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In 1977 Tony Adams was a clinical lecturer in the Nuffield department of Anaesthetics in Oxford having been an anaesthetic consultant since 1969. He became the foundation professor at Guy's Hospital in 1979 and in 1982 the Chairman of the Division of

Anaesthetics of the United Medical and Dental Schools of Guy's and St Thomas's Hospitalsⁱⁱ.



Equipment and measurement

His first five publications appeared in 1967 and were about equipment/ventilation and measurement; a very busy year.

It is an interesting set of publications - a paediatric ventilation system was designed with the aid of DER Fox from Cape Engineering (Warwick) [1]. This self-filling ventilator attachment delivered tidal volumes from 10 ml to 700 ml, which is a very impressive range. It worked with most ventilators, was a non-rebreathing system, and could be used for manual inflation of the lungs.

Two papers with Morgan-Hughes on electrodes for measuring pH and blood gases [2, 3], a paper describing three dry gas meters [4] and a presentation at an ARS meeting in Sheffield on rebreathing using a Magill circuit [5]. This was later published as a full paper in *Anaesthesia* [6]. The bottom line was that as long as the fresh gas flow was greater than the alveolar ventilation then rebreathing did not occur - this was just confirming what Mapleson had predicted in 1954ⁱⁱⁱ.

ⁱ Photograph courtesy of http://londonsurgicalskills.co.uk/The_20Tutors.htm

ⁱⁱ J F Nunn. *British Journal of Anaesthesia*. 1999; 83(6): 916

ⁱⁱⁱ Mapleson WW. *Br.J.Anaesth.*,1954;26:323

The three dry gas meters were assessed with the help of the Meter Testing Department, North Thames Gas Board, Willesden[4]. (It's interesting who you work with when starting out in research!) They concluded that "*The dry gas meter is cheap, robust, and accurate enough for measuring gas volumes in most applications.*" Are they still the 'gold standard' for measuring gas volumes?

The papers with Morgan-Hughes (and Sykes) on electrodes were aimed at reducing inaccuracies in the measurements of pH and blood gases. Errors had been noted by MKS of up to 0.3 units in pH, 15mm Hg in PCO₂ and 20mm Hg in PO₂ during the use of electrode systems. It was thought that these errors could lead to incorrect clinical management.

The paper addressing problems of the oxygen electrode was about the determination of the 'blood-gas factor'; an adjustment for the fact that the output from the electrode was lower for a sample of blood than for the gas with which the blood had been equilibrated. A lot of investigators had noticed this but there wasn't a system of equilibrating the blood quickly and then transferring it directly to the electrode. Their tonometer solved this problem. It was a completely thermostatted bubble tonometer incorporating a humidifying unit. There are many factors that can influence the blood-gas factor and they admit that it "may not be of great importance in many clinical situations". However, if the result of the analysis is to be further processed to calculate shunts, for example, then the errors could be significant and their tonometer would enable quick calibration.

The second paper [3], *pH and blood-gas analysis - Methods of measurement and sources of error using electrode systems* is a 'how-to do it' type of paper, addressing all the potential problems – and there are many – read the original. At the end they 'advertise' the second installment – "*The second part of this article, dealing with the measurement of carbon dioxide tension, together with references and acknowledgements will appear in the January 1968 issue of Anaesthesia*". This paper could not be found on Medline (Jan 2014). It was found using Google: "Methods of measurement and sources of error using electrode systems. Part 2 Measurement of carbon dioxide tension and acid-base [7].

The other equipment-related subjects were...

