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Moving towards green anaesthesia: are patients' safety and environmentally friendly practices compatible? A focus on single-use devices

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Abstract

Objective: Discuss if the use of disposable or reusable medical devices leads to a difference in terms of hospital acquired infection or bacterial contamination. Determine which solution is less expensive

and has less environmental impact in terms of carbon footprint, energy and water consumption and amount of waste.

Methods: A narrative review, including a literature review of articles published in English and French from January 2000 to April 2020 were identified from PubMed.

Results: We retrieved 81 articles, including 12 randomised controlled trial, 21 literature reviews, 13 descriptive studies, 6 experimental studies, 9 life-cycle studies, 6 cohort studies, 2 meta-analysis, 4 case reports and 8 other studies. It appears that pathogen transmission in the anaesthesia work area is mainly due to the lack of hand hygiene among the anaesthesia team. The benefit of single-use devices on infectious risk is based on weak scientific arguments, while reusable devices have benefits in terms of costs, water consumption, energy consumption, waste, and reducing greenhouse gas emissions.

Conclusion: Disposable medical devices and attire in the operating theatre do not mitigate the infectious risk to the patients but have a greater environmental, financial and social impact than the reusable ones. This study is the first step towards recommendations for more environmental-friendly practices in the operating theatre.

Keywords: Anaesthesia; environment; disposable equipment; durable medical equipment; nosocomial infection; life cycle

Introduction

The use of disposable medical devices has become the standard of care over the past decades. Most healthcare facilities in the western world have switched to single-use medical devices.

One of the main reasons is the risk of infectious disease transmission through reusable medical devices and the application of the precautionary principle. This principle is used in public health and environmental policies to make decisions in fields where scientific evidence is scarce. It states that “in the case of serious or irreversible threats to the health of humans or the ecosystem, acknowledged scientific uncertainty should not be used as a reason to postpone preventive measures” [1].

In the 1990s the new Creutzfeldt Jakob (vCJD) disease epidemic struck the United Kingdom (UK) where as many as 125 patients have died between 1996 and 2002 [2]. A few cases were iatrogenic, through the administration of growth hormone or dura mater graft [2]. Many tests have shown persistent protein traces on reusable devices, even after sterilisation [3]. The duration of incubation of the vCJD was unknown and thought to be as long as several decades. Therefore, even though no cases of iatrogenic transmission of the disease through medical devices were reported, French authorities decided to apply the precautionary principle: “when the potential risk to public health is substantial there is no to wait for indisputable evidence” [4]. This is why single use began to be used for many surgical interventions in order to prevent the transmission of the disease [4]. In 2001 in the UK, The Spongiform Encephalopathy Advisory Committee advised that, “where discrete procedures could be identified as suitable, and provided patient safety would not be compromised, single-use equipment should be considered” [2].

Following this advice, disposable equipment was used for several surgical procedures, instead of the reusable devices. One of the main surgical procedures involved was tonsillectomy. Involving lymphoid organs, this procedure was considered particularly at risk for vCJD transmission and both surgical and anaesthetic equipment were switched for disposable devices in July 2001. Less than one year after this modification of practices, several adverse incidents occurred (bleeding and one case of death), because of the poor quality of the disposable surgical equipment, leading the Department of Health of the UK to cancel its directive and allow reusable equipment for such procedures [5]. This return to reusable equipment was supposed to apply to the surgical and anaesthetics fields, however

the anaesthetic devices such as laryngoscopes blades, endotracheal tubes or ventilation masks remained disposable in most countries. In the following years, a lot of disposable devices have emerged in the anaesthetic field, from ECG cable and wire systems, headgear, attire, and blood pressure cuffs. However, the benefit for the patient of the use of single use medical devices in anaesthesia can be questioned.

On the other hand, in the actual era of major concerns about climate change due to CO₂ emission, the environmental impact of the waste produced by health care facilities has to be evaluated. In France in 2010, health care facilities produced as much as 700,000 tons of waste and one ton per hospital bed [6]. The processing of this waste is responsible for different types of pollution: CO₂ and greenhouse gas emissions, water pollution, soil pollution due to landfill of waste. Nowadays health care facilities have the duty to take action in order to make their activity more sustainable. In France, such goals are listed in the Haute Autorité de Santé (French Health Authority) certification guidelines as follows: water management, air management, energy management and waste management. Quality of work life is also assessed [7].

