Veterinary Green Theatre Checklist

Compendium of Evidence

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Introduction

Healthcare provision results in significant carbon emissions, with notable hotspots resulting from acute care. Operating theatres are a particularly resource-intensive area, with an estimated 3-6 times higher energy use than other parts of the hospital (NHS 2022). This compendium supports the implementation of the Veterinary Green Theatre Checklist (VGTC) v1.0, applying sustainability quality improvement principles to target environmental outcomes. The VGTC v1.0 builds on the Intercollegiate Green Theatre Checklist | RCSEd (IGTC) v2.0 (released in November 2024) created and written by our medical colleagues, integrating veterinary evidence where it exists.

While this checklist focuses on mitigating the impacts of veterinary healthcare once operating theatres become necessary, sustainable practices should extend throughout the entire surgical pathway. Primary prevention remains the most effective carbon reduction strategy, although future research must establish for which conditions surgery may have lower environmental impact over the longer term than medical management. When surgery is necessary, pathway optimisation can include telemedicine, consolidated diagnostics, and ambulatory procedures where clinically appropriate. The 2023 Green Surgery Report provides more information on reducing the environmental impact of surgical care pathways.

There is ongoing, rapid evolution of understanding in this field and it is expected that this checklist is iterative and will be adapted as new evidence emerges. As such, the VGTC v1.0 stands as a practical tool for veterinary clinics to audit current practices and take simple and impactful first steps into sustainable practices in operating theatres.

Development Methodology

The project was initiated by the Association of Veterinary Anaesthetists (AVA) in 2024 and a core working party was formed. A range of cross-specialism assessors were invited to collaborate through a call-to-action at the Autumn 2024 AVA conference and/or direct introduction through the core team. Approval was sought and received from the authors of the IGTC to review and adapt their work as required for the veterinary healthcare sector.

Each statement from both IGTC v1.0 and 2.0 received independent dual review, including literature assessment, to determine inclusion or modification into the VGTC based on their veterinary applicability and evidence quality. Additionally, new statements specific to veterinary practice were proposed and added following the same review process.

The core working party made final determination for inclusion in the final checklist, prioritising document concision, high impact, high quality of evidence and ease of implementation. Recommendations were prioritised using the waste hierarchy; prevent, replace, reduce, reuse, and recycle. Some statements and evidence were adopted directly from the IGTC v2.0, where considered appropriate. Finally, consent was sought for review and high-level endorsement from a range of veterinary organisations to further disseminate the recommendations and information provided in the VGTC v1.0 and its accompanying compendium.

Feedback and research updates for future iterations are expected due to the rapid growth in this field. Offers of ideas for improvements or future collaborations are welcomed via the AVA webpage contact form (https://ava.eu.com).

How to Use the VGTC v1.0

The VGTC v1.0 is intended to support evidence-based, sustainable operating theatre practices in veterinary clinics, primarily small animal and equine.

The VGTC v1.0 is organised into 4 sections of recommendations based on actions related to preparing for surgery, using pharmaceuticals, during surgery and after surgery. The activity-based focus of the sections is designed to reflect the collaboration needed between theatre teams to provide a high quality of clinical care whilst simultaneously practising sustainably.

The VGTC v1.0 serves as both an immediate action tool and a roadmap for departmental transformation. Successful implementation requires change management and engagement with relevant stakeholders including management, procurement, facility and operations teams. Many of the actions represent cost-effective strategies with quality of care and environmental co-benefits. The VGTC v1.0 is supported by this compendium of evidence, reviewing the available supporting evidence behind each statement.

Veterinary Green Theatre Checklist v1.0 (2025)

Preparing for surgery

1. Reduce clinically unnecessary interventions e.g. minimise variability in procedures & consumables, rationalise diagnostic tests and catheterisation ☐
2. Rationalise use of single-use items e.g. non-sterile single-use gloves, kennel liners ☐
3. Use surgical textiles rationally e.g. choose the appropriate gown considering the procedure, switch to reusables gowns, drapes and instrument wraps, consider field sterility ☐
4. "Rub don't scrub": after first hand wash of day, use hand sanitiser for subsequent cases ☐
5. Review equipment packs to consolidate equipment into reusable sets, and rationalise re-sterilisation protocols ☐
6. Source renewable electricity; upgrade and electrify heating, lighting and energy systems where possible ☐

Using pharmaceuticals

7. Ensure rational choices for pharmaceutical use ☐
8. Decommission nitrous oxide and desflurane ☐
9. Reduce volatile consumption (where safe and appropriate) by planning carefully to minimise duration of anaesthesia, and use of lower flow anaesthesia ☐
10. Choose lower carbon pharmaceutical options (where safe and appropriate) e.g. sevoflurane over isoflurane; oral over parenteral routes of administration ☐
11. Consider injectable techniques such as regional anaesthesia, PIVA, and TIVA (where safe and appropriate) ☐
12. Open pharmaceuticals and equipment only when needed ☐
13. Ensure unwanted pharmaceuticals are disposed safely, and encourage returns of medications (if unused or out-of-date) ☐

During surgery

14. Limit CO_2 insufflation in minimally invasive surgery ☐
15. Transfer single-use items with the animal if still needed e.g. suction tubing, warming consumables ☐
16. Consider reusable or refurbished equipment and consumables for anaesthesia (e.g. laryngoscopes, warming equipment, kennel liners, CO_2 absorbent canisters) and surgery (e.g. theatre hats, facemasks, surgical textiles, staplers, sterile containers) ☐
17. Choose lower carbon equipment options (where safe and appropriate) e.g. skin sutures vs. clips, passive warming systems, use of gallipots for surgical preparation ☐

After surgery

18. Introduce "*shut-down*" and "*power-on*" checklists for heating, ventilation, air conditioning, AGSS, lights, computers, autoclaves and other equipment ☐
19. Encourage active maintenance and repair of equipment ☐
20. Segregate waste into the lowest carbon (appropriate) waste stream e.g. optimising recycling waste streams (electrical waste, cardboard/paper, metals, plastics, organic waste, pet hair), prioritising non-infectious offensive waste streams where appropriate, ensuring appropriate contents in healthcare waste containers (only uncontaminated packaging in recycling) and switching to lower impact containers where appropriate (reusable, cardboard, larger volume containers) ☐

