breathing systems was calculated to derive the volatile agent cost.
3. The cost of other additional components required for the choice of breathing system were added.

For the purpose of simplicity the calculations are made assuming a 70kg patient with minute volume 5 litres/minute and duration of anaesthesia one hour. It is also assumed that the carrier gas is a 50/50 oxygen/air mix with isoflurane as the volatile agent. The fresh gas flow used is that recommended for the breathing system under review[1,2]. For equilibrium to exist between arterial and brain anaesthetic concentrations, at least 15 minutes is required[3], therefore the inspired concentration of isoflurane is 2% for the first 15 minutes and 1.5% thereafter. This assumption has been validated through an analysis[4] of nearly 1000 anaesthetics where an end-tidal volatile agent concentration of 1-1.3 MAC was achieved using this approach.

Mapleson's theoretical ideal fresh gas flow sequence for maximally efficient low-flow anaesthesia[5], validated in humans[6], was used to calculate the cost of "low flow" anaesthesia in a circle system.

The breathing systems studied were Mapleson A and D with spontaneous and intermittent positive pressure ventilation; a circle system both with working soda lime (using Mapleson's ideal fresh gas flow sequence[5]) and without carbon dioxide absorption (where fresh gas flow is equal to minute ventilation); and a draw-over system with either cylinder oxygen or an oxygen concentrator[7].

RESULTS

1. Volume of carrier gas used

The gas flows recommended[1,2] to produce normocapnea using the breathing systems under review are listed in Table 1.

When using the draw over system a flow rate of supplementary oxygen of 2.5 litres/minute will deliver an FiO_2 of approximately 50% under the conditions of the study[4]. With most draw over systems such as the tri-service apparatus this is delivered from an oxygen cylinder. For the Glostavent anaesthetic machine[7], supplementary oxygen is supplied from an oxygen concentrator with battery backup, so cylinder oxygen is not used but the cost of electricity for the oxygen concentrator must be included. Regardless of the flow rate of oxygen the concentrator consumes 420 Watts, costing around six pence per hour[8].

The costs of cylinder-supplied gases (Table 1) are calculated by taking the current rates of the British Oxygen Company (Nigeria) as representative of some parts of the developing world. List prices of oxygen are NGN720 (£3.15) for a 680L size E oxygen cylinder and NGN5040 (£22) for a 7000L air cylinder[9]. The cost of cylinder rental and transport, although they may be significant, are dependent on location and therefore have not been included.

2. Volume of volatile agent used

The volume of isoflurane used to produce an inspiratory concentration of 2% for the first 15 minutes followed by 1.5% for the next 45 minutes using the various breathing systems is given in Table 1. There is extreme variation varying from 75ml with spontaneous ventilation via a Mapleson D circuit to less than 11ml when using the circle system under low flow conditions. The cost of the isoflurane is currently £0.19/ml[10].

3. Additional expenses

In addition to the cost of the compressed gas and the volatile agent used with each of the breathing systems shown above, the following extra costs must be taken into consideration when the circle system is in use with low flows:

(a) Soda lime: This is required to prevent rebreathing of carbon dioxide. Consumption of soda lime depends on a number of different factors including the flow rate of fresh gas passing into the circle system and the patient's metabolic rate. Under ideal conditions 1 kg of soda lime will last approximately 25 hours and will add approximately 25 hours, adding approximately four pence to the cost of anaesthesia over an hour.

(b) Essential monitoring: When using low flows with a circle system it is essential that the concentrations of inspired oxygen and volatile agent are continuously monitored as these mainly do not reflect the dialled concentrations. Similarly the percentage of carbon dioxide in inspired gas should be monitored continuously to confirm the efficacy of the soda lime. When the other breathing systems are in use, measurement of these parameters is not essential as they can be inferred from the oxygen flow rate, the vapouriser setting and observation of the patient's respiratory movements. The cost of a simple volatile agent monitor with oxygen and carbon dioxide analysis is £7000[11], with a maintenance contract of 10% of the purchase price (or £700) per year. Assuming a life of 10 years for the monitors and £700 for each year for the maintenance contract then the outlay for purchase and maintenance over the life of the monitoring is £1400/year. Assuming the operating theatre performs six operations per day for 250 days per year, a monitoring cost of £0.93 must be added to each anaesthetic delivered via a low flow circle system.