The incidence of surgical site infection was 0.79 to 3.9% of the surgeries in France in 2017 [8]. The risk factors commonly identified are mainly linked to the patient and the surgery itself rather than the type of devices used. The main risk factors are an ASA score equal or higher than three, a duration of surgery higher than the 75th percentile, obesity, perioperative smoking and inadequate surgical antibiotic prophylaxis [8]. Among the intraoperative risk factors, poor-quality surgical hand scrubbing and gloving are the only risk factors linked to attire and mentioned by the American College of Surgeons [9]. Hospitals can also be a source of surgical site infection, through the inadequate ventilation of the room, increased operating theatre traffic, contaminated environmental surfaces and non-sterile equipment [9]

However, surgical site infection is only one of many types of hospital-acquired infections. During a surgical procedure, patients are at risk of other types of hospital-acquired infections such as

bloodstream infections, upper respiratory tract infections, pulmonary infections, skin infection or urinary tract infection.

This narrative review is aimed at gathering evidences to answer two questions:

Are disposable or reusable devices different to prevent hospital-acquired infections (or surrogates such as contamination)? Which solution is less expensive and has less impact on the environment in terms of carbon footprint, water and energy consumption and amount of waste?

Narrative review

We achieved a targeted narrative review of the articles from the PubMed database, from January 2000 to April 2020. The year 2000 corresponded to the start of the use of disposable anaesthetic and surgical equipment in the operating theatre.

The inclusion criteria were all type of study related to hospital-acquired infections or environmental impact associated with anaesthetic medical devices or attire in operating theatre. Exclusion criteria were studies related to surgical devices or studies focusing on the technical characteristics of the devices.

The search terms “reusable”, “disposable”, “infection”, “operating room” and “life cycle” were associated with medical devices commonly used in the anaesthesia work area: “anaesthesia work area”, “scrubs”, “attire”, “masks”, “head covering” (and associated terms), “gloves”, “laryngoscope blade and handles”, “skull cap”, “ECG cable”, “ECG wire”, “Blood pressure cuff”, “Ambu bag”, “bag mask ventilation”. Both articles in English and French were considered. All PubMed search items have been put together to avoid any duplicates.

Two hundred and ninety-eight studies were identified through PubMed searching (**Figure 1**). After screening titles and abstracts, 89 studies were assessed for eligibility and after full text reading, 81 studies were included in the literature review: 67 studies on infectious risks, 30 on medical devices, 37 on operating theatre attire and 14 on the environmental impact. Among the 8 studies excluded, one was a case report on misused Ambu bag, one was a letter to the editor, one was a life

cycle analysis on cataract surgery and surgical tools, one was a survey on disinfection practices, one was an acceptability study on disposable laryngoscope blades, one was not talking about clothing or medical devices, one has been updated in a more recent study and one was a study on the impact of long sleeves on airborne contaminants.

Amongst these 81 articles, 12 were randomised controlled trials (RCTs), 21 literature reviews, 13 descriptive studies, 6 experimental studies, 9 life cycle studies, 6 cohort studies, 2 meta-analysis, 4 case reports and 8 other studies.