1970 Effects of ventilation [8-11]:

- i. The effects of variations of inspiratory flow waveform on cardiorespiratory function during controlled ventilation in normo-, hypo- and hypervolaemic dogs
Four waveforms, sine, square, early peak and late peak, were used and the results were uniformly negative in that there was no significant change in cardiorespiratory function.
- ii. The effects of variations in inspiratory:expiratory ratio on cardiorespiratory function during controlled ventilation in normo-, and hypo- and hypervolaemic dogs.
Three different inspiratory: expiratory ratios (1:2, 0.5:2.5, and 2:1) were used. Changes in deadspace/tidal volume were not statistically significant and there were no significant changes in cardiac output due to changes in the I:E ratio. Different combinations of I:E ratio and volume status did cause significant changes in the arterial-alveolar PCO₂ difference, in the PCO₂ difference, arterial PO₂ and in venous admixture.
- iii. The effects of variations in end-expiratory inflation pressure on cardiorespiratory function in normo-, hypo- and hypervolaemic dogs
Cardiac output decreased less in the hypervolaemic group. But the deadspace/tidal volume ratio increased in all groups. When using a negative pressure the venous admixture increased, but did not affect the deadspace/tidal volume ratio.
- iv. The effect of mechanical ventilation after open-heart surgery: Mechanical ventilation after open-heart surgery (most patients were having aortic valve surgery) "rarely causes much fall in cardiac output". This was assessed by the small changes in arteriovenous oxygen content difference when they changed to spontaneous breathing. Some patients' shunts increased with the onset of spontaneous breathing which led to hypoxaemia. The authors were very cautious about advocating prolonged IPPV post surgery as "technical problems associated with mechanical ventilation may result in an increased morbidity and mortality."

1971 Models of the lung [12]... this is part of a three way discussion about the intricacies of the functioning and mathematical treatment of lung models and refers back to [8].

1975 A transportable anaesthetic apparatus [13]... this is the description of a miniature version of a Boyle's anaesthetic machine that could be attached to a patient's trolley whilst being wheeled between operative areas in the hospital. There was also an assessment of the Bain circuit for controlled ventilation [14].

1976 A scavenging system, a co-axial breathing circuit and scavenging valve, and the Bain anaesthetic system 1976 [15-17]. In the 1970s the scavenging of exhaled anaesthetic gases/vapours was a hot topic and many systems were designed, both by equipment manufacturers and individuals. A co-axial breathing circuit (The Bain system): An improved version of the Bain circuit, made by Respiratory Care Inc., incorporated a valve which allowed attachment to British anaesthetic machines. This was described and the system was further investigated during controlled ventilation. The results of the study showed that a highly predictable PaCO₂ could be obtained if the fresh gas flow was determined by body weight. The *"...mean PaCO₂ at a fresh gas inflow of 70 ml/kg/minute = 40.8 mmHg; mean PaCO₂ at a fresh gas inflow of 100 ml/kg/minute = 34.3 mmHg)...It is suggested that it may qualify as a universal breathing system."* They also determined that by interposing a 1 m length of corrugated 22 mm diameter anaesthetic breathing tubing between a lung ventilator delivering air and the Penlon Bain-type co-axial anaesthetic circuit air-dilution of the respired gas mixture was unlikely. A reasonably common practice.

1977 The Bain circuit [18]and a new generation of anaesthetic ventilators [19]. He described the 'new generation' as being constructed on the moving-part fluid logic principle; they were considered to be simple, inexpensive and robust with facilities for PEEP, a scavenging system and for relief of over-pressure.

1978 A laboratory study of the Nuffield lung ventilator with the injector technique [20]... using a Nuffield lung ventilator he showed that the control module was an efficient means of automatically controlling the ventilation of the lungs using an injector technique through a bronchoscope. The effects of

compliance, airway resistance and the driving flow rate through various injectors on the oxygen concentrations and tidal volume were determined. A 14 gauge injector provided seemed optimal.

There was also a paper on the hazards of excessive airway pressure and their prevention [21].

1990 An end-tidal carbon dioxide detector [22]. This was the description of a colorimetric method for detecting carbon dioxide - a disposable device with a pH-sensitive chemical indicator. It was found to be a reliable, rapid and easy method for the detection of oesophageal intubation. A letter concerning false-positives with the end-tidal carbon dioxide detector was published in 1992 [23]. After ingestion of a carbonated beverage a colour change indicating correct tracheal tube placement could occur even though the endotracheal tube has actually been placed in the oesophagus. They explained that these false-positives were also found with other CO₂ detectors.