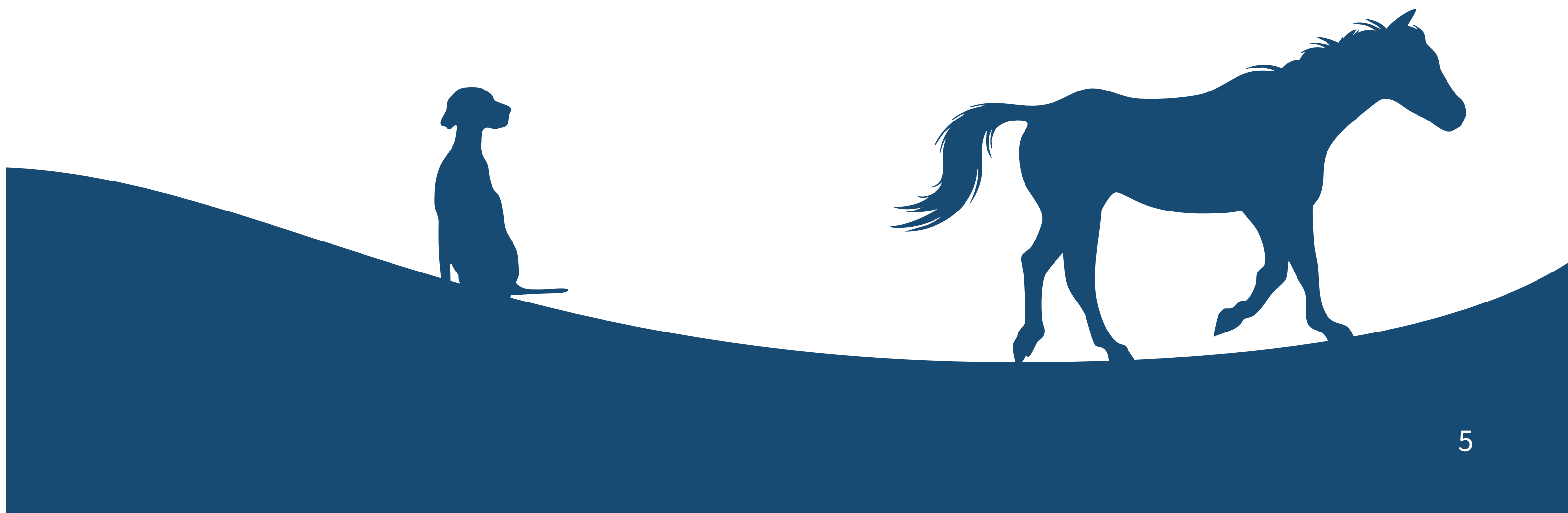
Association of Veterinary Anaesthetists · BEVA · BVNA British Veterinary Nursing Association · ESVN · ECVN · RCVS Knowledge · ANZCVS · Vet Sustain

The VGTC v1.0 consists of 20 recommendations to reduce the environmental impact of veterinary operating theatres when preparing for surgery, using pharmaceuticals, during surgery, and after surgery.

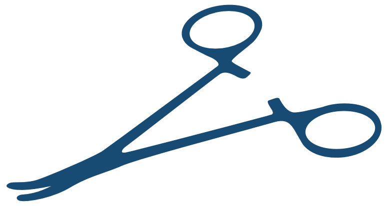
Responsibility remains with the user to prioritise animal and staff safety, seek expert advice before changing protocols as required and to remain in compliance with local regulations.

DISCLAIMER: These suggestions are based on current evidence collated by the authors of the VGTC v1.0 and are broadly generalisable; however, specific environmental impacts will depend upon local infrastructure and individual clinic implementation strategies.

Footnote: Veterinary Green Theatre Checklist v1.0 July 2025



COMPENDIUM OF EVIDENCE



Preparing for surgery

1	Reduce clinically unnecessary interventions e.g. minimise variability in procedures & consumables, rationalise diagnostic tests and catheterisation	☐
2	Rationalise use of single-use items e.g. non-sterile single-use gloves, kennel liners	☐
3	Use surgical textiles rationally e.g. choose the appropriate gown considering the procedure, switch to reusables gowns, drapes and instrument wraps, consider field sterility	☐
4	“Rub don’t scrub”: after first hand wash of day, use hand sanitiser for subsequent cases	☐
5	Review equipment packs to consolidate equipment into reusable sets, and rationalise re-sterilisation protocols	☐
6	Source renewable electricity; upgrade and electrify heating, lighting and energy systems where possible	☐

1. Reduce clinically unnecessary interventions e.g. minimise variability in procedures & consumables, rationalise diagnostic tests and catheterisation

Studies have shown large variability in the equipment and pharmaceutical choices made by surgeons performing the same procedure, including variable quantities of consumables (Baxter et al. 2021; Booth & Shaw 2025). Rationalising the use of single-use consumables and eliminating them where appropriate will decrease the carbon footprint of the procedure (Baxter et al. 2021; Kloevekorn et al. 2024; Badhe et al. 2025).

Lean healthcare is the application of principles and practices to identify and eliminate waste in healthcare processes. This is a concept borne out of manufacturing which has been applied in the healthcare setting, initially to optimise efficiency and patient satisfaction, (Lawal et al. 2014) but that can also create significant benefits in reducing environmental impact (Rizan et al. 2020a). This preventative approach has been crystallised in the US ‘Choosing Wisely’ and UK ‘Getting it Right First Time’ initiatives (McGain et al. 2021).

Every healthcare activity has an associated carbon footprint. Diagnostic tests should be reviewed to determine if they are clinically essential; for example, routine histopathological examination of the gall bladder following human cholecystectomy was noted to be very rarely of clinical value, if gross appearance was typical and pre-operative and intra-operative findings were not sinister (Darmas et al. 2007). Certain consumables have particularly high impact, for example single-use urinary catheters (Sun et al. 2018) or those containing persistent per- and polyfluoroalkyl (PFAS) chemicals. Any choice to perform a test or intervention should be based on clinical benefit.

2. Rationalise use of single-use items e.g. non-sterile single-use gloves, kennel liners

Infection control protocols must be followed in all settings and single-use materials used when necessary. However, their use should be rational and only when needed, where possible reusable items should be considered (e.g. use of reusable aprons during clipping and surgical site preparation).

Use of single-use consumables in medical care can give the illusion of quality assurance (Naumann et al. 2020), when in fact it may detract from other practices, such as proper hand-hygiene during use of non-sterile examination gloves (NSEG). There are additionally human labour rights issues raised by the medical sector in production of particular single-use items such as NSEG (Feinmann 2020).

NSEG are usually intended to protect the healthcare worker but are open to overuse. Great Ormond Street Hospital (GOSH) carried out a campaign to help staff risk assess the use of NSEG and improve adherence to hand hygiene protocols (Dunn H 2019a; Dunn H 2019b; Leonard et al. 2019; Mahase 2019). Audits showed that NSEG over-use meant opportunities for hand decontamination during patient care were missed. The campaign was motivated by concerns regarding infection control (Lindberg et al. 2020), but had additional benefits by reducing use of consumables, therefore affording financial and environmental benefits.

An education program for relevant clinical staff was developed and communicated via focus groups and practice educators. The campaign appeared very effective; in the *“year after the campaign, GSOH ordered 3.7 million fewer NSEG compared to the year before, saving over £90,000 and avoiding the use of 18 tonnes of plastic. Plus, staff reported hand dermatitis less frequently”* (Dunn H 2019b). This campaign has now been adopted by other NHS trusts (Mahase 2019) and further developed by organisations such as the Royal College of Nurses, UK in their annual “Glove Awareness” campaign (RCN 2025).

3. Use surgical textiles rationally e.g. choose the appropriate gown considering the procedure, switch to reusables gowns, drapes and instrument wraps, consider field sterility

The necessity to use gowns and drapes to create a sterile surgical site is unrefuted. This will prevent the welfare, environmental and financial costs of treating infections and their consequences. However, a detailed life-cycle analysis, comparing all aspects of environmental impact from the use of a single-use disposable gown versus a reusable gown, documents the significantly lower environmental impact of reusable gowns, even when laundering, repackaging and resterilisation is considered (Vozolla et al., 2020). This provokes a re-evaluation of the interplay of factors which may affect the choice of gown.