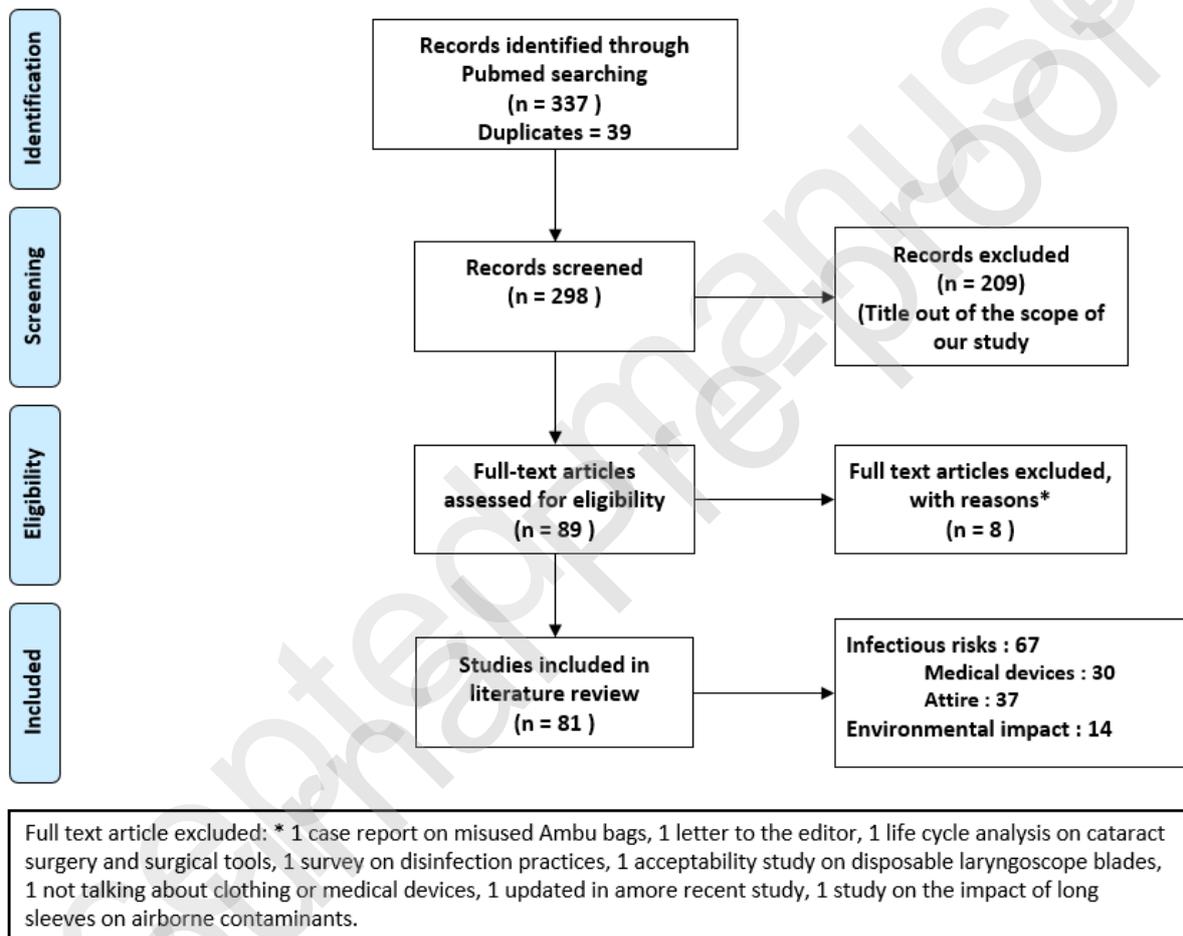


Figure 1: Flow Chart of literature search results, adapted from Moher et al. [10].

Infectious risks

Medical devices

In 2008, Loftus' et al. [11] hypothesised that anaesthesia work area could be a source of nosocomial infections. In an initial pilot study, they showed that the agent flowmeter dial and the adjustable pressure-limiting valve complex on the anaesthesia machine had the highest bacterial counts. The contamination of intravenous stopcocks occurred in 32% of cases. Highly contaminated work areas were an independent factor of stopcock contamination and patients with positive stopcock cultures had a significant increase in 30 days mortality, suggesting that their infections might be more severe. Later studies showed that the main potential infection sources coming from the anaesthesia work area were the hands of the anaesthesia providers (gram negative bacteria, *Enterococcus spp*) [12–14], and the patients skin and hair (*S. aureus*)[15], and that the pathogens found on the anaesthesia provider's hands can lead to postoperative infections [16].

Hand hygiene: The improvement of hand hygiene by anaesthesia providers has been shown to reduce horizontal contamination from the anaesthesia work area and thus decrease perioperative infection ($p < 0.002$) [17]. The wearing of double gloves during intubation might decrease the contamination of the anaesthesia work area [18].

If the greater infectious risk comes from the hands of the anaesthetist, are disposable medical devices a solution to decrease hospital-acquired infections?

Blood pressure cuffs: Blood pressure cuffs have been shown to be contaminated with pathogens (Methicillin-susceptible *Staphylococcus aureus* (MSSA), methicillin-resistant *Staphylococcus aureus* (MRSA), *C. difficile*...) [19–22]. Blood pressure cuffs in the operating theatre appeared to be less contaminated than those from the emergency department or from the High Dependency Unit but as many as 76% of them are likely colonised, as shown by Grewal et al. in a prospective cohort study [23]. This contamination was linked to the lack of disinfection of the devices between patients in a literature review by Uneke et al. [24]. However, there are few evidences that

this contamination could lead to hospital-acquired infection. We found only one case report of an outbreak in an intensive care unit (ICU), which originated from the reusable blood pressure cuff Velcro (Spengler, Aix-en-Provence, France). The outbreak ended when the ICU switched to blood pressure cuffs submersible in disinfectant [25].

ECG leads: One retrospective study based on a Medicare database found less surgical site infections in the disposable ECG leads group ($p = 0.03$) [26]. The patients with the reusable ECG leads have had their surgeries before the patients with the disposable ECG leads (for some cases, as long as 3 years before, as the study included patients from 2011 to 2014). As the authors stress in the discussion, other variables involved in infectious risk had probably evolved over this period of time, but such information was not available. A randomised controlled trial in ICU with 7240 patients did not show any difference in infection rates between reusable and disposable ECG wires even after adjusting for discharge disposition and comorbidity index ($p = 0.10$) or for patients staying more than 48 hours ($p = 0.10$). However, there were only 86 cases of infection in the entire study population [27]. As a result, the level of proof for the responsibility of reusable ECG leads in surgical site infection was very weak.

