General Anesthesia

# The oxygen concentrator is a suitable alternative to oxygen cylinders in Nepal

*[L'oxygénoconcentrateur peut convenablement remplacer les bouteilles d'oxygène au Népal]*

Bisharad M. Shrestha DA FRCAT, Birendra B. Singh DA, Madhav P. Gautam DA, Man B. Chand DA

**Purpose:** To review the efficacy and reliability of oxygen concentrators used over the last six years in Nepal. The apparatus used was a DeVilbiss® oxygen concentrator that provided $O_2$ for anesthesia supplemented with compressed air to drive a Penlon Manley Multivent Ventilator®. It remains difficult to supply oxygen in cylinders to peripheral hospitals in Nepal due to lack of proper roads.

**Methods:** We conducted a retrospective analysis of a sample of 378 cases anesthetized at the Bir Hospital and at a private hospital in Kathmandu from April through October 1999. The Bain circuit or its modification was used in adults, and Bain or Ayre's T piece in children. High flows from the oxygen concentrator used with the Bain and Ayre's T- circuits were reduced to 2 $L \cdot min^{-1}$, delivered through the halothane vaporizer, supplemented by room air in the modified Bain circuit. Positive pressure ventilation was provided with an Ambubag, Oxford Inflating Bellows or Penlon Manley Multivent Ventilator. Blood pressure, electrocardiogram, $FIO_2$ and $SpO_2$ were monitored in all cases.

**Results:** Surgery included urologic, general surgery, obstetrics and gynecological procedures, neurosurgery and closed mitral valvotomy. Age ranged from six months to 78 yr. The anesthetic time lasted from 45 min to 12 hr. The $FIO_2$ ranged from 0.5 to 0.6 in the Bain and Ayre's T circuits, and from 0.34 to 0.40 in the modified Bain circuit with a flow of oxygen of 2 $L \cdot min^{-1}$ from the concentrator.

**Conclusion:** With regular maintenance and servicing done locally, the oxygen concentrator can be used safely in adults and children. Use of the oxygen concentrator is a suitable alternative to oxygen cylinders in the developing world.

***Objectif :*** *Vérifier l'efficacité et la fiabilité des oxygénoconcentrateurs utilisés pendant les six dernières années au Népal. Le dispositif utilisé était un concentrateur d'oxygène DeVilbiss® qui fournissait l'$O_2$ pour l'anesthésie associée à un ventilateur mécanique Penlon Manley Multivent Ventilator® actionné par de l'air comprimé. Étant donné le pauvre état des routes, il est encore difficile de transporter de l'oxygène en bouteilles vers les hôpitaux périphériques au Népal.*

***Méthode :*** *Il s'agit de l'analyse rétrospective de 378 cas d'anesthésie réalisés d'avril à octobre 1999 au Bir Hospital et dans un hôpital privé de Katmandou. Le circuit de Bain, ou sa modification, était utilisé chez les adultes et une pièce en T de Bain ou de Ayre, chez les enfants. Les grands débits de l'oxygénoconcentrateur des circuits en T de Bain et de Ayre étaient réduits à 2 $L \cdot min^{-1}$ administrés par des vaporisateurs d'halothane et complétés par l'air ambiant dans le circuit de Bain modifié. La ventilation à pression positive était assurée par un respirateur manuel, type Ambu, ou un ventilateur Oxford Inflating Bellows ou Penlon Manley Multivent. La tension artérielle, l'électrocardiogramme, la $FIO_2$ et la $SpO_2$ étaient surveillés dans tous les cas.*

***Résultats :*** *Les interventions chirurgicales concernaient l'urologie, la chirurgie générale, l'obstétrique et la gynécologie, la neurochirurgie et la commissurotomie mitrale fermée. Les patients avaient de six mois à 78 ans. L'anesthésie allait de 45 min à 12 h. La $FIO_2$ variait de 0,5 à 0,6 pour les circuits en T de Bain et de Ayre, et de 0,34 à 0,40 pour le circuit de Bain modifié avec un débit d'oxygène de 2 $L \cdot min^{-1}$ provenant du concentrateur.*

***Conclusion :*** *L'oxygénoconcentrateur peut être utilisé sans danger pour les adultes et les enfants dans des conditions d'entretien régulier et de réparation sur place. Le concentrateur d'oxygène peut remplacer convenablement les bouteilles d'oxygène dans les pays en voie de développement.*

From the Department of Anaesthesia, Bir Hospital, Kathmandu, Nepal.