Where a choice of gown is available, veterinary surgeons should use the correct gown for the procedure they are performing. Each surgical procedure varies in terms of the risk of fluid contamination on the gowns or drapes, and the anticipated risk to the patient should a wound infection develop (e.g. if an implant is used the risk is greater) and therefore the selection of surgical textiles for a particular procedure and patient can be made on a rational basis (Belkin 1994).

A range of gown materials are available, from reusable options including traditional woven natural fibres, such as cotton, and subsequently polyester and cotton mixes, to modern textiles with multi-layered synthetic fabrics; or single-use options, typically made of spun-bond polypropylene (Belkin 2002). Different materials have varying physical properties, with particular focus placed upon permeability when wet, and therefore potential for bacterial ingress. Whilst re-usable woven materials perform well in ensuring that the surgeon is sterile, if there is significant wetting of the fabric, microbial strike-through becomes possible (Belkin 2002).

Single-use textiles that are made of non-woven material (typically synthetic fibres, such as polypropylene) have superior barrier properties to the ‘old’ style of woven reusable (cotton, ‘green cloth’) materials, however this depends upon the performance of the particular gown utilised (Belkin 2002). In some veterinary practices, only reusable surgical textiles are used, whilst other practices rely on single-use items (Delisser et al. 2012). Single-use textiles have become commonplace due to convenience and reliability. However modern materials and the necessary decontamination and sterilisation protocols for their reuse are rigorous and robust, thereby providing quality assurance (McNamee et al. 2024).

Systematic review of the literature in human medicine, comparing surgical site infection when using single-use textiles versus re-usable textiles (gowns and drapes), concludes non-inferiority for reusable surgical textiles (WHO 2018b; Vasanthakumar 2019); the textiles of the reusable gowns and drapes varied, however in most reviewed papers the gowns were traditional reusable cotton (woven) gowns (WHO 2018a). Modern re-usable gowns, some of which are multi-layered fabrics, in fact perform in a superior manner to single-use gowns both in terms of permeability and comfort (McQuerry et al. 2021) and should meet EN 13795 standards for sterile surgical textiles.

There is no evidence to support a difference between reusable or disposable drapes to reduce the risk of surgical site infection in human orthopaedic and spinal surgery (Kieser et al. 2018). A prospective multicentre parallel group randomised controlled trial is currently being conducted in first opinion veterinary practices in the UK for cats and dogs undergoing routine neutering. Recruited patients are randomised to having their procedure using either single-use or reusable drapes; the interim report revealed no differences between the groups (Dyer et al. 2024; James 2025). Staff satisfaction with reusable drapes in a human hospital was very high with all users happy to adopt the change after an initial trial (Snow et al. 2024).

Studies conducted with theatre teams from human hospitals (Yap et al. 2023), and veterinary hospitals (Halfacree 2024), document the need for education regarding the standard and performance of modern reusable surgical gowns, with many respondents expressing quality concerns and assumptions that reusable gowns were poor quality and 'a thing of the past', instead of recognising the benefits of modern material technology. Where reusable gowns were introduced in a human gynaecological surgery unit, they were well accepted in terms of comfort levels and performance (van Nieuwenhuizen et al. 2024).

Re-usable surgical textiles should be monitored for number of uses and for signs of wear, as the barrier function reduces after a certain number of washes without appropriate maintenance (McQuerry et al. 2021). Typically, modern reusable gowns can be used for over 50-75 washes; where specific guidelines are not available, high thread count woven fabrics should be considered a noneffective barrier after 75 reprocessing cycles (McQuerry et al. 2021). The optimal solution may be use of modern reusable gowns that have good performance (i.e. impermeable), a system that allows ongoing tracking of washes and wear and tear and a facility that these gowns can then be recycled at the end of their useful life (Das et al. 2021). Circular textiles systems have been introduced successfully in NHS hospitals in the UK (Bhutta & Rizan 2024).

Any change that we make for sustainability must be aligned with sustainable quality improvement, and we must not risk issues with infection control and increased surgical site infection. Whilst the evidence base does not indicate that use of re-usable surgical textiles is associated with an increased rate of infection, it is essential that surgical site infection rates are monitored. This provides quality assurance but also contributes valuable data to the evidence base supporting changes for environmental sustainability.

Some procedures that have historically used surgical gowns and full draping may in fact be appropriate for 'field sterility'. Human carpal tunnel surgery protocols have been adapted to use a smaller 'field' drape with the surgeon wearing sterile gloves (in addition to a mask and surgical hat) but not a sterile surgical gown (Leblanc et al. 2011; Yu et al. 2019; Silver & Lalonde 2024); no increase in infection rate was documented over 1,500 cases.

Single-use adhesive incise drapes have been proposed to decrease skin recolonisation following surgery, however in human studies, skin recolonisation was increased following use of an incise drape (Falk-Brynhildsen et al. 2013) and in veterinary studies there has been shown to be no difference (Owen et al. 2009). Conversely, use of iodine impregnated incise drapes has been documented to prevent bacterial recolonisation (Milandt et al. 2016). Non-impregnated plastic incise drapes have no clinical benefit and therefore should not be used, where high risk of infection is a concern iodine-impregnated incise drapes may be appropriate.

4. "Rub don't scrub": after first hand wash of day, use hand sanitiser for subsequent cases

Traditional surgical hand scrub requires prolonged contact time of disinfectant soap (Widmer et al. 2010), scrubbing with a plastic brush and, unless motion senser taps are used, utilisation of large volumes of water (estimated at 20 litres per surgeon, per scrub) (Ahmed 2007).

In recent decades, use of alcohol-based hand rub, in place of traditional surgical hand scrub, has been recognised to be equivalent, or superior, to traditional scrubbing techniques in terms of efficacy and cost (Parienti et al. 2002; Tavolacci et al. 2006; Widmer et al. 2010; Verwilghen et al. 2011; Mann 2016). Traditional scrub techniques have also been associated with hand dermatitis (Larson et al. 2006) and the carriage of a more pathogenic microbial population (Coelho et al. 1984). Use of alcohol-based hand rub has a significantly lower carbon footprint (Duane et al. 2022b).

Verwilghen et al. (2011), published results of a survey of 550 specialist veterinary surgeons (ECVS & ACVS) regarding their use of surgical hand asepsis, despite WHO guidelines recommending alcohol-based hand rub as the optimal protocol for hand preparation, 80% of surgeons in this study continued to use the traditional technique.