Laryngoscope blades and handles: Laryngoscope blades and handles often carry a significant protein deposit [3] as well as bacterial load [28] despite cleaning. In a study by Ayatollahi et al. where 1980 samples swabs were collected from different equipment in hospital wards, the highest level of contamination by gram negative bacilli among medical equipment was found on the laryngoscopes (10.48%) [29]. These devices carried microbial loads, up to 92% of the time, as shown by Negri de Sousa et al. in a descriptive study [30] and Choi et al. [31]. The cleaning procedures of these devices vary between facilities and between staff members in a single facility, as shown by Pidduck et al. [32], and most of them resulted in a low level of disinfection (cleaning with water and soap and in some cases 70% alcohol). The insufficient decontamination of these devices have led to several cases of infection and even deaths in neonates [33] and in one paediatric intensive care unit patient [34]. The risk of cross contamination associated with laryngoscopes and the lack of standardised cleaning

procedures was confirmed in several literature reviews [35–37]. It is not possible to draw a conclusion as to whether disposable laryngoscopes blades might have prevented such infections. As laryngoscope blades are in contact with mucous membranes, they are semi-critic medical devices and require a process of cleaning by high-level disinfection (HLD) or steam sterilisation according to manufacturer's instructions and/or national guidelines [38]. However, as Pidduck et al. [32] and Yee et al. [34] pointed out, even sterile laryngoscopes blades and handles can be contaminated during storage or by the hands of the anaesthetic practitioners. If the germs come from the hands of anaesthesia providers, even sterile disposable laryngoscopes can carry pathogenic germs. While it is unsure that disposable laryngoscope blades can mitigate the infectious risk associated with laryngoscopy, some disposable plastic blades might lead to difficult intubation with life-threatening consequences to the patient, as stressed out by Vailly et al. [39].

Attire in operating theatre

In 1871, Lister showed that antiseptics could prevent infection and used carbolic spray in the operating theatre to reduce contamination, whereas in the middle of the 19th Century, Ignaz Semmelweis postulated that hand washing can reduce puerperal sepsis [40]. In the 1880s, surgeons began wearing gowns, masks and gloves. Halsted was the first to use rubber gloves in 1889, as described by Eisen et al. [41]. Ritter et al. reported that Mikulicz started using sterile gloves in 1897 in order to reduce surgical site infection [42], as well as masks to reduce droplet spread [41,43]. Sterile surgery gowns started to be used in late 19th century with Gustav Neuber who showed in 1883 a decrease in surgical site infections, as reported by Salassa et al.[44].

While these measures initially seemed to be effective in reducing surgical site infections, recent studies have difficulty proving their effectiveness. Assuming 1.5 to 2.0% of infection rate and a power higher than 80%, a study would require the enrolment of 10,000 patients to determine the effect of one independent variable [45]. Air flow handling systems have appeared more recently in operating theatres and have probably participated in decreasing infection frequency by decontaminating the air and surfaces, as Zargar et al. showed with an experimental model [46].

Scrubs and gowns: Are scrubs and gowns a source of hospital acquired infections? A literature review by Mitchell et al. in 2015 showed that between 20% and 63% of healthcare workers scrubs or lab coat are contaminated with pathogens such as *C.difficile*, MSSA, MRSA or multi-drug-resistant organisms. Pathogens were also retrieved from clean and unworn scrubs. In the view of the authors, laundry areas can be insufficiently cleaned and disinfected or workers and post-laundering practices can recontaminate them [47]. But is reusable clothing really more at risk than disposable attire? In 2012, Wright et al. reported 3 sternal wound infection by *Gordonia bronchialis* after contamination of the home-laundered attire of a nurse anaesthetist [48]. We found no other case report that showed a direct link between reusable attire and surgical site infection. In the USA, a recent debate followed the implementation of the AORN (Association of periOperative Registered Nurses) recommendations that led to using disposable attire in the operating theatres for all staff [49]. A retrospective cohort study by Stapleton et al. of 60,009 patients from 12 hospitals in the USA found no significant difference in terms of surgical site infection between the period where surgeons used reusable gowns compared to the period where they switched to disposable gowns ($p = 0.61$; $p = 0.07$ in multivariable analysis) [50]. On the other hand, the financial burden associated with the purchase of disposable attire was important, as shown by Elmously et al. [51]. Nevertheless, this financial burden might vary between countries, the private or public status of the facilities, the fabrics used and which laundry facilities are available. The literature seems to be in favour of facility-laundered attire rather than home-laundered ones, as the latter carry a higher microbial load [47,52]. The use of tightly woven fabric such as polyester-cotton blend scrubs leads to less contamination of the operating theatre but it is unclear whether it might reduce the number of hospital acquired infections [44]. The benefit of changing scrubs whenever the staff goes out of the operating theatre (for meetings, breaks, etc.) is also unclear [53,54]. In the end, the main risk factor for contaminated attire remains insufficient hand hygiene, leading to contamination of attire [47]. The lowest microbial shedding is observed when the surgeon is not wearing any attire, as Bartek pointed out to close the debate [55].