*Address correspondence to*: Dr. B. M. Shrestha, Senior Consultant Anaesthetist, Department of Anaesthesia, Kathmandu Medical College Teaching Hospital, P.O. Box 7964, Kathmandu, Nepal. Phone: 977 1 421 150; Fax: 977 1 247 032; E-mail: bisharadshrestha@hotmail.com

*Accepted for publication July 30, 2001.*
*Revision accepted September 17, 2001.*

NEPAL is a land locked country with a medical history of just over 110 years. Anesthetic history in the country dates back to 1955 when the first qualified anesthesiologist joined the Bir Hospital.[a] Open drop ether was quite popular until recently. EMO (Epstein Macintosh Oxford) or other draw over apparatus with oxygen ($O_2$) supplementation was introduced later. Modern balanced anesthesia and use of proper anesthetic machines were introduced in 1966. At that time $O_2$ and nitrous oxide had to be imported from India. The first $O_2$ plant in the country was established in 1972. Due to lack of proper roads, supplying $O_2$ in cylinders to all peripheral hospitals remains very difficult.

In order to solve the problem, the use of oxygen concentrators was introduced in 1985. However, the first concentrator delivered a low percentage of $O_2$ and broke down within six months.[b]

In 1993, while conducting a trial of the Penlon Manley Multivent Ventilator (PMMV) we received a DeVilbiss oxygen concentrator[1] which could supply $O_2$ supplemented with compressed air to the ventilator for use in anesthesia.[c] Since then, we have used an oxygen concentrator as a source of $O_2$ in anesthesia for draw over or plenum systems or in a modified Bain system.[2] We have used this oxygen concentrator in a wide range of surgical cases including neurologic and cardiothoracic operations. We have used it in the central hospitals and in surgical camps at remote mountain sites[d] with satisfactory results.

The concentrator is still functioning and reliable, as it is still delivering more than 85% oxygen at flow rates of 5 $L \cdot min^{-1}$. Our experience suggests that this should be the prime source of oxygen supply to the operating rooms,[3] wards and for domiciliary use in our country keeping $O_2$ cylinders in reserve if needed.

## Materials and methods

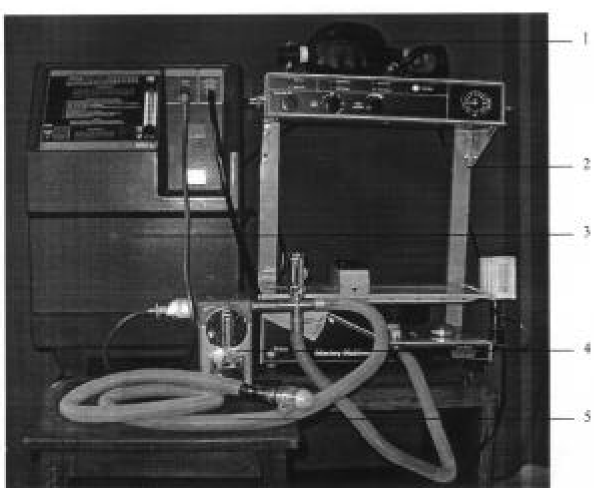
We have used an oxygen concentrator in anesthesia since the last six years. For the purpose of this study, we analyzed retrospectively the cases done in a six month period from April 1999 to October 1999 in two centres, the central Bir Hospital operated by the

[a] *Rana NB, Shrestha BM, Maltby JR* History of Anesthesiology in Nepal. Anesthesia History Association Newsletter.

[b] *Swar BB*. Oxygen concentrators in Nepal, how useful and reliable? 5th Symposium SAN Souvenir May 15–16, 1992: 33–5.

[c] *Shrestha BM, Amatya R, Basnyat NB, Singh BB, Lekhah BD, Gurung A* The Penlon Manley Multivent in Nepal. World Anaesthesia Newsletter 1995; 13: 10–1.

[d] *Singh BB, Gautam MP, Gurung A, Chand MB, Shrestha BM*. Field trial of the Penlon Manley Multivent and the DeVilbiss oxygen concentrator. World Anaesthesia Newsletter 1995; 14: 4–5.



