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How can we address the ever-pressing need to "green up" surgical practice in the NHS?

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Full title: How can we address the ever-pressing need to “green up” surgical practice in the NHS?

Short title: Enabling “green surgery” in the NHS

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Abstract

Clinical practice has inadvertently changed after the COVID-19 pandemic and currently the need to provide sustainable surgical services is more pressing than ever. The NHS has committed to a long-term efficient plan to reduce carbon footprint production but there is no detailed plan for surgical practice, then domain that contributes the most to hospital derived pollution. A series of consecutive steps and measures ought to be taken, starting from a hybrid approach quantifying surgically attributed carbon footprint. Then a variety of suggested measures can be widely discussed and accordingly applied on a wider or more local level. Appropriate training should always precede new practices to ensure that staff is familiar with these. These measures cover a wide range and should be arranged on a patient-centred basis from preoperative preconditioning to an effective follow-up. The need for more intense research and implementation of enhanced recovery protocols is widely discussed. Also, the necessity of green research and reinvestment of materials and resources is highlighted. A change of philosophy from a cradle to grave approach to a repurposing approach is suggested. We are confident that a new era is dawning in surgical practice and teamwork is the key for providing greener surgical services.

Key words

sustainability, green surgery, surgical practice, carbon footprint, enhanced recovery

Introduction

We have recently experienced radical changes in healthcare provision in an attempt to tackle effectively with the COVID-19 pandemic, which will doubtlessly be integrated for the long run, in national health systems. However, until recently, little has been done to address a more subtle issue, climate change. Surprisingly, several studies have shown healthcare systems to be responsible for 3-10% of the national annual carbon footprint[1], with concomitant increase in national health expenditures annually on a global scale[2]. On a worldwide scale, several nations have attempted to record their annual carbon footprint, with various limitations, as displayed in Table 1.

Table 1. Comparison of healthcare carbon footprint across the globe

AUTHOR	COUNTRY	YEARS	CARBON FOOTRPINT	NATIONAL CONTRIBUTION
Malik A et al[2]	Australia	2014-15	35772 kilo tonnes CO_2e	7%
Eckelman MJ et al[3]	Canada	2009-15	33 million tonnes CO_2e	4.6%
Wu R et al[4]	China	2012	315 million tonnes of CO_2e	2.7%
NHS Net Zero Expert Panel[5]	NHS	2019	25 million tonnes of CO_2e	4%
Eckelman MJ et al[6]	US	2013	614 million tonnes of CO_2e	10%

The NHS – Surgical Practice

The NHS is the biggest employer in the UK and its emissions account for 4% of the national total. Regular monitoring of carbon footprint, along with a set of measures to reduce it, were implemented since 2008, with the introduction of the Climate Change Act, when the NHS committed to two clear targets[5]. For the emissions controlled directly by the NHS (NHS Carbon Footprint) the target is an 80% reduction by the years 2028 – 2032 and a net zero by 2040, while for the emissions the NHS can influence (NHS Carbon Footprint Plus) target is an 80% reduction by the years 2036 – 2039 and a net zero by 2045[5].

Estimating carbon footprint

Carbon foot printing estimates the Greenhouse Gas (GHG) emissions from a sector, process or product and rather sophisticated tools have been developed in order to provide analytical guidance as to how it can be calculated. The Greenhouse Gas Protocol describes the different approaches to quantifying carbon footprint[7].

Box 1. Approaches to carbon foot printing

"Top-down" (environmental extended input-output / EEIO) analysis: appropriate for categories that can be assessed on economic terms and interactions between sectors, services or individuals and can also provide environmental and epidemiological insights. *Drawbacks*: estimate of the carbon footprint of a sector, as it omits the specific procedures undertaken within the sector.

"Bottom-up" (process-specific) analysis: indicated when the footprint of a certain procedure needs to be evaluated.

Drawbacks: unclear or arbitrarily set extent for carbon footprint calculation; can be defined in accordance with GHGP.

Hybrid approaches: combine the best features of the two methodologies, by utilising a process-based approach in specific hotspots earlier identified by top-down analysis, and can be tailored to the specific needs of the analyst or the particular characteristics of the subject of analysis.[8]

The NHS Carbon Footprint consists of the emissions directly controlled by the NHS, which are divided in the 3 scopes, as per GHGP[7,9]. In addition to those, patient and travel derived emissions to NHS facilities constitute the NHS Carbon Footprint Plus[5].