Masks: As for masks and head covering, their importance to reduce surgical site infection is unproven. In 1991, Mitchell and Tunevall called into question the usefulness of masks especially in modern operating theatre with forced ventilation (as defined by Jain et al: "Laminar air flow which uses positive pressure air currents through filtration units to direct air streams away from the operative field in order to create an ultraclean zone around the operative site" [56]) .[43,57]. As early as 2001, Romney et al. tried to answer it by carrying out a systematic review. Due to the lack of evidence, of a well-conducted randomised controlled trial and the absence of a standardised method to measure the filtering efficiency of surgical masks, he thought it was premature to change practice guidelines [58]. Zhiqing et al. experimentally showed in 2018 that the external side of the mask contained many bacteria from the surgeon's skin [59]. However, the clinical impact on surgical site infections is uncertain, especially for the anaesthesia teams. Skinner et al. [60] showed in a review that new operating theatre designs like laminar flows provided the greatest reduction in environmental contamination. Masks have a low impact for infection control and cannot be scientifically justified for non-scrub operating theatre staff. In a randomised controlled trial with 820 patients performed by Webster et al. in 2010, there was no increase of surgical site infection when non-scrub operating theatre personnel were not required to wear masks ($p = 0.151$) [61]. A meta-analysis updated in 2016 by Vincent et al. with 3 studies and a total of 2,100 patients also showed no difference [62]. This is the reason why in 2010, anaesthesia teams of a Stockholm hospital decided to stop wearing masks in several sectors, except those most at risk of infection [63].

Head covering: Some studies demonstrated that hair and ears of patients, nurses and doctors can harbour *S.aureus* [64–67]. Nevertheless, there is no evidence that headgear, with or without ears coverage, can reduce infection rate as described by Spruce et al. in a literature review in 2017 [68] and confirmed by other new studies in 2018 (Kothari : $p = 0.016$ but $0.66 > p > 0.85$ when adjusting for the type of surgery ; Farach : $p = 0.321$; Shallwani : $p = 0.629$) [69–71]. As recently as 2020, in a retrospective cohort of 34,000 patients, Wills et al. did not show a significant difference in surgical site infection when comparing three types of attire: both mandatory surgical jackets and bouffant

hats, mandatory surgical jackets alone or neither ($p = 0.28$) [72]. Markel et al. showed that airborne particle contamination was higher in a dynamic operating theatre environment with disposable bouffant hats as compared with cloth skullcaps ($p < 0.05$). Microbial shedding on passive settle plate was higher with disposable bouffant hats compared to disposable and cloth skullcaps even though bouffant hats covered all hair and ears. Permeability measured by electron microscopy was higher in bouffant hats than in skullcaps. Cloth skull caps offer better cleanliness after proper laundering [73]. Switching from disposable to reusable skullcaps could also be an opportunity to use role-based and name-based head covering system to improve patient safety and anxiety as well as mitigate errors in the operating theatre [74].

Gloves: Although the contribution of gloves seems incontestable, the superiority of sterile gloves compared to non-sterile remains uncertain for some contaminated procedures, as well as wearing two layers of gloves [41,44,53]. In an experimental study, Creamer et al. showed significantly more bacteria spread by clean gloves *versus* sterile gloves ($p < 0.001$), but failed to show a clinical impact [75]. Several studies have not shown any superiority of sterile *versus* non-sterile gloves. We can cite among these the randomised controlled trial of Perelman et al. in 2004 for repair of uncomplicated traumatic lacerations ($p = 0.295$) [76] or those of Cheung et al. ($p = 0.81$), Adeyemo et al. ($p = 0.09$) and Chiu et al. ($p = 0.66$) for wisdom tooth surgery [77–79]. For minor skin surgery like skin cancer excision and wound repair phase, Xia et al. did not show superiority of sterile gloves ($p = 0.99$) and Heal et al. concluded to a non-inferiority of non-sterile gloves (Difference (95% CI): -0.6% (-4.0% to 2.9%)) in two prospective, randomised and controlled trial, as well as Mehta et al. in a retrospective study ($p = 0.82$) [80–82]. Rhinehart et al. also showed a cost difference of \$0.95 per pair, which can be significant when multiplied by the number of procedures (\$2,078.60 for 1400 procedures in this study) [83]. These results have been confirmed in 2016 by Brewer's et al. meta-analysis with 11,000 patients (RR (95% CI): 1.06 (0.81 to 1.39)) and by a new prospective, randomised study by Michener et al. in 2019 ($p = 0.99$) [84,85].