5. Review equipment packs to consolidate equipment into reusable sets, and rationalise re-sterilisation protocols

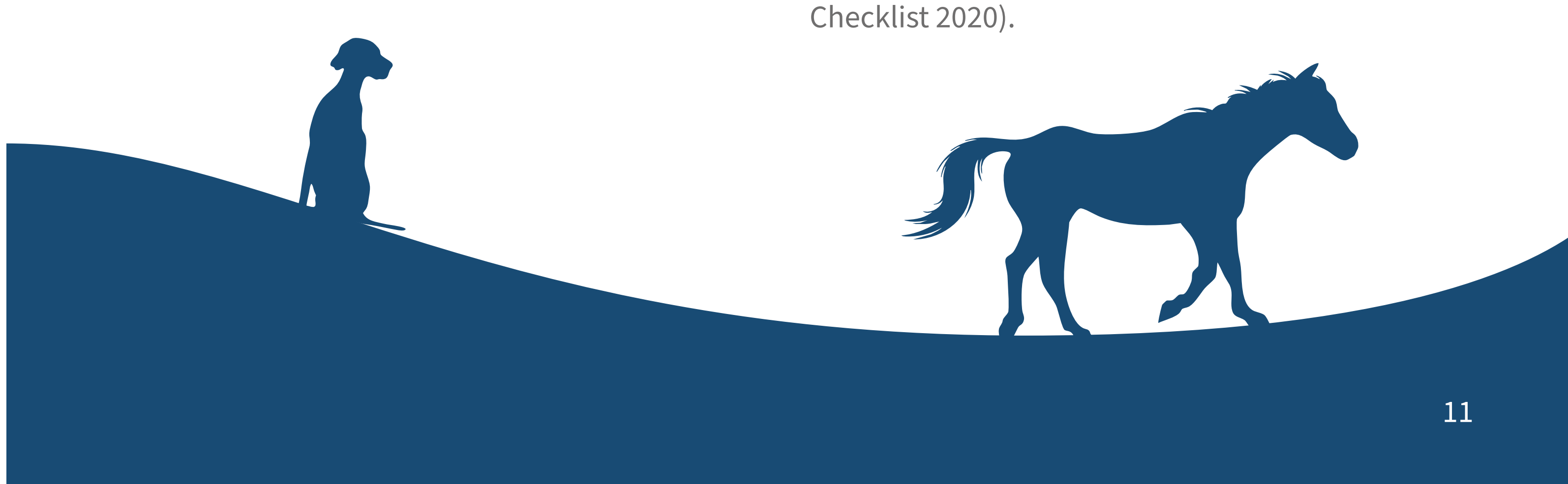
Consolidation of surgical instruments into defined kits is a key opportunity for reducing the impact of the kit's use; a reusable kit may have 2-3 times less carbon footprint than the same equipment packaged individually (Rizan et al. 2022b). This may require consensus on instruments that should be included if there are multiple users of the set. However, for single-use kits in particular, instruments should be optimised to avoid 'overage' and contain only the necessary instruments for a procedure and for immediate response to an adverse event (Thiel et al. 2018; Rizan et al. 2022b).

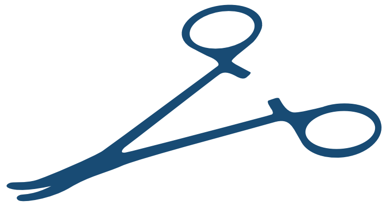
Several studies have demonstrated that clinician review of the instrument tray (observational studies as to which instruments are used by the surgeon) can be unreliable in creating a lean instrument tray instead, mathematical optimisation models to guide instrument inclusion have been described for several human surgical procedures (Toor et al. 2022; Eussen et al. 2025; Klarenbeek et al. 2025). There is currently limited but conflicting evidence for carbon reductions from reusable metal surgical containers; however, avoiding single-use will certainly reduce waste. Reusable surgical containers, reusable autoclavable pouches and reusable textile wraps are all commercially available (Friedericy et al. 2022; Rizan et al. 2022b).

Reprocessing of surgical equipment in veterinary practices is predominantly performed by cleaning followed by heat sterilisation in steam-autoclaves in packets, wraps or containers. It is standard practices in some hospitals for unused packaged sterile instruments to be removed from their sterile packets, repackaged and resterilised following a pre-defined period, which can vary depending on factors such as conditions of storage (e.g. 3-12 months). However, there is evidence to support that resterilisation within the same pouch can be performed up to three times, and that pouch can remain on the shelf for up to six months per cycle (Duane et al. 2022a). There is also a potential shift in mindset to consider a packaged sterile instrument to have an "event-related shelf life" rather than a time-dependent shelf life. Depending upon the packaging, some may be considered sterile until breached, i.e. if the packaging remains intact then the instrument is considered sterile. This depends upon careful monitoring of the environment in which the instruments are stored; examples of event related incidences that would prompt the need for resterilisation include physical damage to packaging, water contamination and increased humidity (Duane et al. 2022a). Careful management of sterilisation protocols should be in place to avoid the incidence of surgical infections, which are likely to vary between clinics based on individual circumstances.

6. Source renewable electricity; upgrade and electrify heating, lighting and energy systems where possible

Onsite renewable options such as solar or wind power may not be readily available, although suppliers increasingly provide competitive renewable energy through contracts. Installing higher efficiency equipment, such as LED lighting or occupancy sensors, optimising building management systems during operating room hours, and electrifying fossil-fuel based systems are natural additional steps to take (Practice Greenhealth Greening the Operating Room Checklist 2020).





Using pharmaceuticals

7	Ensure rational choices for pharmaceutical use	☐
8	Decommission nitrous oxide and desflurane	☐
9	Reduce volatile consumption (where safe and appropriate) by planning carefully to minimise duration of anaesthesia, and use of lower flow anaesthesia	☐
10	Choose lower carbon pharmaceutical options (where safe and appropriate) e.g. sevoflurane over isoflurane; oral over parenteral routes of administration	☐
11	Consider injectable techniques such as regional anaesthesia, PIVA, and TIVA (where safe and appropriate)	☐
12	Open pharmaceuticals and equipment only when needed	☐
13	Ensure unwanted pharmaceuticals are disposed safely, and encourage returns of medications (if unused or out-of-date)	☐

7. Ensure rational choices for pharmaceutical use

Pharmaceutical sourcing comprises 1/5th of the carbon emissions in NHS England (human healthcare service) (NHS 2022). Pharmaceutical use, not including volatile agents, was the highest category for emissions in two studies examining carbon footprints of veterinary procedures, albeit with predominantly (now historic) spend-based carbon conversion factors (Ryan et al. 2024; Nixon 2025). Concerningly, drug waste can subsequently comprise up to 26% of an entire anaesthesia department's medication budget (Gillerman & Browning 2000).

Veterinary specific guidance on pharmaceutical stewardship includes evidence-based prescribing, avoiding prescribing 'just in case', reducing wastage during the use phase, optimising prescribing choices for the environment and improving owner compliance with medications use (BSAVA 2023). Due to significant One Health impacts, it is particularly important to follow guidelines for surgical antibiotic prophylaxis to avoid overtreatment and use of critically important antibiotics (O'Neill 2016; Pelligand et al. 2024). Prescribing guidance may be available for specific medications, such as the BSAVA PROTECT ME resources for antibiotics (BSAVA 2025).

8. Decommission nitrous oxide and desflurane

Most of the global impact of inhalation anaesthetics on carbon emissions are due to two agents; nitrous oxide, which is released to the atmosphere in the greatest quantity with the longest persistence, and desflurane, which has the highest global warming potential over 100 years (GWP_{100}) of the inhalation anaesthetics (Sherman et al. 2012). Additionally, nitrous oxide emissions are one of the largest contributors to ozone depletion, avoidance of its use has been described as the "*largest contribution to reducing anaesthetic greenhouse gas emissions*" (Muret et al. 2019).