The footprint of theatres and surgery (what do we do now?)

Several single or multiple centre studies prove that surgical practice is one of the main drivers of hospital-derived environmental pollution. Despite that there are no clear national records of annual waste attributed to surgery. Even in the NHS, where a detailed recording of carbon footprint has been undertaken for over a decade, the exact percentage that surgery contributes to total healthcare carbon footprint is vaguely delineated and can be deduced by calculations. Thus, the first step towards a "greener" surgical practice is a precise census of the exact carbon footprint it produces.

Some steps have been made towards this direction, as a small number of surgical units have attempted to document their carbon footprint, utilising different approaches on occasion. The first study comparing the carbon footprint of the operating theatres in three hospitals (UK, US, and Canada) within the boundary of the surgical theatre follows GHG protocol[10]. As displayed in this study, the NHS scheme to reduce desflurane usage in general anaesthesia has yielded results, with the UK hospital being the least carbon intensive; this being attributed to anaesthetic gas usage. However, it should be underlined that failing to

modernise operating theatres energy management systems and to purchase energy from eco-friendly resources can dramatically increase the environmental impact of surgery. While anaesthesia induction in a separate room before entering the operating theatre has been proven to increase efficiency in delivery of surgical service, this leads to higher environmental burden from HVAC[10].

Surgical carbon footprint has been assessed on a smaller scale in Australia, where the carbon footprint of a single private outpatient facility was compared to the practices of a public hospital, using a bottom-up approach. In 2014-2015 skin malignancy related procedures Australia produced 8461 tonnes of CO_2e, and 22.25% of these were produced by hospitals, which conduct approximately 10% of these procedures, thus emphasizing the energy-wasting practices still in place[11].

Several attempts have been undertaken to quantify the carbon footprint of specific surgical procedures. In the UK, 57000 tonsillectomy procedures were conducted in the year 2019. The ENT team from Alder Hey Children's Hospital recorded the approximate weight of orange bags per adenotonsillar procedure, which was a mean of 1.86 kg, and extrapolated to a national 106 tonnes of waste for incineration on an annual basis.[12]

Another study quantified the environmental impact of discarded drugs in cataract surgery from 4 centres in the US. Surprisingly, it was reported that 45.3% of medication was discarded unused, with eyedrops reaching a 65.7%. Antibiotic drops were the most abundantly consumed type of unused medication resulting in a discard of 80-100% volume of unused antibiotics and the need for a new prescription. The authors have highlighted the lack of current evidence on the benefit of local antibiotics in the reduction of endopthalmitis[13,14]. All the above-mentioned clinical studies have followed bottom-up analysis to evaluate the carbon footprint of particular surgical procedures in single or small number of centres and extrapolate to the total national of procedures, assuming homogeneity of practice across the country, which itself constitutes a severe limitation.

What can we do? (measures)

In the spirit of greening surgical practice, it must be underlined that a holistic approach should be applied, not only implementing measures that can maximise emissions reduction, but introducing policies that will guide staff towards adopting more sustainable clinical pathways.

Anaesthesia

Commonly used volatile anaesthetics include sevoflurane and desflurane, have a high heat trapping capacity, measured in global warming potential over 100 years (GWP_{100}). For sevoflurane and desflurane GWP_{100} is 130 and 2540, respectively. Thus, restricting desflurane usage can drastically reduce the carbon footprint of any operation[15]. Anaesthetic gases account for 2% of total NHS carbon footprint[5]. When volatile anaesthetics cannot be avoided,

there are disposal systems for these gases, which involve adsorption on appropriate materials[15].

Nitrous oxide, apart from its heat-trapping properties, can also damage irreversibly the ozone layer. Mask induction with nitrous oxide is used in paediatric anaesthesia and it does not increase induction speed when used as supplement to sevoflurane induction. It can be substituted, when clinically indicated, by distraction techniques[15].

In terms of pharmaceutical waste, propofol is the most wasted, by volume, anaesthetic medication, while emergency medications are quite often opened but remain unused. Multiple measures can be adopted such as use of prefilled syringes, splitting of vials and the role of hospital pharmacy can be vital to the matter at hand.