Current hygiene rules [86] on operating theatre attire are mainly based on precautionary principle. When they were introduced, there was no environmental consideration, and no question about amount of waste. While there is a lack of evidence that these rules decrease surgical site infection, we should maybe question and change our practice to minimise waste, using reusable mask and skullcaps, or stop wearing them in areas where it is not necessary.

Environmental impact

Today, global warming and pollution are known to be one of the greatest threat to health worldwide [87].

Studies have shown that pollution is one of the leading causes of death in the world. The World Health Organization (WHO) reported about 7 million deaths worldwide in 2012 related to pollution [88]. As reported by Landrigan et al., the Global Burden of Disease Study by the WHO estimated in 2015 the annual number of deaths at 9 million. As premature death is not the only consequence of pollution, the authors used the DALY (disability-adjusted life year, one DALY representing the loss of one year of full health) and found that ambient particulate matter and household air pollution are amongst the ten largest contributors to global DALYs [89–91]. Lelieveld et al. estimated at 659.000 the annual excess mortality caused by pollution in the European Union in 2019 [92].

In a sustainable development perspective, one must take into account not only the economic aspect of medical devices, but also the social and environmental impact. In our opinion, the cost of single-use devices is probably underestimated: the complete life cycle from the raw materials to the waste processing is often unknown. The social impact of such devices (no need for sterilisation staff anymore for disposable devices) is not evaluated either.

The choice between single use and reusable in the hospital often seems based on infection prevention, but also on direct and indirect costs and the possibility of short-term saving. This is not surprising considering the fact that the life cycle of a device, from manufacture to its end of life is complex and that decision-makers do not have access to such information before choosing what to

purchase. Choices are sometimes made on the basis of personal opinion, anecdotal or incomplete information and misleading or biased information, as written by Ison and Miller [93]. They were the first to perform a life cycle assessment of medical devices in 2000. They focused on suction receptacles, showing how important the life cycle assessment is in the decision-making for the purchase of medical devices. Fortunately, some authors have begun to compare life cycle for other medical devices in the operating theatre. For example, Eckelman et al. has shown that 40 uses of one reusable laryngeal mask airways have a lower environmental impact than 40 disposable ones by reducing greenhouse gases emission, especially because production and polymerisation of PVC is associated with high greenhouse gases emission (23% of life cycle CO₂ emission for disposable laryngeal mask airways) [94]. Reusable devices also decrease CO₂ emission related to transportation and waste.

Perioperative textiles (surgical gowns and drapes) have also been compared. Overcash et al. synthesised 6 environmental life cycle studies between 1993 and 2010 and found benefits such as the decrease of energy consumption (50 to 66% less), carbon footprint (50 to 66% less) and a drastic reduction of waste (86% less), if each surgical gown or drape is reused 50 to 127 times [95]. More surprising and contrary to common perceptions, reusable surgical gowns are also a water-sparing option, compared to disposable ones. Indeed, washing attire uses 60 to 70% less water than the manufacturing of a disposable gown. Vozzola et al. confirmed these results for isolations gowns in 2018 and for surgical gowns in 2020 with a similar environmental impact [96,97].

Reusable can also reduce costs: McGain et al. showed a two-fold cost reduction with reusable laryngeal masks, laryngoscopes and videolaryngoscopes. The savings were estimated as high as AUD\$ 2.3 million a year in Australia [98]. When reusable laryngoscopes are used, considering a lifetime of 4000 use, Sherman et al. showed that in a hospital with 60,000 intubation per years, financial savings are between \$675,000 and \$869,000, depending on which type of process is used (disinfection or sterilisation) [99]. Environmental benefits were also important, even if recycling is increased to 100%.

Moreover, in a country where disposable devices are imported, the need to disinfect or re-sterilise reusable equipment can relocate jobs.

McPherson et al. worked on reducing greenhouse gas emissions by using reusable and bigger sharps containers [100] and McGain et al. worked on single-use plastic anaesthetic drug trays, which cost twice as much, and consume three times more water [101].