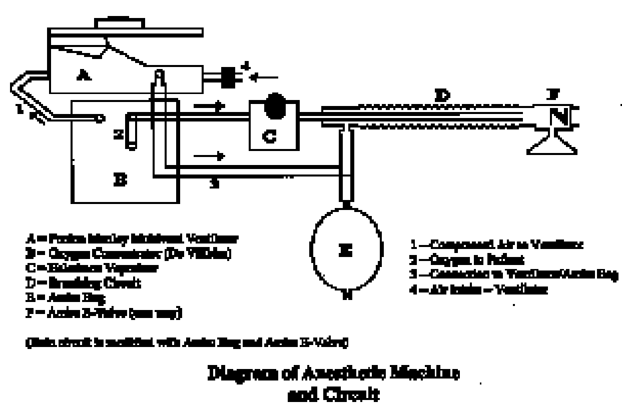




FIGURE 1 Diagram of anesthetic machine and circuit.
Anesthesia Machine used in this study
Ambu Bag
Penlon Manley Multivent Ventilator
DeVilbiss Oxygen Concentrator
Halothane Vaporizer
Modified Bain Circuit

TABLE I

| *Monitors used* | *Private hospital* | *Bir Hospital* |
|---|---|---|
| | Anaeroid blood pressure | Blood pressure |
| | Pulse oxymetry | Pulse oxymetry |
| | Electrocardiogram (ECG) | Electrocardiogram (ECG) |
| | Peripheral nerve stimulator (PNS) | Peripheral nerve stimulator (PNS) |
| | | Measurement of $FIO_2$ |
| | | End-tidal $CO_2$ |
| | | $F_i$ halothane |

TABLE II

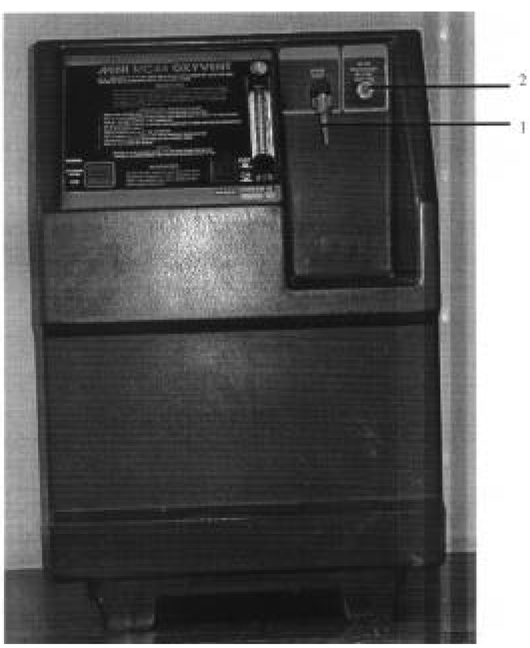
| *Age group* | *Age* | *Private hospital* | *Bir Hospital* | |
|---|---|---|---|---|
| | 0 to 10 | 10 | 34 | 44 |
| | 11 to 30 | 84 | 76 | 160 |
| | 31 to 50 | 78 | 32 | 109 |
| | 51 to 70 | 28 | 32 | 59 |
| | 71> | 3 | 1 | 4 |
| | Total | 201 | 175 | 376 |
| | *Sex* | | | |
| | Male | 91 | 122 | 213 |
| | Female | 110 | 53 | 163 |
| | | 203 | 175 | 378 |

In two patients the procedure was repeated.

government and in a small private hospital, both in Kathmandu. Kathmandu lies at an altitude of 1,337 meters (4,500 feet), where the average barometric pressure is 646 mmHg and the partial pressure of $O_2$ is 135 mmHg.

In both centres, a DeVilbiss oxygen concentrator, halothane vaporizer (Mark 2 or later model) and PMMV were available. Ambubag or Oxford Inflating Bellows (OIB) were also available in case of emergency or failure of the PMMV. All patients needing general anesthesia were anesthetized with the Bain system using oxygen and halothane or modified Bain system using $O_2$, air and halothane (Figure 1).

The anesthetic technique used was *iv* sedation with diazepam and pentazocine, followed by induction with thiopentone. Intubation of the trachea was facilitated with suxamethonium or a long acting muscle relaxant. Using the modified Bain system, 2 L of $O_2$ from the concentrator was passed through the halothane vaporizer set at 2% or more as necessary, the rest of the minute volume consisting of air. Ambubag or OIB or PMMV was used for ventilation. In small children either a Bain system or an Ayre's T piece was used and the oxygen concentrator supplied total minute volume. An $O_2$ cylinder was kept for back up purposes. Most of the cases were ASA physical status I or II. Peripheral