Drawing from human healthcare experience, many nitrous oxide manifolds have significant leaks, with evidence documenting over 80% of nitrous oxide escaping into the atmosphere before reaching point of delivery (Seglenieks et al. 2022; Chakera et al. 2024; Gaff et al. 2024). A recent consensus statement from the Royal College of Anaesthetists, the Association of Anaesthetists, the College of Anaesthesiologists of Ireland, the Obstetric Anaesthetists' Association and the Association of Paediatric Anaesthetists of Great Britain and Ireland has recommended that nitrous oxide no longer be considered an essential drug in modern anaesthetic practice, advising healthcare facilities to decommission nitrous oxide manifolds by the end of the 2026/27 financial year (Anaesthetists' 2024). For veterinary facilities still using nitrous oxide systems, the most effective environmental intervention would be to decommission these systems entirely.

Nitrous oxide is not useful as a sole anaesthetic agent in veterinary species due to its low potency. The two main indications for its use, facilitating rapid anaesthetic induction using inhalational agents and provision of analgesia, are not relevant to modern veterinary anaesthesia. Mask induction of domestic species is not routinely recommended, and the addition of nitrous oxide does not significantly speed induction with modern inhalational anaesthetics in dogs (Mutoh et al. 2001). Nitrous oxide is not generally recommended in equine anaesthesia due to its propensity to expand gas-filled spaces. Targeted analgesia can be better provided with injectable analgesic agents and loco-regional techniques.

For desflurane, NICE evidence reviews have determined no significant therapeutic advantages for neurological procedures or patients with higher Body Mass Index (NICE 2024). Faster recovery is cited as the main advantage of using desflurane, and whilst individual clinics may prefer this drug's characteristics, there is currently little evidence that this translates to improved clinical outcomes such as recovery quality over isoflurane and sevoflurane in horses and dogs (Lozano et al. 2009; Valente et al. 2015).

In human healthcare, desflurane usage has declined dramatically due to environmental concerns, with NHS Scotland removing it from their supply chain in 2023 (Gov.Scot 2023). Notably, desflurane represents the first medicine decommissioned by NHS England specifically for environmental impact reasons. Recent EU regulations state that "*the use of desflurane should be permitted only where alternatives cannot be used for medical grounds*" (EU 2024).

The continued use of desflurane is hard to justify currently given its substantially increased greenhouse gas emissions, absence of clear clinical benefits, and higher financial costs compared to alternatives.

9. Reduce volatile consumption (where safe and appropriate) by planning carefully to minimise duration of anaesthesia, and use of lower flow anaesthesia

A recent study evaluating the carbon footprint of canine cruciate operations reported a range of 60-93 $kgCO_2e$ or 48-82 $kgCO_2e$ per procedure in two centres using only isoflurane, or only sevoflurane, respectively (Ryan et al 2023). The duration of procedures and travel emissions (but not the choice of volatile agent) were significantly correlated with the carbon emissions from the procedure. This highlights the importance of mitigating the volatile consumed during procedures by minimising (without compromising safety) anaesthetic durations, and careful planning and team readiness for procedures.

Since volatile consumption is directly proportionate to the fresh gas flow (FGF), the FGF should be minimised when safe and appropriate to do so (Mosley et al. 2024; Ryan & Nielsen 2010). In one veterinary study, a lower flow approach was modelled to reduce the carbon footprint of a series of procedures by up to 63% (McMillan 2021a). Both human and veterinary studies advocate for the use of low FGF when using circle breathing systems (Wagner & Bednarski 1992; Feldman 2012; McMillan 2021b; Mosley et al. 2024). Some advanced workstations now include target-controlled mechanisms, which have been shown to reduce emissions by up to 44%. Specifically, low flow anaesthesia is defined as a FGF of 0.5–1 L/min, with minimal flow at 0.25–0.5 L/min, and metabolic flow equal to oxygen consumption (Feldman 2012). However, it is important to recognise that using low FGF requires adequate anaesthetic monitoring including inspired oxygen and agent gas concentrations to ensure animal safety. Anaesthetists must also be aware of equipment limitations. Lower FGF therefore implies minimising flows to the safest, lowest value at a given point in the anaesthetic (West 2021).

A last comment is included for potential production of compound A at lower flows with sevoflurane. Since sevoflurane's introduction, research has demonstrated its interaction with CO_2 absorbents produces compound A. Studies suggest a dose and time-dependent nephrotoxic effect in rats with compound A exposures of 150-300 ppm-exposure hours (or 50 ppm for 3-6 hours), with hepatic and cerebral injuries occurring at higher concentrations

(Gonsowski et al. 1994a; Gonsowski et al. 1994b). Effects were reversible within 14 days in rats exposed to 114 ppm (Keller 153).

No clinically significant effects were found in humans with compound A concentrations reaching 27-39 ppm during sevoflurane administration at various flow rates (Ebert et al. 1998a; Ebert et al. 1998b). Other clinical studies in humans have consistently shown no significant adverse outcomes despite compound A exposure for prolonged periods, or in patients with renal disease (Kennedy Bito et al. 1997; Obata et al. 2000). Based on this evidence, the American Society of Anaesthesiologists concluded: "*there is no reasonable evidence to support a lower limit of FGF when using sevoflurane*" (ASA, 2023).

Studies in companion animal species are limited. Muir & Gadawski (1998) studied 6 dogs and found compound A concentrations reached 18-61 ppm at flow rates between 0.05-0.5 L/min in dogs. Similar compound A concentrations of 15-20 ppm over 3 hours of sevoflurane administration through NaOH-based CO_2 absorbents were observed at 0.5 L/min (Kondoh et al. 2015). No research has established specific toxic thresholds for renal or hepatic injury in dogs or cats, with conclusions often extrapolated from rodent or human data. A multisite analysis showed the common tendency for veterinary anaesthetists to administer sevoflurane with 0.5 L/min of oxygen, suggesting minimal concern about compound A's clinical relevance (Branson et al. 2001).

Importantly, compound A production is closely associated with strong alkali hydroxides (NaOH and KOH) in CO_2 absorbents. Modern CO_2 absorbents contain either no, or reduced levels of strong bases. Kharasch et al. demonstrated that a calcium hydroxide-based absorbent (containing no NaOH or KOH) produced no compound A, while other alkaline absorbents resulted in 20-40 ppm (Kharasch et al. 2002). Similar findings were reported elsewhere (Kobayashi et al. 2004; Struys et al. 2004; Kondoh et al. 2015).

The clinical relevance of compound A toxicity in dogs and cats is unclear. A prudent approach could be when administering sevoflurane at lower flow rates, consider using CO_2 absorbers that are either non-alkaline or contain <2% NaOH (Feldman et al. 2021). Alternatively, a less precautionary approach is to use sevoflurane with low-alkaline CO_2 absorbers at flow rates no less than 0.5 L/min. It is worth noting that clinical considerations which may restrict use of sevoflurane include species-specific licensing, local marketing authorisations and manufacturer restrictions around use of sevoflurane under lower FGF conditions.

