Article:
Bilmen, JG and Hopkins, PM orcid.org/0000-0002-8127-1739 (2018) The use of charcoal filters in malignant hyperthermia: have they found their place? Anaesthesia, 74 (1). pp. 13-16. ISSN 0003-2409

https://doi.org/10.1111/anae.14407

The use of Charcoal Filters in Malignant Hyperthermia: Have they found their place?

Jonathan G Bilmen[1] & Philip M Hopkins[1,2]

1. Malignant Hyperthermia Unit, St James's University Hospital, Leeds, UK
2. Leeds Institute of Biomedical & Clinical Sciences, University of Leeds, Leeds, UK

Dr Jonathan G Bilmen, Consultant Anaesthetist, Leeds Teaching Hospitals NHS Trust. Email: jonathanbilmen@nhs.net
Professor Philip M Hopkins, Professor of Anaesthesia, University of Leeds and Consultant Anaesthetist, Leeds Teaching Hospitals NHS Trust

Twitter: @BillersJ
@profhop

Corresponding author: Philip M Hopkins, Leeds Institute of Biomedical & Clinical Sciences, St James's University Hospital, Leeds, LS9 7TF, United Kingdom. Phone +44 113 2065274, Fax +44 113 2064140. Email: p.m.hopkins@leeds.ac.uk

Conflicts of Interest

The authors confirm that they have no conflicts of interest

Keywords

Malignant hyperthermia

Activated charcoal filters

Potent inhalational anaesthetics

Malignant hyperthermia (MH) is a potentially fatal condition caused by exposure of genetically-predisposed individuals to potent inhalational anaesthetic agents. It has been promulgated that exposure to agents at a concentration above 5 parts per million (ppm) may be sufficient to trigger a crisis in MH-susceptible individuals. This is based on a publication of work performed in MH susceptible swine [1]. While 5 ppm probably affords a large safety margin, subsequent research has focused on reducing anaesthetic agent residue in inspired gases delivered by workstations to under 5 ppm when they are used in the anaesthetic management of MH-susceptible patients [2].

The evolution of anaesthetic workstations has led to incorporation of more and more internal non-metal pipework. As a result, there is now a significant increase in anaesthetic vapour residue after delivery and cessation of greater than 60 minutes of inhalational agents. A comparison of newer anaesthetic workstations has shown that inhalational agents can be measured above 5 ppm for up to 144 minutes following cessation of delivery of anaesthetic agents and application of high-flow oxygen through the system [3].

In the days of less complex (and cheaper) anaesthetic machines many hospitals stored a vapour-free machine that could be used when a patient at increased risk of developing MH needed surgery: this is no longer a financially viable solution. There was therefore great interest in the commercial production and marketing (in 2010 in the United States and 2015 in Europe) of activated charcoal filters (ACFs) that were designed to rapidly eliminate inhalational anaesthetics from anaesthesia workstations.

It has long been suggested that activated charcoal could serve as an excellent adsorbent to remove inhalational anaesthetic agents as both a pollutant in operating theatres and from anaesthetic circuits [4,5]. Activated charcoal is carbon, purified from wood and other organic sources, which has been treated to create an extremely porous structure. The treatment used is either:

- Chemical, by addition of an acid, strong base or salt, followed by heat treatment, or

- Physical, by heating the charcoal in an inert gas (nitrogen or argon) to between 900 and 1200 Kelvin and then exposing it to oxygen to create the porous state.

The highly porous structure creates a huge surface area of exposed carbon atoms that are readily available to bond to any organic matter that passes over them. Hence, when volatile anaesthetic agents pass through activated charcoal, they bind to these exposed carbon atoms and are held within the charcoal (the process of adsorption). This effect makes activated charcoal an ideal substance to filter out volatile anaesthetic agents in our workstations.

As early as 1992, groups have been experimenting with activated charcoal as a method to reverse inhalational anaesthesia [6]. Activated charcoal is used in many day-to-day products, including toothpaste, skincare products, water purifiers and as an aid to digestion as an oral tablet. It is also used in healthcare, as an adsorbent for ingested toxins and in facial gas mask filters to help clean air in contaminated atmospheres. It is considered a very safe substance in terms of human exposure (either through contact or ingestion) with almost no side effects (very occasionally vomiting or constipation with excessive ingestion) [7]. Studies performed by Krivoy et al. in 2005 studied the use of activated charcoal in respiratory systems containing supplemental oxygen to demonstrate its safety in use with high oxygen containing systems [8]. They found no increased risk whatsoever in exposing activated charcoal to high partial pressures of oxygen (up to 100 % oxygen) at ambient temperatures, demonstrating its safety in breathing circuits.

Following introduction of ACFs, there have been several studies regarding efficacy and also debate about whether it should be compulsory for them to be stocked at locations where inhalational anaesthesia is administered. As noted in recent correspondence in *Anaesthesia* the currently available AAGBI guidelines for the management of a MH crisis pre-date the availability of ACFs in Europe [9]. The AAGBI has convened a Working Party tasked with producing a new comprehensive guideline for the management of MH susceptible patients but this may not report until early 2019.