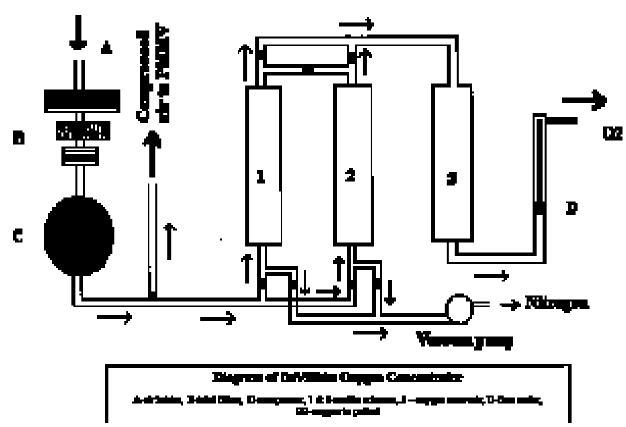




FIGURE 2 Diagram of DeVilbiss oxygen concentrator
DeVilbiss Oxygen Concentrator
Port for supply of oxygen
Port for supply of compressed air to the Penlon Manley Multivent Ventilator

oxygen saturation ($SaO_2$), blood pressure and electrocardiogram (ECG) were monitored in all cases. The small private hospital used Stellar monitoring equipment manufactured by Larson and Turbo Medical, India, which monitored peripheral oxygen saturation and ECG. At the Bir Hospital the monitoring equipment used was a Drager PM 8014 for peripheral oxygen saturation, ECG and noninvasive blood pressure. Fractional inspired $O_2$ ($FIO_2$), inspired concentration of halothane (FiHalo) and end-tidal $CO_2$ ($EtCO_2$) were also measured at the Bir Hospital with a Datex Engstrom - Capnomac Ultima (Table I).

## Results

Of the 378 patients, 175 underwent neurosurgical operations at the Bir Hospital. The other 203 patients were operated at the private hospital. The duration of the operations ranged from 45 min to 12 hr. The patients ranged in age from six months to 78 yr (Table II).

The oxygen concentrator was used to supply $O_2$ throughout the anesthetic and recovery period. There were no cases of hypoxia, nor any mortality or morbidity due to anesthesia. The monitored variables were satisfactory in all cases with $FIO_2$ ranging from 0.34 to 0.4 with 2 L of $O_2$ flow, $SaO_2$ of 96–100% and $EtCO_2$ within normal limits.

## Discussion

Oxygen is essential for anesthesia and resuscitation. The gas is normally supplied in cylinders, which are bulky to transport, and occupy a lot of space. In a developing country like Nepal, transportation of $O_2$ cylinders is difficult, erratic and unreliable. During landslides, floods and other disasters, hospitals may not be approachable by road. The supply of $O_2$ cylinders has failed many times, even in the operating rooms of the central hospitals, leaving the anesthesiologist to provide anesthesia for emergency surgery without access to $O_2$. This puts the patient at considerable risk of hypoxia and even death. Smaller hospitals have more acute problems since the supply of $O_2$ cylinders is limited and, once the stock is exhausted, it can take months to be re-supplied. A portable oxygen concentrator that extracts $O_2$ from the atmosphere seems to be the answer.[3–6 e]

Oxygen concentrators have been available in some of the central hospitals in Nepal since 1985. These were used in wards for patients needing $O_2$. Due to lack of reliable maintenance service most of the older concentrators broke down within a year, and even the percentage of $O_2$ supplied by the concentrators was not satisfactory.[b] Spare parts were not available in the country. Thus, doctors and nurses were not keen on using these concentrators. At present, very few functioning units are available in central and peripheral hospitals in Nepal.

The Patan Hospital, another hospital in the Kathmandu valley, has used the concentrator in the operating room since 1985 for $O_2$ supplementation in a draw-over anesthetic system. Our personal experience with an oxygen concentrator (DeVilbiss) in anesthesia dates from 1993 when we first received it, supplied with the trial model of the PMMV. We started using the oxygen concentrator in anesthesia, and until now we have used it in over 4,000 operative cases including cardiothoracic and neurosurgical anesthesia without any problems.

### *How the oxygen concentrator works*[7 ef]

Atmospheric air consists of approximately 79% nitrogen (N) and 21% $O_2$. A simple method of on site production of $O_2$ from air became possible nearly 25 years back by using membrane or zeolite molecular sieve technology. The membrane type can only produce 40% pure O2, whereas the molecular sieve technology can produce up to 95% pure $O_2$.

Room air is drawn into the oxygen concentrator through a series of filters to remove dust and bacteria. The concentrator contains two columns of the zeolite molecular sieve in a canister. The sieve adsorbs N from the air as it is forced through under pressure. The sieve allows $O_2$ to pass through along with the 1% argon present in the air. The two columns function alternatively so that there is a continuous supply of $O_2$. Synthetic zeolite is used for the production of oxygen. It consists of a rigid framework of silica and aluminium with an extra cation of calcium or sodium to make up the missing positive charge in the structure.