1991 Oxygen delivery systems [24]: The inhaled concentration of oxygen was measured in the oropharynx whilst the volunteers breathed through either a low flow oxygen mask or through nasal catheters. The bottom line was that both were equally effective but the nasal catheters were cheaper.

1993 Checking anaesthetic machines [25]... an editorial. *"The aims of checklists are to prevent the development of problems. Compliance with the existing guidelines leaves much to be desired. Why anaesthetists do not follow these, or some other guidelines, is difficult to understand, particularly when ample evidence exists in the literature of the folly of not doing so. It is hoped that the pictorial checklist will persuade more anaesthetists to check their equipment responsibly before each operating session."* Well said.

1994 Breathing system disconnections [26]; disconnections of various bits of breathing systems had been 'tolerated' for quite some time^{iv}. Adam's publication goes into great detail; covering causes and possible remedies. Disconnections occurred so often as to be considered as routine and grudgingly accepted for easy access to the airway; they were however a cause of preventable serious injury and death. Disconnections occurred most frequently

^{iv} Harrison MJ, Tomlinson PA, Mann MS. (letter) *Anaesthesia* 1984;39:721

at the connection of the tracheal tube to the breathing system. Separations occurred primarily at conical fittings and many specifications were obsolete because of changes in materials. The clinicians were also concerned about accidental extubation, a risk associated with tight fitting joints. Alarm misuse or devices with inadequate alarm systems were also a problem. The 'hanging bellows' anaesthesia ventilators also presented a serious hazard as the bellows still appeared to fill even in the presence of a disconnection.

Pacemaker failure [27]. This is a case report of cardiac arrest in a patient with a fixed-rate ventricular pacemaker; interference caused by activation of a nerve stimulator resulted in pacemaker failure.

1996 A new tracheal tube [28]. A new Portex tracheal tube was compared with the Oxford tube in performing simulated grade 3 difficult intubations. One of the side issues highlighted in this study was a learning effect; intubation time decreased progressively over the period of the study. Their "estimate of the learning "half-life" was 15 intubations; we conclude that 30 simulated grade 3 intubations would be a reasonable objective for trainees before handling high-risk cases."

2004 Dead space and paediatric anaesthetic equipment [29]. Dead space and paediatric anaesthetic equipment...this, another laboratory study using a model lung, showed that functional dead space with a breathing filter created too much dead space. However, a poorly fitting, leaking, facemask reduced the dead space – "*to near optimal conditions*".

About 20% of Adam's publications relate to equipment or measurement.

Ventilation

This topic, related to equipment, was investigated in relation to how it affects the cardiorespiratory system and eyes.

Firstly, effects on the cardiovascular system; the effect of the waveform [8], the inspiratory/expiratory ratio [9] and the end-expiratory inflation pressure [10]. These were followed by the effect of mechanical ventilation after open-heart surgery [11].

Secondly... effects on the eye... Normocapnic anaesthesia with trichloroethylene [30, 31], and with enflurane [32]. Measurements of intraocular pressure showed that a normocapnic anaesthetic technique using 0.4% trichloroethylene with large tidal volumes (14 ml/kg) reduced IOP by 13-

20%. So it was considered that trichloroethylene was suitable for lens extraction surgery when it was desirable to avoid halothane. Similar studies were done with halothane and enflurane.

Distantly related to ventilation is the Valsalva manoeuvre. Adams used it as a test of circulatory responses in neurosurgical patients. It was an unreliable predictor of a patient's ability to tolerate the upright or sitting position [33].

Pharmacology

In the 60s and 70s deliberate hypotension gained popularity as a method of reducing blood loss, the goal was "the dry surgical field". The combination of halothane and curare was efficacious but greater control was sought and so short acting agents were investigated...the agent de jour was sodium nitroprusside. Adams investigated this agent for its effect on myocardial contractility and haemodynamics, it was presented at the ARS meeting in Cardiff in November 1972 [34]^v and was published in full in 1974 [35].