10. Choose lower carbon pharmaceutical options (where safe and appropriate) e.g. sevoflurane over isoflurane, oral over parenteral routes of administration

Amongst volatile anaesthetic agents, desflurane has the highest global warming potential over 100 years (GWP_{100}), followed by isoflurane, and lastly sevoflurane (Ryan & Nielsen 2010). Sevoflurane currently comprises 95% of UK medical volatile use by volume (ICGTC v2.0, 2024) whereas isoflurane remains popular in veterinary practice. Final clinical choice may depend on factors such as licensing.

Use of oral administration routes, rather than intravenous administration where safe and appropriate, will reduce the carbon footprint of medications predominantly due to mitigating packaging and sterilisation costs (McAlister et al. 2016). For example, oral paracetamol administration in humans has a 12-fold lower carbon footprint than intravenous administration (Davies et al. 2024). This can be extrapolated to veterinary patients for appropriate medications and, when clinically appropriate, oral dosing may be given peri-operatively in place of an intravenous preparation. Strategies which promote early return to enteral nutrition are necessary for this approach.

Medical air requires $1/10^{th}$ lower energy in its production using compressors compared with liquid oxygen; prioritising use of medical air where feasible and appropriate may confer carbon savings (Balmaks et al. 2022; Tariq et al. 2024).

Volatile capture technology (with the intent to reuse volatile agents) is in its infancy, with a handful of suppliers globally and a limited number of published papers in clinical human and animal patients (Hinterberg et al. 2022; Gandhi et al. 2024; White et al. 2025). For this reason, it is not included as a recommendation of the VGTC v1.0. A major limitation is the retention of anaesthetic gases by the animal; improvement on the 76% capture efficiency reported in cats and dogs may depend on modifications to anaesthetic practices, including robust management of hypotension (White et al. 2025). Single-use passive capture devices are frequently used in veterinary practice used to mitigate occupational exposure and may limit atmospheric release of volatiles if the volatile is destroyed after capture. A recent assessment of passive carbon filter systems suggested that "*it can be hypothesised that the saturated filters not only release sevoflurane when streamed with air, but also when exposed to atmosphere*" and concluded that further studies were needed (Wenzel et al. 2024).

11. Consider injectable techniques such as regional anaesthesia, PIVA and TIVA (where safe and appropriate)

Where incorporation of local/regional anaesthesia techniques and partial intravenous anaesthesia (PIVA) reduces volatile agent consumption, atmospheric release of volatiles may be mitigated. Regional anaesthetic techniques including nerve blocks, epidurals, and local infiltration provide targeted analgesia which allows for varying degrees of reduced volatile anaesthetic requirements during veterinary procedures depending on the technique and species (Valverde 2008; Steagall et al. 2017; Garcia-Pereira 2018; Portela et al. 2018a; Portela et al. 2018b; Castejon-Gonzalez & Reiter 2019; Grubb & Lobprise 2020). For medical procedures, they are also demonstrated to reduce length of hospitalisation and thereby associated resource use (Desai et al. 2018; Balentine et al. 2021).

Similarly, PIVA protocols combining injectable agents (such as opioids, alpha-2 agonists, lidocaine, or ketamine) with lower concentrations of inhalational anaesthetics maintain adequate anaesthetic depth and stability while reducing volatile agent consumption (Duke 2013; Gozalo-Marcilla et al. 2014; Gozalo-Marcilla et al. 2015). This multimodal approach not only decreases volatile emissions but often provides superior perioperative analgesia and potentially enhancing recovery characteristics compared to volatile-only techniques.

Most pharmaceuticals have the potential to cause bio toxic effects in land and water ecosystems (Kostrubiak et al. 2021). There is ongoing debate regarding the environmental balance of a range of impacts between volatile and injectable anaesthetics (Kalmar et al. 2024; Bernat et al. 2025). The current literature suggests that use of injectable agents results in somewhat lower carbon emissions than inhalant agents for maintenance of anaesthesia, hence inclusion of this recommendation in the VGTC v1.0; however the degree of reduction is variable depending on study design and agents, and there remains less clarity regarding the persistence, bioaccumulation and toxicity impacts of individual pharmaceutical agents, or the resource impacts of combinations (Sherman et al. 2012; Sherman & Barrick 2019; Hu et al. 2021; Narayanan et al. 2022; Yang et al. 2024). All pharmaceuticals should be administered under judicious prescribing principles and disposal routes of unused or waste pharmaceuticals should avoid environmental exposure (see checklist items 7 and 13). Further research in this area is needed.

12. Open pharmaceuticals and equipment only when needed

Operating theatres generate large amounts of waste, compounded by frequently opening but then not using equipment. One study suggested that annual wastage of controlled analgesic medications was over 20% (Ishaqui et al. 2023). Emergency medications are reported to be wasted in 39% to 91% of cases (Lejus et al. 2012a).

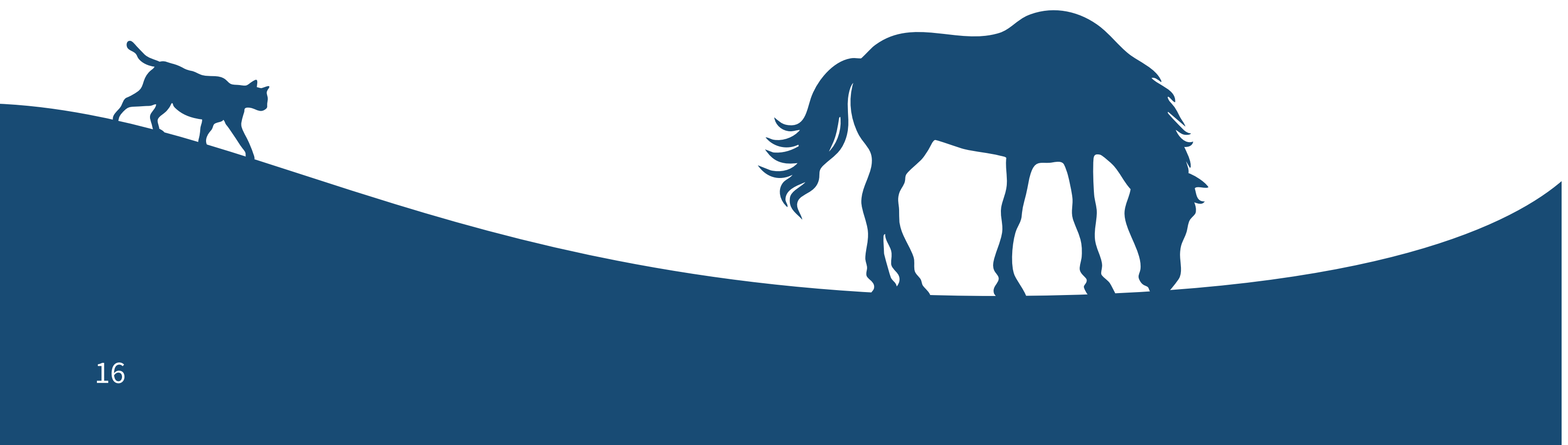
Following use principles such as "open or prepare only when needed" and using prefilled syringes may be significant carbon and waste saving opportunities (Lejus et al. 2012b; Petre & Malherbe 2020). Prefilled syringes may be particularly appropriate for emergency drugs such as lidocaine, adrenaline and atropine which may be stored in crash boxes and remain unused for long periods. Clinical feedback on wastage has also been shown to reduce drug waste (Lubarsky et al. 1997; Body et al. 1999).