However, it is necessary to put the emission of CO₂ into perspective. Indeed, some studies are not in favour of reusable devices, from an environmental point of view. For example, McGain et al. found that reusable central venous catheter insertion kits, emit 3 more times more CO₂, and consume 11 times more water than 300 disposable kits, when used 300 times. The explanation for these results was the use of brown coal-sourced electricity in Australia where the study was carried out. In a European model in which electricity is not mainly produced with coal, CO₂ emissions are similar for both devices [102]. This example shows the importance of optimising the cleaning and sterilisation phase. It also emphasises that a lot of elements have to be included into the life-cycle assessment of a device. Indeed, one can hypothesise that life-cycle assessment would not always be in favour of reusable devices. The source of electricity matters, but the fragility of a reusable device does also. Losing or breaking reusable equipment is rarely taken into account. It has environmental and cost consequences, especially if the equipment is at the beginning of its life.

Table 1: Infectious risk and environmental impact of devices commonly used in the anaesthesia work area

	Infectious risks	Environmental impact
Blood pressure cuffs	Many of them are contaminated with pathogens because of the lack of disinfection [23,24]. No evidence that could lead to hospital-acquired infection.	Still to be studied
ECG leads	Discordant results from two studies on the risk of surgical site infection [26,27].	Still to be studied
Laryngoscope blades and handles	They are often contaminated by germs and poorly cleaned [3,28–32,35–37]. Insufficient decontamination has led to several cases of infection [33,34]. No study compares reusable and disposable blades on the risk of infection.	Significant reduction in costs and greenhouse gas emissions with reusable laryngoscopes <i>versus</i> disposable plastic or metal laryngoscopes. [98,99]
Perioperative textiles	Scrubs and gowns can be contaminated with pathogens and there is one case report on sternal wound infections [47,48]. A large retrospective study on gowns found no significant difference in terms of surgical site infection [50].	The synthesis of 6 studies on reusable textiles shows a significant reduction of energy and water consumption, carbon footprint and wastes [95]. These results are confirmed by 2 new studies [95,96].
Masks	Wearing a mask in the anaesthesia team does not decrease the risk of surgical site infection in several studies and meta-analyses [60–62].	Still to be studied
Head covering	There is no evidence that headgear with or without ears coverage can reduce infection rate [68–72]. Cloth skullcaps appear as clean as disposable skullcaps if properly laundered [73]. Opportunity to use role-based and name-based head covering system [74]. However bouffant hats are not able to protect properly from microbial shedding and particle emissions [73]. It is also useless to put bouffant hat under another headgear as this provides more waste.	Still to be studied
Gloves	No superiority of sterile <i>versus</i> non-sterile gloves in several contaminated procedures [76–85].	Additional costs with sterile gloves [83].

Discussion

Through our narrative review, we found that the infectious risk to the patient in the operating theatre comes mainly from the hands of the surgical and anaesthesia team and from the patient's skin. As for the anaesthesia work area, the lack of hand hygiene leads to the contamination of the environment and can lead to horizontal contamination of patients. The intubation period seems to be particularly high risk and can lead to contamination of the anaesthesia machine (the APL valve being the most contaminated item). The anaesthesia workspace is also a reservoir for pathogens *per se*.

Our results assess the undeniable ecological benefits of reusable medical devices, by reducing waste of resources, waste of water, electricity consumption, greenhouse gas emissions, and the amount of waste. According to the current literature, going back to reusable devices should have positive economic and environmental effects. However, life-cycle studies should be carried out for all devices before purchasing. Therefore, financial savings would not be the only argument for choosing between single-use and reusable devices.

Our study is a qualitative review of the literature. We chose to take into account the articles published between 2000 and April 2020 and not older ones, as they might not reflect current practices.

Most of the studies included are literature reviews, case reports or cohort studies. We were not able to do a meta-analysis. Nevertheless, to our knowledge no other literature review puts into perspective the environmental impact and patient safety in the anaesthesia work area.

Randomised control studies are needed to prove or disprove whether reusable items have a significant impact on patient's safety and infection prevention. New diseases are susceptible of arising, as it happened with new Creutzfeldt Jacob Disease in the early 2000s. Then all the risk-benefit analysis of reusable *versus* disposable items might be completely out-dated.

But without certitude, what should be our attitude? The application of the precautionary principle would lead to choose disposable items as one might think that reusable items could lead to the

transmission of new unknown diseases. This strategy has already failed in the past: it has a significant impact on the environment, leads to a great financial burden, and sometimes even puts the patients at risk when disposable devices are less precise or efficient.