The concentrator needs 300 watts AC power. Adsorption efficiency is enhanced by a modest increase in operating pressure and takes place at a pressure of 20 PSI *(140KPa)*. After about 20 sec the supply of compressed air is automatically diverted to the second canister where the process is repeated enabling uninterrupted output of $O_2$. While the pressure in the second canister is at 20 PSI, the pressure in the first canister is reduced to zero. This allows discharging most of the adsorbed N from the zeolite to the atmosphere. The zeolite is then regenerated and ready for the next cycle. As the second column approaches saturation, the

---

e *Dobson MB*. Oxygen concentrator for the smaller hospital - a review. Tropical Doctor, April 1992.

f *Roberts CW*. Synthetic zeolite molecular sieves. Reprinted from Specialty Chemicals Production Marketing and Applications, February 1981.

process is reversed. By alternating the pressure in the two canisters a constant supply of $O_2$ is produced while the zeolite is continually being regenerated. Individual units have an output of up to 5 $L \cdot min^{-1}$ with an $O_2$ concentration of up to 95%. Higher flows result in a loss of concentration, and most machines are flow-limited to prevent this from occurring. The gas emerging from the columns normally is composed of 95% $O_2$ and 5% argon. This gas passes into a small reservoir chamber, and then through a flow control system to the patient.

The life of the zeolite crystal can be expected to be at least 20,000 hr, which in most situations would give about ten years of use. Routine maintenance consists merely of changing the filters at regular intervals as directed by the manufacturer. This can be achieved easily, using skills available locally. If recommendations are followed, the unit requires no other attention and will continue to function for many years (Figure 2).

The concentrator is extremely easy to operate. The controls consist of an on/off switch and a flow meter. A pressure alarm sounds when the unit is first turned on and over the next few seconds while the pressure initially builds up to 20 PSI, after which the alarm remains silent. Subsequently, it sounds only if the pressure falls. This usually means that the filters need changing. The noise of the compressor is subdued and does not disturb work in the operating room. It is powered electrically from the mains, or if this fails a small generator will suffice. The output is continually analyzed and the user is alerted by an orange warning light on the front panel if the output concentration falls below 85% $O_2$. If the concentration of $O_2$ falls below 70% a red warning light illuminates, indicating malfunction, and the unit shuts down automatically.

In a developing country like ours, one may anticipate problems associated with the effects of high relative humidity during the rainy season, high dust content in the air during the dry season, and high altitude. In our experience, water infiltration into the anesthetic ventilator and machine is minimal and has not affected the function of these machines till now. The three standard filters at the air intake have proven sufficient to keep dust out of the concentrator. Altitude has no effect on the concentration of $O_2$ produced. Hence, the overall use of the oxygen concentrator has been reliable and satisfactory.

## Conclusion

We have used the oxygen concentrator regularly in our anesthesia practice. From time to time we have used it for resuscitation of patients on the ward or in the postoperative rooms. Many surgical camps in Nepal use the concentrator in field situations. The concentrator has been very reliable and cost effective. We have calculated that it can generate enough $O_2$ to pay for its cost within a year. The overall use of the oxygen concentrator in anesthesia has been reliable and satisfactory. Thus we recommend the oxygen concentrator as a safe, simple and reliable method to provide oxygen in locations where cylinders may not always be available.

## Acknowledgements

We thank Prof. Roger Maltby, Prof. Arnold Tweed, Prof. Kari Smedstad, Dr. Dough Maguire, and Dr. R.M. Friesen for their valuable suggestions and help in preparing this article.

## References

1 *Eltringham RJ, Varvinski A.* The oxyvent. An anaesthetic machine designed to be used in developing countries and in difficult situations. Anaesthesia 1997; 52: 668–72.
2 *Shrestha BM, Tweed WA, Basnyat NB, Lekhak BD.* A modification of the Bain system for ambient air- oxygen inhalation. Anaesthesia 1994; 49: 703–6.
3 *Friesen RM, Raber MB, Reimer DH.* Oxygen concentrators: a primary oxygen supply source. Can J Anesth 1999; 46: 1185–90.
4 *Fenton PM.* The Malawi anaesthetic machine. Experience with a new type of anaesthetic apparatus for developing countries. Anaesthesia 1989; 44: 498–503.
5 *Pedersen J, Nyrop M.* Anaesthetic equipment for a developing country. Br J Anaesth 1991; 66: 264–70.
6 *Jarvis DA, Brock-Utne JG.* Use of an oxygen concentrator linked to a draw-over vaporizer (anaesthesia delivery system for underdeveloped nations). Anesth Analg 1991; 72: 805–10.
7 *Friesen RM.* Oxygen concentrators and the practice of anaesthesia. Can J Anaesth 1992; 39: R80–4.