(c) Sterilization of the breathing system: When a rebreathing system is in use the expired gases re-enter the breathing system and carry the risk of spreading infection to subsequent patients. For this reason bacterial filters should always be used when the anaesthetic is being administered via rebreathing system, with a typical bacterial filter costing £1.80[12].

An estimate of the total cost of one hour of inhalational anaesthesia with each of the breathing systems, including the cost of the fresh gas required, inhalational agent, and additional costs such as soda lime, bacterial filters and essential monitoring are listed in Table 1.

DISCUSSION

It is generally assumed that the circle system with low fresh gas flows is the most cost-effective way of administrating inhalational anaesthesia. The present study identifies the scale of the savings that can be made in the cost of compressed gas and volatile agents with this system. For this reason it is commonly used in hospitals having full facilities for monitoring and a reliable supply of electricity and soda lime.

However in hospitals where monitors are unavailable or unreliable, the use of the circle system with low flows of fresh gas can be hazardous. In these circumstances a breathing system which cannot accidentally administer a hypoxic mixture and in which the inhaled concentration of volatile is the same as that leaving the vaporizer should be used. In the absence of capnography, any deficiency in the function of the soda lime may induce a dangerous degree of hypercarbia.

In some parts of the world, anaesthetic agents may be in short supply, the electricity supply may be suddenly cut off and the delivery of oxygen cylinders may fail. Furthermore the expertise required to service and maintain sophisticated equipment may not be available locally with the result that breakdowns are frequent and monitoring devices are unreliable.

In these circumstances anaesthetic techniques that are in common use in the developed world have to be adapted to meet these additional challenges. The safety and reliability of inhalational anaesthesia in difficult environments can be enhanced and the costs contained by conservation of supplies and the use of simple techniques compatible with clinical monitoring rather than sophisticated electronic monitoring devices.

The draw over system, long considered obsolete by some, may indeed have marked advantages for those practising in difficult conditions. Although the requirement for volatile agents is greater, the requirement for oxygen is minimal. Indeed where an oxygen concentrator is the source of oxygen, the cost of supplying oxygen is negligible. As expired gases do not re-enter the breathing system a bacterial filter is not essential and the need to sterilize the anaesthetic equipment is greatly reduced and is usually only undertaken if there is obvious infection.

When the hidden costs of using a circle system are taken into consideration its advantages in difficult environments become less marked. Furthermore, in many parts of the world, functioning soda lime is not available so low flow systems are not an option.

Without the additional requirements for monitoring, bacterial filters and soda lime, it becomes clear that the draw over system has marked advantages in parts of the world where facilities are limited, particularly in more remote regions where delivery of compressed gases can be costly and unreliable.

When monitoring facilities are unavailable there are obvious advantages in using a breathing system in which the inspired concentration of oxygen and volatile agent are directly controlled by the anaesthetist, and the expired carbon dioxide concentration and depth of anaesthesia can be estimated by observation of the respiratory movements.

If the availability of oxygen, electricity and soda lime is also in doubt then the full advantages of the drawover system begin to emerge. It is, however, a technique that is seldom used in the UK although it remains extremely popular in parts of the developing world and with the armed forces of many nations.

It will be a poor reflection on present training if this valuable technique is allowed to fall into disuse in the UK when, as well as being cost-effective, it is frequently the only technique available in many poorer parts of the world.

ACKNOWLEDGEMENTS

The author wishes to thank Dr R Eltringham, Consultant anaesthetist, Gloucestershire Royal Hospital, and Mr R Tully, Engineer, Diamedica Ltd., for their expert advice.