Is it then possible to switch to reusable devices and still respect national and international recommendations?

The American College of Surgeons recommends that the surgeons wear double-gloves [9]. The AORN has changed their recommendations and leaves the decision to each Healthcare facility, saying it is “a facility decision” that has to be made by an interdisciplinary team, taking environmental parameters into account [103].

The WHO recommendations insists on hand washing and using alcohol based solutions for skin preparation, among other parameters [104]. According to the last recommendations of the French Society of Digestive Surgery [105], care-givers can wear either disposable or reusable attire in the operating theatre, providing this attire is changed at least every day.

As stated by the WHO, non-critical items, in contact with intact skin, such as blood pressure cuffs, stethoscopes, can be reused after a simple cleaning (visibly clean). Semi-critical items, in contact with mucous membranes or body fluids (*e.g.*, laryngoscope blades, masks...) require a high level of disinfection before reutilisation [106]. Most devices used in anaesthesia belong to these two categories and thus could be reused after proper disinfection or proper sterilisation.

Overall, the recommendations are based on a very scarce literature and for many aspects the level of proof is weak. No recommendation is made about using single-use attire or medical devices in order to mitigate surgical site infections or hospital-acquired infections in general.

We are now aware that sustainable development is necessary to prevent global warming and pollution and that practices have to change. Some non-governmental organisations such as Healthcare Without Harm have warned about the environmental impact of healthcare. The operating theatre is no exception to the rule and several anaesthesiologists have already started to implement protocols to improve the carbon footprint of their workplace by promoting the model of the Centre

for Sustainable Healthcare, a model that “reduces the environmental impact without reducing health by decreasing both (wasteful) activity and carbon intensity” [107,108]. The European Society of Anaesthesiology (ESA), the French Society of Anaesthesia and Intensive Care (SFAR) or the UK Association of Anaesthetists have created sustainability committees.

Reducing the greenhouse gas emissions in hospitals seems possible as shown by the British experience, which was able to reduce its carbon emissions by 18.5% between 2007 and 2017 [109].

With these new parameters in the equation, one cannot longer simply follow the precaution principle to guide the choice of equipment and define hygiene rules. Environmental and social impact should be assessed and considered each time a disposable device is used or when hygiene rules have not clearly demonstrated their effectiveness.

According to our exhaustive narrative review, the following improvements could be implemented in the operating theatre in order to improve the sustainability of our work as anaesthetists:

- Use reusable cloth skullcaps and scrubs, providing they are properly washed.
- Use reusable sterile gowns when sterile attire is needed.
- Use reusable monitoring devices (blood pressure cuff, ECG wires...).
- Use reusable laryngoscopes blades and handles, providing they are properly disinfected or properly sterilised.
- Improve hand hygiene in the anaesthesia work area, especially after performing intubation.
- Improve the disinfection of the work area between patients, with a special focus on the anaesthesia machine and the pressure-limiting valve.

All steps should be evaluated by a hygienist.

Healthcare facilities, through a “sustainable purchase” policy could influence their suppliers and lead them to mitigate the environmental impact of their products.

In the future, other life-cycle studies should be carried out on devices not yet studied. Stepped-wedge cluster-randomised controlled trials are used in a wide range of areas of public health and

may be helpful to unravel the problem of patient's safety in the operating theatre using disposable vs. reusable equipment.

The COVID-19 pandemic has shown that massive use of disposable personal protective equipment (PPE) leads not only to a massive amount of waste, but also to shortages when industrials are not able to cope with the increased demand. As stressed out by Mc Gain [110], a system with locally processed and reusable medical PPE is not only better on an environmental point of view, but also more resilient.

Conclusion

Single-use medical devices were widely chosen by health care facilities over the past decades. Several decades later, nor the literature, neither the national or international recommendations provide enough scientific material to conclude that disposable devices are better for the patient's safety.

The additional environmental costs in terms of greenhouse gases, energy consumption, water, amount of waste and raw materials of disposable medical devices are well demonstrated. Reusable devices are more environment-friendly and some are cheaper than disposable ones. Reducing the use of disposable devices in the hospital must be part of the many measures to reduce our environmental impact. Such choices also have a social impact. Cleaning and sterilisation could prevent job cuts, at no additional costs if it is included in the choice of reusable devices. Staff satisfaction might also be greater if their work seemed less polluting, less wasteful, without putting patients at risk.

On the basis of the literature, new guidelines on sustainable practices in the operating theatre are needed. The environmental impact of medical devices should be as small as possible. Life-cycle studies are one of the tools one can use to achieve this goal. But beyond this, it is time to change our habits in the hospital, in order to treat patients without harming the planet.

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