At last, avoiding general anaesthesia whenever possible, by substituting it with local or regional can drastically reduce the carbon footprint of an operation. This has been observed in the "Lean and Green" initiative, endorsed by the American Association for Hand Surgery, with the implementation of the "Wide Awake Local Anaesthesia No Tourniquet" (WALANT) protocol. Not only multiple procedures can be carried out using lidocaine with epinephrine, instead of general anaesthesia, but this has been well received by patients (96% satisfaction rate)[16].

Material use

The actions by which a significant reduction in carbon footprint can be achieved by means of better material usage are summarised in the 5 R's: reduce, reuse, recycle, rethink and research[17]. As highlighted by Thiel et al, combining multiple interventions in the material usage sector yields maximum results[18].

In their study, minimizing material use, by preparing sets with the minimum required instruments for specific procedures, and substituting single for multiple use devices can lead to high reduction of carbon footprint. Addressing the issue of "overage", which is surgical equipment readied for an operation, but ultimately not used and discarded, is of utmost importance. Unfortunately, overage is frequently linked with surgeons' preferences while conducting an operation and pre-labelled surgical trays can help increase the life span of surgical instruments by avoiding pointless resterilisation[19]. Well - established policies, such as increased recycling, lead to smaller reductions in carbon footprint[18].

Waste segregation is an effective way to reduce the volume of waste that will be led to incineration[20]. It has been proven that even up to 90% of the waste classified as infectious does not fall in this category[21]. Misplacement of waste can be the result of multiple factors, such as staff unaware of waste segregation policies or fear of being reprimanded in case of misplacing clinically hazardous waste to general waste, lack of appropriate bags and so on[20]. Expert panels have arbitrarily set the percentage of clinical waste produced by theatres at 15% of the total waste, a target that hospitals often fail to achieve[22]. One efficient measure

to that end would be to avoid installing hazardous clinical waste bags in the theatre space before patients are transferred inside[21]. This should always be exercised in a controlled manner be underlined though, bearing in mind the consequent acidification of water[11].

Materials often purchased in large amounts by the NHS should have a clearly documented and well-known life cycle assessment, readily accessible by the public. The organisation could largely benefit financially by purchasing from providers with low environmental impact. This policy is known as environmentally preferable purchasing and guarantees a more sustainable workplace for staff and less impact on patient health. To that end, the NHS and other relevant organisations, on a worldwide level, should engage in discussion with the industry to encourage a more detailed life cycle assessment of multiple products[20].

Shifting daily practice from a cradle-to-grave approach, in life cycle assessment, to cradle-to-cradle should become the new standard. In that, waste from usage of materials could be recycled or their purpose redefined. This principle particularly applies to surgical instruments and devices[23]. First, reusable devices can lead to huge cost savings, even when accounting for the resterilisation, being mindful of chronic usage wear. Another measure is reusing disposables, a practice not widely accepted in many healthcare systems[24]. Despite lack of hard evidence against reusing single-use devices, concerns have been expressed by healthcare practitioners against resterilising them[21].

Another issue that needs to be addressed is material packaging. It has been observed that packaging disposal increases dramatically the volume and weight of operating theatre-derived waste. Furthermore, it should be underlined that not all packaging materials are recyclable; this increases the volume of landfill-dedicated waste, especially when they are mixed with recyclables or clinical waste, skyrocketing the environmental impact and financial burden to the hospital. Many efforts have focused on studying the impact of minimizing packaging; of specific interest is the combination of “wide awake hand surgery” protocols with simplifying packaging. This protocol led to reduced expenses and waste quantity, without an impact on patient outcomes or satisfaction, proving that combined measures significantly improve procedure-related carbon footprint[25].

HVAC – Building energy

Surgical units, not only theatres, but also post-anaesthetic rooms, wards and outpatient clinics consume a rather large amount of the energy distributed to hospitals. “Greening the theatres” as parts of the facilities takes multiple measures that do not fall in the expertise of healthcare staff.

In the NHS, 10% of the organisation’s carbon footprint is attributable to building energy expenses and, in the US, hospitals were found to consume 5.5% of the energy consumed by the commercial sector, while accounting for less than 1% of all commercial buildings.