The following year he was the author of an article on "Techniques of vascular control for deliberate hypotension during anaesthesia" in the BJA [36], this was part of a special issue in which GEH. Enderby wrote on "Some observations on the practice of deliberate hypotension", JM Leigh on "The history of controlled hypotension", B. Nilsson, K. Norberg and BK Siesjo - "Biochemical events in cerebral ischaemia" (a slightly worrying juxtaposition), L Strunin - "Organ perfusion during controlled hypotension" and MJ Lindop, "Complications and morbidity of controlled hypotension".

There were a variety of other drug related papers; two of interest are those relating to intravenous 'aspirin' [37, 38]. Both compared the efficacy of morphine with lysine acetyl salicylate, both as infusions; one in a series of patients after herniorrhaphy and the other after thoracotomy. In the hernia patients it was determined that lysine acetyl salicylate (LAS) provided equivalent analgesia with less drowsiness, nausea and vomiting. In the

^vDeliberate hypotension was popular; in that same journal were items about sodium nitroprusside by JAW Wildsmith et al. Br. J. Anaesth. (1973) 45 (1): 71-74 and by H Eppen, Br. J. Anaesth. (1973) 45 (1): 124 and another about trimetaphan by B Collier, Br. J. Anaesth. (1973) 45 (1): 123-124 s

thoracotomy study mean pain scores were not significantly different and LAS was not associated with any significantly greater blood loss.

In the author's experience intravenous aspirin is not commonly used, intravenous paracetamol is.

Clinical

Throughout the almost 40 years of publications, there was a wide variety of clinical observations. Amongst them are papers on preoxygenation [39], air embolism [40, 41], three-dimensional echocardiography [42], aspiration of gastric contents [43] and others.

Here are three of interest:

Acute amphetamine abuse [44]: Acute amphetamine abuse by a 22-year-old girl [sic] led to serious intracranial hypertension during a neurosurgical procedure. It was difficult to maintain adequate anaesthesia with a ventilational technique using pancuronium, N₂O/O₂ and supplements of fentanyl.

Hysteria. A cause of failure to recover after anaesthesia [45]:

A case report of a 22-year-old female (*another 22 year old — in 1979 described as a girl, now in 1991 as a female!*) who was suffering severe dental phobia and was undergoing dental conservation. She had, three years previously, had a dental appointment and had become unresponsive and hypotonic for 11 days. Following the described general anaesthetic for dental work she again, after apparent recovery from the anaesthetic drugs, remained unresponsive. Four hours later a tetanic stimulus (50 Hz for 5 seconds) was applied to the ulnar nerve, she then awoke, fully orientated in time and space.

The third paper also involved young persons [46] – an **assessment** of the ability and confidence of clinical medical students **to insert endotracheal tubes** correctly and quickly and to recognize oesophageal misplacement was evaluated. It was determined that ninety-three percent of students intubated correctly on their third attempt. It was said however that it was the ability to recognize oesophageal intubation promptly that is a life-saving skill and that this skill "*should be taught during the introductory anaesthesia programme through the use of clinical patients.*" Without being pedantic, the "use" of patients sounds politically incorrect nowadays.

The remaining references are a mixed bag but they do include a selection of cardiac-surgery/anaesthesia related topics [47-50] and a selection on airway management/difficult intubation studies [51-54]. Two papers on the subject of delayed respiratory depression due to opiates (Fentanyl) reflect an interest at this time of this phenomenon. The first was based on case reports and the concept of recirculation of opiates by secretion of the opiate into the stomach and then subsequent reabsorption in the jejunum was discussed [55]. This was followed a year later by a 30 patient study where plasma concentrations of fentanyl were measured and clinical observations made [56]. Their final comment was that it was “*no longer wise to regard fentanyl as a short acting drug*” and to be careful with additional postoperative analgesics.

So what was Adams’ main interest? Maybe it can be summarised by the keywords — breathing systems and equipment, cardiorespiratory physiology and cardiac anaesthesia.

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