The early research on the use of the commercially available ACFs, unsurprisingly perhaps, involved authors who were instrumental in the product coming to market and therefore with a financial interest (albeit appropriately declared) in the product. In 2011, Birgenheier et al. described the successful integration of charcoal filters into an anaesthetic circuit and proposed that they could be used for preparing an anaesthetic workstation for use in MH susceptible patients [10]. These experiments involved bench testing an Apollo (Drager, Luebeck, Germany) anaesthetic workstation, using contaminated parts and determining the most expedient method of ACF placement and disposable pipework replacement to reduce volatile agents to safe levels (< 5 ppm). In addition, as part of their marketing in Europe, Dynaesthetics LLC (the manufacturers of the ACFs) successfully obtained the CE (Conformité Européene) marking, meaning that the ACFs met the necessary standards of halth and safety to be used as described in anaesthetic workstations.

The usefulness of ACFs in MH susceptible patients undergoing anaesthesia are several-fold:

1: For patients requiring immediate surgery (e.g. from major trauma admission to the Emergency Department), any anaesthetic workstation can be prepared within 3 minutes with the use of ACFs.

2: For patients undergoing elective surgery, the use of ACFs, can reduce the theatre downtime by up to 2.5 hours (the time taken to wash out certain anaesthetic workstations to safe concentrations of anaesthetic agents).

3: The storage and use of ACFs will reduce the requirement of 'clean' (vapour free) anaesthetic workstations to be immediately available, thus making a cost-saving to operating suites.

Subsequent work undertaken by Kern et al [11]. has shown that ACFs can be employed successfully with a wide variety of anaesthetic workstations. In numerous tests this group found that the filters, when applied according to

manufacturer guidelines, successfully reduced vapour concentrations to < 5 ppm in all but one anaesthetic workstation (the Leon +) and even here, the rise only occurred when the workstation was switched from spontaneous to controlled ventilation [11]. Furthermore, the rise in concentration of anaesthetic vapour did not exceed 10 ppm, a concentration that is likely to be a safe level of exposure in MH susceptible patient [2].

Meanwhile, other groups have conducted further bench studies to examine the optimal use of ACFs. It has been demonstrated, for example, that only one ACF is needed when preparing an anaesthetic workstation, provided that it is placed on the inspiratory limb of the anaesthetic circuit [12,13]. The manufacturer still recommends using two filters and this will avoid the potential to put a single filter on the expiratory limb by mistake. The manufacturer also recommends changing the filters for a new pair should a case last longer than 12 hours. However, we cannot find any reasonable justification for not just simply removing them after this time period, whilst maintaining a fresh gas flow of 10 l/min, as evidenced by Bilmen and Gillies [12].

Contrary to the assumptions of some, the incidence of MH reactions from inhalational agents in the UK has remained remarkably constant over the past 30 years and the mortality remains approximately 4% [14]. Indeed, in the United States, mortality from MH increased in the past decade [15]. In our experience, a poor outcome is invariably related to the interval between onset of the reaction and institution of effective treatment. The diagnosis of MH can be challenging, for example in a septic patient undergoing surgery, and so there is an imperative to be able to institute multi-faceted treatment as soon as possible after the diagnosis has been made. The initial treatment includes elimination of the triggering inhalational anaesthetics, administration of an effective dose of dantrolene and promotion of heat loss. Actions that can be implemented immediately in all cases are turning off the vaporiser, increasing fresh gas flows to maximum, mechanical hyperventilation of the lungs, switching off warming devices and exposing as much of the patient's body as possible. All other measures are tasks that ideally should be allocated to theatre

team members while the anaesthetist leads and coordinates the patient's management.

When the emergency is first called, the number of staff available to help is likely to be limited and there will be competing priorities. However, there should be no delay in retrieving dantrolene from its stored location and, ideally, two dedicated team members should begin preparing dantrolene for administration, as well as switching to a non-volatile based anaesthetic, essentially propofol based total intravenous anaesthesia (TIVA). The evolution of modern anaesthetic workstations has made it more difficult to eliminate the volatile agent but also made it impractical to rapidly substitute with an alternative "clean" machine or replace components that adsorb the anaesthetic. The immediate alternatives available before the introduction of ACFs were essentially either to manually hyperventilate the patient's lungs, using a non-rebreathing circuit to bypass the workstation circuit or to accept that it would take some time for the volatile agent to be eliminated. Further arrangements could then be made, such as procuring an ICU ventilator, though this takes time to practically arrange, as well as personnel, which may be crucially needed to perform more immediate tasks such as mixing the necessary doses of dantrolene. Even then, an ICU ventilator carries risk of contamination with inhalational anaesthetics, as they are often used to transfer patients from theatres to ICU, which in itself poses a risk to MH susceptible patients.
In situations where a known MH susceptible patient is undergoing elective surgery, appropriate precautions can be made that do not involve the use of ACFs, such as flushing the workstation to reduce vapour levels to safe margins or to utilise a clean ICU ventilator, though this can be time consuming. In such cases, TIVA would be required.