The proportion of propofol that is wasted in human anaesthesia has been reported to be up to 60% (Gillerman & Browning 2000; Mankes 2012; White et al. 2023; Bernat et al. 2024). Where safe to do so, use of preservative-containing solutions, smaller pre-drawn volumes based on accurately calculated required doses, optimising propofol concentrations, sharing vials across animals, minimising pre-emptive preparation and preparing doses only when required may reduce propofol wastage (Mankes 2012; Petre & Malherbe 2020).

13. Ensure unwanted pharmaceuticals are disposed safely, and encourage returns of medications (if unused or out-of-date)

Between 30-90% of administered pharmaceuticals are excreted as active drugs in urine and faeces (EU 2018). Active pharmaceutical residues are widespread and represent a serious concern for human, animal and planetary health, most notably through their contribution to antimicrobial resistance development, which is an urgent and growing public health threat (Wilkinson et al. 2022).

Alongside careful prescribing (see checklist item 7), pharmaceutical products and contaminated materials should be disposed of through designated pharmaceutical waste streams to avoid contributing to this problem, subsequent incineration is likely to destroy pharmaceutical residues.



During surgery

14	Limit CO_2 insufflation in minimally invasive surgery	☐
15	Transfer single-use items with the animal if still needed e.g. suction tubing, warming consumables	☐
16	Consider reusable or refurbished equipment and consumables for anaesthesia (e.g. laryngoscopes, warming equipment, kennel liners, CO_2 absorbent canisters) and surgery (e.g. theatre hats, facemasks, surgical textiles, staplers, sterile containers)	☐
17	Choose lower carbon equipment options (where safe and appropriate) e.g. skin sutures vs. clips, passive warming systems, use of gallipots for surgical preparation	☐

14. Limit CO_2 insufflation in minimally invasive surgery

Carbon dioxide (CO_2) is the main gas used for insufflation in minimally invasive surgery and its use directly contributes to emissions responsible for global warming. However, the actual amount of CO_2 emitted (0.9 kg CO_2e) is minor compared with the whole footprint of a laparoscopic procedure (11–29 kgCO_2e) (Chan et al. 2023; Cunha et al. 2025). An abdominal retractor has been developed and is in use for inflation-less laparoscopic human surgery, which is suitable for some procedures or settings (Boag et al. 2022).

15. Transfer single-use items with the animal if still needed e.g. suction tubing, warming consumables

For items that must be single-use, transferring these objects with the animal when still needed (such as suction equipment or body warmers) maximizes utility and reduces unnecessary waste.

16. Consider reusable or refurbished equipment and consumables for anaesthesia (e.g. laryngoscopes, warming equipment, kennel liners, CO_2 absorbent canisters) and surgery (e.g. theatre hats, facemasks, surgical textiles, staplers, sterile containers)

Infection control

Hospital-acquired infections carry a carbon, waste and welfare cost through use of pharmaceuticals, chemicals and consumables for their treatment. The recommendation remains to maintain robust infection control measures to ensure the safety and quality of reused items. However, not all infection prevention control measures are evidence-based or necessary to maintain quality of care (Bolten et al. 2022). This may apply to reusable items, or reuse of single-use items, and manufacturers may be able to provide reuse guidance for their products. Future guidance for veterinary clinics may derive from organisations such as the FDA (FDA 2024) and the veterinary interest group of the Infection Prevention Society (IPS 2025).

Reusable or refurbished equipment

Procurement of medical equipment contributes 10% of the NHS carbon footprint (NHS 2022) and a switch to reusables is a key carbon reduction opportunity for surgical procedures (Rizan et al. 2023b). The lifecycle of reusable equipment compared to single-use equivalents has been studied for many types of medical equipment, and in the vast majority of cases the environmental impacts were significantly lower for reusable equipment, with the exception of increased water use for reprocessing (Keil et al. 2023; Klarenbeek et al. 2025). The only described increase in carbon footprint due to reprocessing resulted from using a coal-based power source in Australia (McGain et al. 2017b), so reinforcing the need for renewable energy sources (see checklist item 6). The impact effect size varies between equipment, depending mostly on embedded carbon costs and number of reuses, and environmental impacts. There is typically wider variation, but higher impact reduction potential for invasive medical equipment (Keil et al. 2023). Additionally, disposable medical devices can contain phthalates, which are endocrine disruptors, and are associated with impaired reproduction and development in wildlife and humans (Gore et al., 2015, Weaver et al., 2020).

In human healthcare, using reusable anaesthetic equipment including supraglottic airways, laryngoscopes, direct-contact heaters, and drug trays has been shown to reduce carbon footprints by as much as 84% (Eckelman et al. 2012; Sherman et al. 2018). Reusable steel scissors were found to have an environmental impact of only 1% of that of disposable steel scissors. In another study, reusable instruments were found to cumulatively be more cost effective and to help reduce the carbon footprint of minor oculoplastic operations (Putri et al., 2021). Other available reusable equipment includes diathermy, kennel liners (incontinence pads) and CO_2 absorbent canisters. For detail on carbon impacts from reusable surgical containers and textiles, see checklist items 3 and 14, respectively.

There are some sub-categories of medical equipment where reprocessing of a single-use item potentially has a lower carbon impact than the reusable alternative; for example, there is currently conflicting evidence for which type of cystoscope has a lower carbon footprint, varying depending on number of reuses possible and reprocessing techniques (Davis et al. 2018; Baboudjian et al. 2023; Kemble et al. 2023; Jahrreiss et al. 2024). As more evidence emerges, guidance around safe reprocessing, reuse and environmental impacts will become clearer.

Non-sterile surgical textiles: hats and masks

Reusable surgical scrub hats are associated with a lower carbon footprint (Agarwal et al. 2023; Cohen et al. 2023; Donahue et al. 2024; Gumera et al. 2024). Research has demonstrated that the use of clean reusable scrub hats results in no difference in microbial contamination, less particulate matter in the theatre (Markel et al. 2017) and showed that incidence of surgical site infection is not influenced by choice of surgeon headwear (Haskins et al. 2017). Re-usable surgical scrub hats can also have an individual's name and role embroidered on the front, which has been shown to improve communication within the team (Dougherty et al. 2020; Wong et al. 2023).

Reusable facemasks have a 3.5 times lower carbon and waste footprint compared with their single-use (and fossil-fuel based) alternatives (Chau et al. 2022; Walsh 2024). Facemasks which meet type 2R standards are commercially available. There is also some discussion about whether facemasks prevent surgical site infection when worn by either surgical or non-surgical staff. A Cochrane review concludes "*from the limited results it is unclear whether the wearing of surgical face masks by members of the surgical team has any impact on surgical wound infection rates for patients undergoing clean surgery*" (Vincent & Edwards 2016). Wearing of facemasks may encourage a demarcation of 'clean' areas.

