Pioneers in South African Anaesthesia:

Thomas Voss and the "Elephant Tube"

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Figure 1: Dr Thomas Voss, MBChB, Conjoint DA RCP(Lond), RCS(Eng), FRCA, FANZCA

Introduction

Thomas James "Tom" Voss was born in Windhoek, Namibia, on 26 March 1926 (Figure 1). He matriculated in South Africa from Pretoria Boys High School, and qualified with a Bachelor of Medicine, Bachelor of Surgery degree from the University of Cape Town (UCT) in 1950. After passing the Conjoint Diploma in Anaesthesia in London, he was appointed as a registrar in the Department of Anaesthesia at Groote Schuur Hospital in 1954. He was appointed as a specialist at Groote Schuur Hospital in 1958, and developed a special interest in the relatively new discipline of paediatric anaesthesia. In 1961, he became Head of Department at the Red Cross War Memorial Children's Hospital, taking over from his mentor, Arthur Bull. In 1975, he was promoted *ad hoc* to Associate Professor at UCT.

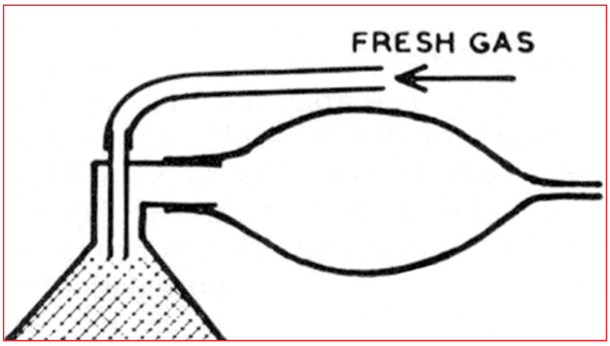

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Figure 2: The Cape Town Circuit[1]

Dr Voss had an internationally recognised passion for the development of safe and paediatric-appropriate anaesthetic equipment, and strived tirelessly to achieve this throughout his working life. He was one of the designers of the "Cape Town Circuit" (Figure 2), a minimal dead-space breathing circuit for children. In 1962, while on sabattical in Prof Mushin's unit in Cardiff, he performed a laboratory study that investigated apparatus dead space in paediatric breathing systems. This demonstrated that the Cape Town circuit was superior to both the Potter and Magill circuits for small children breathing spontaneously using a face mask.[1]

Some of his other major contributions to paediatric anaesthesia included determining blood loss during surgery by weighing swabs and performing colorimetric estimations, investigating intraoperative temperature changes, developing a suitable warm-water humidifier for use under anaesthesia, and using a water manometer to measure arterial and central venous pressure in children at the Red Cross War Memorial Children's Hospital.[2] As Head of Department, he collected all the anaesthetic records for the week and discussed them with the anaesthetists concerned on a Friday afternoon.

In 1974, he became the first South African to be awarded a Fellowship of the Royal College of Anaesthetists by election. This is the College's highest accolade, "awarded to practitioners across the world who have made sustained and significant contributions to the practice of anaesthesia… at an internationally active level".

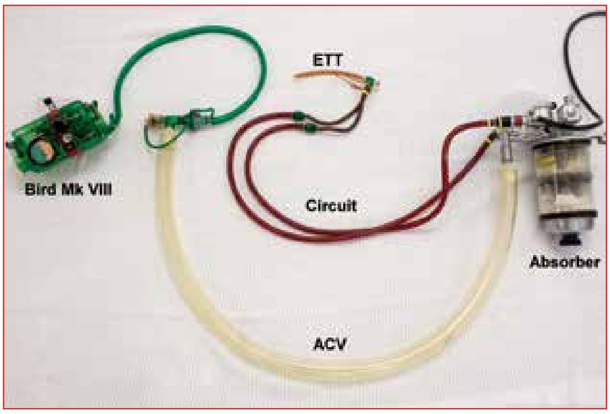
In 1977, Voss and his family emigrated to Australia, where he continued his work as a paediatric anaesthetist, initially at the Royal Brisbane Hospital, and later at the Westmead Hospital in Sydney. He rose to prominence in Australia for the development of paediatric intensive care, and was a member of the Australian Standards Committee HT7, which deals with anaesthetic equipment. Now in his 80s, Emeritus Prof Voss is retired, and resides in Sydney. His pioneer work in the ventilation of paediatric patients during anaesthesia is described below.

"The Elephant Tube"

The occurrence of respiratory suppression has been recognised since the advent of modern anaesthesia. The introduction of curare into anaesthetic practice by Griffith and Johnson in the 1940s led to the need for artificial ventilation.[3] At Harvard in 1949, John Emerson developed the first automated positive pressure ventilator, but the common use of ether and cyclopropane led to less-than-enthusiastic adoption of electrically driven ventilators because of the risk of fire and explosions.

Roger Manley's simple, gas-driven minute volume divider debuted at London's Westminster Hospital in 1952, and was instrumental in widespread acceptance of positive pressure ventilation in anaesthesia, which became standard practice in Europe for four decades. In the USA, a military aviator turned biomedical engineer named Forrest Bird, spurred by the lack of access to electrical power during medical evacuations and care near the frontline in the Vietnam War, developed a gas-driven pneumatic ventilator. His initial models were constructed using parts that included a shortcake tin and a doorknob, but soon matured to become the ubiquitous green Bird® ventilators with which all but the newest generation of anaesthetists are familiar.