Table 1 – Total cost of induction and maintenance of anaesthesia for the first sixty minutes of anaesthesia using different anaesthetic breathing systems, based on a minute volume 5 litres/minute aiming for an end-tidal concentration of 1.0-1.3 MAC.

Breathing system and mode of ventilation	**FGF required**		**Cost of FGF for 1 hour induction & maintenance**		**Cost of Isoflurane for 1 hour induction & maintenance**		**Total cost including essential extras such as bacterial filter, gas and vapour analysis, soda lime**
	Fraction MV required	**Flow l/minute**	**Litres gas**	**Cost 50/50 oxygen/ air mix***	**Volume Isoflurane required (ml)**	**Cost Isoflurane**	
Mapleson A (SV)	0.8xMV	4.0	240	£0.93	20.05	£3.81	**£6.54**
Mapleson A (IPPV)	2.5xMV	12.5	750	£2.92	62.67	£11.91	**£16.63**
Mapleson D (SV)	3xMV	15.0	900	£3.50	75.20	£14.29	**£19.59**
Mapleson D (IPPV)	MV	5.0	300	£1.17	25.06	£4.76	**£7.73**
Circle (Mapleson's ideal fresh gas flow sequence[5])	5l/min for 1½ mins, 1.5l/min for 5½ mins, 1.0l/min thereafter		68.8	£0.70	10.74	£2.04	**£5.51**
Circle without functioning soda lime	MV	5.0	300	£1.17	25.06	£4.76	**£7.73**
Drawover + oxygen cylinder	Any FGF can be used as air is entrained, however 2.5l/min should provide $FiO_2 \geq 0.5$		150	£0.70*	25.06	£4.76	**£5.46**
Drawover + oxygen concentrator[7]			150	£0.06*†	25.06	£4.76	**£4.82**

SV=Spontaneous Ventilation; IPPV=Intermittent Positive Pressure Ventilation; MV=Minute Volume; FGF=Fresh Gas Flow; *Cost of oxygen supply only as air in entrained free of charge; †Oxygen from concentrator – cost of electricity only.

REFERENCES

1. Conway CM. Anaesthetic Breathing Systems. *British Journal of Anaesthesia*. 1985; 57:p.649-57.
2. Allman, KG, Wilson, IH (Eds.). Oxford Handbook of Anaesthesia. Second Edition 2006; Oxford University Press, p. 1169.
3. Lin CY. Uptake of Anaesthetic Gases and Vapours. *Anaesthesia and Intensive Care* 1994; 22:p.363-373.
4. Eltringham RJ, Fan QW, Thomas W. Experience with the Glostavent Anaesthetic Machine. *Update in Anaesthesia* 2003; 16:p.31-35.
5. Mapleson WW. The theoretical ideal fresh-gas flow sequence at the start of low-flow anaesthesia. *Anaesthesia* 1998; 53:p.264-72.
6. Ip-Yam PC, Goh MH, Chan YH, Kong CF. Clinical evaluation of the Mapleson theoretical ideal fresh gas flow sequence at the start of low-flow anaesthesia with isoflurane, sevoflurane and desflurane. *Anaesthesia* 2001; 56:p.160-164.
7. Eltringham, RJ, Fan QW. The Glostavent – an anaesthetic machine for difficult situations. *Journal of International Trauma and Critical Care Society* Spring/Summer Edition 2001; p.38-40.
8. World Bank. Public and Private Electricity Provision as a Barrier to Manufacturing Competitiveness. *Findings* 2002; 221 http://www.worldbank.org/afr/findings/english/find221.pdf, accessed 27/5/08.
9. Personal communication, British Oxygen Company, Nigeria.
10. British National Formulary, September 2008, Royal Pharmaceutical Press.
11. Personal communication, RL Dolby & Co Ltd.
12. Personal communication, Intersurgical (UK) Ltd.