The availability of ACFs provides an effective solution to the quandary of balancing the need to eliminate the triggering anaesthetic and the alternative actions that the available manpower might need to prioritise. We recommend that a pair of ACFs is kept with each box of dantrolene at locations where triggering anaesthetics are used. The application of a pair of charcoal filters into the anaesthetic breathing circuit is straightforward: It merely requires

placement of ACFs on the inspiratory and expiratory limb. The manufacturer recommends that the breathing circuit and reservoir bag should be changed at the same time. This requirement during the height of an MH crisis may, however, lead to errors (tubing not placed correctly or connected properly) and a delay in undertaking other interventions.

We are hopeful that the next iteration of the AAGBI guidelines will address the use of ACFs in the emergency management of malignant hyperthermia reactions as well as the anaesthetic management of MH susceptible patients undergoing elective surgery. ACFs are very useful in preparing anaesthetic workstations in situations where time is a critical factor. Furthermore, ACFs may play a critical role in patients who have an 'on-table' suspected MH reaction, by removing all trigger agents from the circuit and hence reducing perpetuation of the potential MH crisis. Therefore, we would recommend their storage in all areas where volatile agents are used.

Recently, an endowment to the University of Leeds has been used to form the UK MH Registry based within the Malignant Hyperthermia Unit at St James's University Hospital in Leeds. One of the main purposes of the Registry is to be a resource for patients, members of the public and health care professionals on all aspects of MH. Details of this can be found at www.ukmhr.ac.uk. Included on this site is a freely downloadable up to date guideline for the management of an MH reaction that includes our advice on activated charcoal filters.

References

1. Crawford MW, Prinzhausen H, Petroz GC. Accelerating the washout of inhalational anesthetics from the Dräger Primus anesthetic workstation: effect of exchangeable internal components. Anesthesiology 2007; **106**: 289-94

2. Hopkins PM. Malignant hyperthermia – pharmacology of triggering. British Journal of Anaesthesia 2011; **107**: 48-56
3. Cottron N, Larcher C, Sommet A, Fesseau R, Alacoque X, Minville V, Fourcade O, Kern D. The sevoflurane washout profile of seven recent anesthesia workstations for malignant hyperthermia-susceptible adults and infants: a bench test study. Anesthesia and Analgesia 2014; **119**: 67-75
4. Hawkins TJ. Atmospheric pollution in operating theatres. A review and a report on the use of reuseable activated charcoal canisters. Anaesthesia 1973; **28**: 490-500
5. Bushman JA, Enderby DH, Askill S. The use of charcoal in a totally closed circuit for the removal of halothane. British Journal of Anaesthesia 1976; **48**: 269-70
6. Romano E, PegoraroM, Vacri A,Pecchiari C, Auci E: Low-flow anaesthesia systems, charcoal and isoflurane kinetics. Anaesthesia 1992; **47**: 1098-9
7. Jones J,McMullen MJ, Dougherty J, Cannon L. Repetitive doses of activated charcoal in the treatment of poisoning. American Journal of Emergency Medicine 1987; **5**: 305-311
8. Krivoy A, Luria S, Gafnit Z, Sukhotnikovt S, Yehezkelli Y. Safetyof biological/chemical respiratory protection filter for patients in need of oxygen supplementation. Military Medicine 2005; **170**: 1029-31
9. Bickmore EG, Aziz E. The use of activated charcoal filters in anaesthetic circuits in suspected malignant hyperthermia. Anaesthesia 2017; **72**: 1415-6
10. Birgenheier N, Stoker R, Westenskow D, Orr J. Activated charcoal effectively removes inhaled anesthetics from modern anesthesia machines. Anesthesia and Analgesia 2011; **112**: 1363-70
11. Kern D, Lamouret O, Kurrek M, Gallix D, Requis J, Blais T, Laur JB, Visnadi G, Minville V, Fourcade O. Efficacité des filtres à charbon actif (Vapor Clean, Dynasthetics) pour la préparation de 7 respirateurs d'anesthésie avant ventilation de patients adultes et enfants suspect d'hyperthermie maligne. Anesthesie & Reanimation 2015; **1(S1)**:A389

12. Bilmen JG, Gillies RI. Clarifying the role of activated charcoal filters preparing an anaesthetic workstation for malignant hyperthermia-susceptible patients. Anaesthesia and Intensive Care 2014; **42**:51-8
13. Sabouri AS, Lerman J, Heard C. Effects of fresh gas flow, tidal volume, and charcoal filters on the washout of sevoflurane from the Datex Ohmeda (GE) Aisys, Aestiva/5, and Excel 210 SE Anesthesia Workstations. Canadian Journal of Anaesthesia 2014; **61**: 935-42
14. Sneyd JR. Thiopental to desflurane - an anaesthetic journey. Where are we going next? British Journal of Anaesthesia. 2017; **119(suppl_1)**: i44-i52
15. Riazi S, Kraeva N, Hopkins PM. Malignant hyperthermia in the post-genomics era: new perspectives on an old concept. Anesthesiology 2018; **128**: 168-80