There was no effective or sensitive ventilator in South Africa in the 1960s that could be used in conjunction with a circle system for anaesthesia. At that time, the value of automated ventilation was as irrefutable as it is today. It freed the hands of the anaesthetist for other tasks, allowed movement further from the anaesthetic machine than one arm's reach, reduced fatigue, and increased accuracy during long procedures. Bag-in-bottle ventilators were not yet commonly available, and the lack of today's sophisticated anaesthetic workstations and monitoring made safe ventilation a challenge. However, the pneumatically driven, pressure-cycled Bird® ventilators were readily available. The Bird® ventilator was designed to ventilate patients with either 100% oxygen, or 40% if the air-entrainment device was activated. Before it could be used for intermittent positive pressure ventilation during anaesthesia, a method had to be developed to separate the driving gas delivered by the ventilator from the anaesthetic gases in the circle system. Armed with ingenuity and straightforward science, Tom Voss sought to create a solution to the problem.



ACV: anaesthetic circuit ventilator, ETT: endotracheal tube

Figure 3: The Voss adaptation of ventilators for anaesthesia, showing the Bird® Mark VIII ventilator, "Elephant Tube" anaesthesia circuit-ventilator space, circle system with absorber, and a paediatric rubber endotracheal tube

Voss's focus fell predominantly on paediatric anaesthesia, and hence he wished to preserve the advantages of the circle system for these patients. To integrate the ventilator with the circuit, he replaced the reservoir bag with a length of smooth-walled, large-diameter plastic pipe, which he termed the "anaesthetic circuit ventilator" (ACV) space. The ACV space then connected to a Bird® Mark VIII ventilator. During operation of the ventilator, to-and-fro movement of gas in the ACV space would transmit the pressure cycles to the circle system, and thereby to the patient. On inspiration, fresh gas flow (FGF) from the anaesthesia machine would be delivered to the patient. As all expiratory valves in the circle system were kept closed, the excess anaesthetic gases passed via the ACV space to the ventilator exhalation valve on expiration. To minimise turbulence and mixing of the gases in the ACV space, smooth-walled plastic tubing was chosen. Its appearance led to it becoming widely known as the "Elephant Tube" (Figure 3).

Voss surmised that, provided the minute or tidal volumes did not exceed a critical level relating to the internal volume of the ACV space, there would be no contamination or dilution of the anaesthetic gases with ventilator gases. To test his invention, Voss devised an elegant laboratory experiment. A Boyle's machine was set to deliver pure nitrous oxide into the circle system, while the Bird® ventilator was set to deliver 100% oxygen into the ACV. Because of the absence of agent analysers in 1967, a Beckman® Pauling Oxygen Analyser, obtained from the Council for Scientific and Industrial Research, was used to measure the contamination of the anaesthetic circuit by oxygen from the ventilator. Rubber "lungs" of varying sizes and compliance were fitted with the oxygen analyser, and ACV spaces of 0.7, 2 and 3 litres were created, using different lengths of 10 cm-diameter pipe. Tidal volumes ranged between 200 and 2 000 ml, while minute volumes were set at 5, 10, 15 or 20 litres. Voss conducted multiple tests, changing the dependant variable with each iteration, and published the results in the *South African Medical Journal* in 1967.[4]

Voss showed that for each particular ACV space, the factor that determined contamination of the anaesthetic circuit with ventilator gas was tidal, not minute volume. He was able to demonstrate the relationship between the ACV and tidal volumes and the required FGF to prevent contamination by ventilator driving gas. Simply stated, the tidal volume should never exceed the ACV space, and by preference, should be significantly less. If tidal volume (VT) is ACV, then FGF of at least 6 litres/minute is required. Where VT is half of the ACV, 3 litres/minute is required, and if VT is a third of the ACV, then FGF of only 2 litres/minute is necessary. For simplicity, he recommended ACV spaces of two litres for adults and one litre for children, allowing FGF of 3 litres/minute to be sufficient in all cases.

The system was elegant in its simplicity and lack of moving parts which could fail unexpectedly. An additional benefit of using the Bird® ventilator with the air-entrainer was the auditory feedback provided by the ventilator during inspiration and expiration that allowed the anaesthetist to count the respiratory rate, assess the inspiratory to expiratory time (I:E) ratio and diagnose circuit disconnection. In an era of few sophisticated alarms, ventilator failure or disconnection could be immediately noticed because of the change in sound. Although developed for paediatric anaesthesia, the system was equally adaptible for adults, and was widely used throughout South Africa. A total of 356 neonates were ventilated using this system at the Red Cross War Memorial Children's Hospital in the three years prior to Voss's publication describing the technique,[4] and it was also used by Dr Joseph Ozinsky to anaesthetise the recipient of the world's first successful heart transplant at Groote Schuur Hospital in December 1967. It continued to be used until superseded by the development of electronic microprocessor-controlled, piston-driven or dual-circuit (bag-in-bottle) ventilators sufficiently sensitive to ventilate small children at low FGF rates. Voss's invention and experiment was revalidated several times over the next 30 years.[5,6]

Acknowledgements

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