The first step to consider, in an era of multiple energy providers, is the source from which energy is obtained. A shift from fossil fuel derived energy to more sustainable sources should be encouraged, along with self-sustainable buildings, that can be self-relying on energy production, ie by solar panels. Also, renovating NHS buildings, by upgrading their energy class, with newer insulation materials or novel energy distribution systems, could make them more efficient[5]. Focusing on theatres, anaesthetic rooms increase the number of procedures offered. However, the increased combined area of theatres and anaesthetic rooms increases the energy consumption in this section of the hospital[10]. Interestingly, theatre are occupied approximately around 40% of the time[22], thus automated heating and ventilation system with sensors could reduce energy consumption in theatres when staff does not occupy these spaces[18]. These investments are expected to be costly and will yield results on the long term.

Outpatient telemedicine appointments have been shown to be effective in reducing building-related costs and patient-satisfactory. The necessity to follow-up patients during the pandemic has led to wider adoption of this outpatients clinic modality. In the setting of vascular surgery, in a series of 87 unique patients, that had 146 telemedicine encounters a clear environmental benefit was shown in comparison to hypothetical face to face patient appointments[26].

Patient-specific considerations

All the above recommended measures are always suggested in the context of maximum patient benefit. Thus, any clinical decision making should first address delivering optimal patient care; that should be ideally combined with offering environmentally friendly health services, meaning that if a suitable sustainable alternative, can be offered, then it should be strongly considered. This mandate both clinical excellence and appropriate training in sustainable healthcare provision.[27]

Moreover, when clinically acceptable, the carbon footprint of equally effective therapeutic modalities should be considered in decision making, when surgical intervention is offered to a patient. In a study of 150 staging procedures for endometrial cancer, open versus laparoscopic versus robotic- assisted laparoscopic procedures were compared with respect to their carbon footprint. Open procedures marked minimal operative time, waste production energy use and single use device, with robotic assisted procedures scoring the highest carbon footprint, in all but the single use device domain. A significant limitation of this study was not considering patients' postoperative course and its respective carbon footprint. However, one can only assume that a robotic approach could minimize post-op resource usage, compensating for intraoperative high emission rates. No clinical studies have been conducted to prove such a hypothesis[28].

While international literature focuses on reducing the environmental impact of the operating theatre, it is imperative that we realise the necessity for standardized "green" surgical pathways. That begins with identifying patient-customized appropriate indications for surgical intervention. In this spirit, an overall reduction in the number of surgical

procedures offered to patients should be examined, taking into consideration current guidelines and protocols, coupled with balancing the benefits of having or not every procedure for each patient individually. As surgical practice changes, the environmental impact of a procedure could be integrated in the list of factors that surgeons consider, when offering patients specific procedures, without ever compromising patients' beneficence.[29]

Designing these pathways can prove to be a difficult task. An element to be consider is minimization of pre-operative evaluation by incorporating all the essential pre-operative assessments (surgical, anaesthetic, cardiac and so forth) in a single visit, together with the minimum of laboratory investigations to ensure a safe anaesthetic and operative outcome. Surprisingly, despite the well-established multiple benefits of Enhanced Recovery after Surgery (ERAS) protocols, a quick literature research yields no results on the environmental benefits of their implementation. To their core, these protocols aim at minimizing homeostasis disturbance during surgical procedures in every aspect. Thus, one could argue that these protocols can reduce carbon footprint. Dedicated research in this field could prove fruitful, especially if it could be proven that ERAS protocols – which advocate for minimally invasive procedures – can outbalance these more carbon-intensive surgical modalities. Surgical care ends with a patient-tailored follow-up. Video follow up has been shown to be highly efficient both on resource allocating and environmental costs, without compromising healthcare delivery.

Table 2. Summary of specific measures to reduce carbon footprint

Anaesthesia	Material Use	HVAC – Building energy	Individualised patient care
Minimise volatile gases / use sparingly	Reduce "overage" / unused surgical material	Maintain buildings aiming at energy efficiency	Carefully consider indications for procedures
Increase usage of intravenous general anaesthesia, when feasible	Recycle effectively	New materials in self-sustainable buildings	Implement enhanced recovery protocols
Substitute general with regional or local anaesthesia, where applicable	Minimise single use device/ Substitute with reusable, according to trust guidelines	Automated control of heating and ventilating of theatres	Consider different modalities of treatment
Manage anaesthetic medication derived waste properly	Segregate waste properly	Encourage telemedicine/ Reduce visitation	
	Ethical purchasing / Work with industry for life cycle assessment		

How to Bridge the Gap?