Theatre shoes

Disposable theatre shoe-covers ('overshoes') have been shown not to reduce operating theatre floor bacterial counts compared with no overshoes (Humphreys et al. 1991), and to potentially cause hand contamination during placement and removal (Woodhead et al. 2002). Permanent theatre shoes are a reusable alternative, although they must be cleaned regularly or when visibly contaminated.

17. Choose lower carbon equipment options (where safe and appropriate) e.g. skin sutures vs. clips, passive warming systems, use of gallipots for surgical preparation

There is an increasing body of literature providing lifecycle data for a range of medical equipment and their lower carbon alternatives. Where there is clinical equivalence, the lower carbon option should be prioritised. For instance, surgical clips have a higher carbon footprint from their manufacture than skin sutures (NICE 2019; Rizan et al. 2023a). Active warming systems require energy use, cleaning consumables and single-use consumables; users should therefore evaluate whether active warming devices are needed routinely for all procedures, and whether passive warming techniques will suffice.

WHO guidelines on preventing surgical site infection from 2016 include skin preparation with alcohol-based antiseptic solution based on chlorhexidine (WHO 2016). The various application techniques (swabs and sponge holders with prep in a sterile gallipot, versus single-use plastic applicators) have demonstrated no difference in efficacy (WHO 2016); however, the use of plastic applicator wands (provided with alcohol and chlorhexidine solution) has been widely adopted (Casey et al. 2017). Simplification of technique using a single-use applicator wand has been cited an associated benefit (Casey et al. 2017), however, improved education with other application techniques would also enhance other protocol compliance (Lundberg et al. 2016). NICE guidelines note that use of sponge holders and a swab has a reduced environmental impact compared with single-use applicators (NICE 2019).

After surgery

18	Introduce "*shut-down*" and "*power-on*" checklists for heating, ventilation, air conditioning, AGSS, lights, computers, autoclaves and other equipment	☐
19	Encourage active maintenance and repair of equipment	☐
20	Segregate waste into the lowest carbon (appropriate) waste stream e.g. optimising recycling waste streams (electrical waste, cardboard/paper, metals, plastics, organic waste, pet hair), prioritising non-infectious offensive waste streams where appropriate, ensuring appropriate contents in healthcare waste containers (only uncontaminated packaging in recycling) and switching to lower impact containers where appropriate (reusable, cardboard, larger volume containers)	☐

18. Introduce "*shut-down*" and "*power-on*" checklists for heating, ventilation, air conditioning, AGSS, lights, computers, autoclaves and other equipment

The theatre environment is estimated as 3-6 times more energy intensive than other parts of a hospital (MacNeill et al. 2017). Energy use is reported to account for 60% of the carbon footprint of a medical operation (Whiting et al. 2020), although a recent veterinary report estimated carbon emissions as 4% of a building's energy (Ryan et al. 2024). In either case, turning off or setting energy systems to match use periods is a rational use of resource. Where this can be automated, its success is more likely to persist. It is worth noting that some medical equipment (such as MRI machines) cannot be powered down without consequence; the manufacturer should be contacted where in doubt.

Active gas scavenging systems (AGSS) typically run from a 3-phase electricity supply. In one medical hospital, around 80% of the energy used by anaesthetic equipment was consumed by AGSS and radiant heaters (Pierce et al. 2014). Hospital autoclaves use 40% of their electricity and 20% of their water whilst idle. Turning off idle machines has been shown to save 26% and 13% of a hospital's electricity and water respectively (McGain et al. 2016, McGain et al. 2017). Avoiding running steam sterilisation cycles with a light load is a sensible step to improve efficiency and avoid waste (Rizan et al. 2022b).

19. Encourage active maintenance and repair of equipment

At the start of life, energy efficient equipment can be sought. Thereafter, maintaining equipment in use for as long as it can perform its function safely makes logical sense from a waste, carbon and cost perspective. This is reflected in the recent legislative movement towards the encouragement of a circular economy and a right to repair for customers (e.g. EU Circular economy action plan, UK Right to Repair Regulations).

One study of reusable surgical scissors demonstrated that repair reduces the per-use carbon footprint by an additional fifth (with concomitant cost savings of around one-third) compared with purchasing new reusable surgical scissors (Rizan et al. 2022a). This approach may require proactive planning, available contractors, and active feedback mechanisms for users to report issues.

20. Segregate waste into the lowest carbon (appropriate) waste stream e.g. optimising recycling waste streams (electrical waste, cardboard/paper, metals, plastics, organic waste, pet hair), prioritising non-infectious offensive waste streams where appropriate, ensuring appropriate contents in healthcare waste containers (only uncontaminated packaging in recycling) and switching to lower impact containers where appropriate (reusable, cardboard, larger volume containers)

Waste in the UK and European Union is designated into multiple "waste streams" with prescribed methods for disposal. The highest carbon footprint is for disposal of hazardous healthcare waste streams via high-temperature incineration (1074 kgCO_2e/kg). The lowest is for recycling of domestic waste (21 kgCO_2e/kg) (Rizan et al. 2021). NHS England recommends targeting 60% of healthcare waste into offensive waste streams in its Clinical Waste Strategy (NHS (2022). Correct waste segregation can thus reduce the carbon footprint 50-fold, which mirrors potential financial savings.

Studies have suggested that less than 50% of recyclable materials are segregated appropriately prior to entering operating areas where they have potential for contamination (Pegg et al. 2022; Kern-Allely et al. 2023). However, in one veterinary hospital's waste audit, only 67% of items sorted into a recycling stream were truly recyclable, indicating a potential lack of recyling infrastructure and/or clarity on recycling options. In addition to setting up the correct infrastructure, education can aid as an impactful intervention to properly segregate waste and reduce the carbon impact related to waste disposal (Cunha et al. 2023). Recycling of uncontaminated surgical packaging may reduce the footprint of the equipment's reprocessing by 6–10% (Rizan et al. 2022b).

Considering the principles of the waste hierarchy; Prevent, Replace, Reduce, Reuse, and Recycle, specialist options may be available for 'waste as a resource'; for example, pet fur can be used to make sustainable adsorbent materials for use in decontamination of oil spills (Murray et al. 2020). Optimised waste segregation also opens the potential for more circular economy routes for waste into new products.

Optimising containers may also achieve carbon and waste savings. UN-approved cardboard pharmaceutical containers are available, which will reduce the single-use plastics used and incinerated in the process of waste management. Other methods to minimise single-use plastic incineration included reuse of delivery equipment (where safe and appropriate), and using the largest possible size of single-use sharps disposal container. Reusable sharps containers, if available, may also reduce carbon emissions by up to 85% compared with single-use systems (Grimmond & Reiner 2012; McPherson et al. 2019).

Endorsing Organisations

Association of Veterinary Anaesthetists (AVA)

British Equine Veterinary Association (BEVA)

British Veterinary Nursing Association (BVNA)

European College of Veterinary Neurology (ECVN)

RCVS Knowledge

Veterinary Anaesthesia & Analgesia Chapter of Australian and New Zealand College of Veterinary Scientists (ANZCVS)

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