After having identified the appropriate set of measures to achieve a more sustainable surgical practice, there is a need for a structured plan for their implementation. It has been shown clinical leaders can heavily impact surgical practice in their institutions by introducing sets of measures. A simplified approach to this matter would be selecting surgeons, specialists

to their respective fields, that can facilitate the application of energy and resource saving policies and act as an example for the staff, within the limits of their organisations. They could help with measures as simple as choosing the minimum number of surgical instruments per tray to facilitating environmentally friendly purchasing[5,18].

Instead of assigning individuals as leaders, Simon and Canacari have advocated that a multi-disciplinary team, with specific roles for its members and a pre-set clear objective of minimizing theatre environmental impact, can be highly efficient. Team members from multiple backgrounds (anaesthetists, surgeons, nurses, non-clinical staff) can facilitate the spread of "greener" policies amongst their colleagues[30].

The first step to establish these pathways of sustainable development is accurate clinical governance. All sectors contributing to carbon footprint have to be documented, not only using a top-down analysis, but involving particular institutions and services both within and outside the NHS that can act as pioneers in the detailed record of carbon footprint. At this stage, apart from accounting for the logistics, staff training and awareness of sustainable development must be evaluated in order to assess the areas in which further training is needed in order to implement the necessary changes[31].

Another important pathway that can facilitate the way towards a zero net carbon footprint is research, and that can yield effects on many fronts. Research should address the "hot questions" on the field. As it has been previously shown, strong interest in research leads in easier recruitment and reduced research cost and time. The comparison of CRASH-1 and CRASH-2 studies is an excellent example of ways to reduce research carbon footprint and obtain results faster; this being of double significance. First, these principles of sustainability ought to be applied in relevant research and secondly, they should be followed by trusts within the NHS in all clinical and basic science fields, as to tackle the environmental impact of research itself, a crucial component of surgical practice[32,33].

Staff education is fundamental to implementing environmental policies in healthcare facilities. That has been clearly shown in the paper by Botelho, in which compliance of private outpatient practices in the EU with waste disposal legislation has been surveyed. While segregation policies at the site were followed by all the 741 healthcare facilities, only 30% succeeded in disposing the appropriate space for waste segregation before collection. As displayed in the statistical analysis of this paper, one of the most effective ways to increase compliance with legislation is through staff training, leading to significantly smaller amounts of misclassified "hazardous" waste[34].

To bridge the gap between the current situation and "greener" surgical services, appropriate funding has to be allocated in the aforementioned activities. As it has been shown many European countries have achieved providing good portion of national expenditure on healthcare without increasing its relative carbon footprint[1]. Thus, one could argue that a source of funding for implementing surgical sustainability is applying green policies. However, understandable reluctancy against these investments could be justified by some, as their

benefits could be harvested on the long-term[5]. Sources of funding sustainability research could be sought after within the academia. Transforming practices and developing new techniques and materials can be the trigger for much needed research and what better source of funding than the university itself. Private funding could also contribute significantly to reducing the financial gap between the future and the present and could be directed to a variety of activities.

Conclusions

Despite the NHS having a solid plan for minimizing its carbon footprint, much could be improved in the domain of surgical practice. A precise record of the carbon footprint of surgical practise using hybrid approaches, involving pillars of provision of surgical service could be a first step, identifying the domains in which measures ought to be taken. As evidenced, there is increased need for high quality studies to identify current "weak" spots and implement appropriate pathways. A strategy for "greener" surgery should be developed in accordance with these research findings and introduced in NHS trusts by senior managerial staff as well as clinical leader teams, who will help implement the new measures and train staff appropriately in complying with these novel practices. Many questions remain unanswered regarding how sustainability can be integrated in the everyday surgical practice of all specialities, underlining the necessity for "eco-friendly" research on such a thought-provoking topic.

BOX 2: Summary of strategy

- Identify carbon footprint of surgical practice in specific, using a mixed approach.
- Educate and involve staff in reducing carbon footprint.
- Allocate funds to research and service improvement.
- Encourage high quality environmentally friendly research and implement relevant changes in related services.
- Use appropriately clinical governance to measure impact of changes.

Declaration of Competing Interests

The authors declare that there is no conflict of interest

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