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Communication

Exploring Anaesthesia Licence Students' Knowledge of the Green Operating Room to Inform Prototype Development

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Abstract

The climate change, the growing accumulation of waste, and the excessive consumption of natural resources highlight the urgent need to embed sustainable development principles within healthcare systems. The operating room, considered the core of hospital activity, is also one of the most polluting units. In this context, the present study was designed to analyze anaesthesia students' pre-acquired knowledge regarding environmentally responsible practices in order to identify gaps and promote the integration of sustainable strategies into medical education. A prospective analytical study was conducted over an eight-week period (January–March 2023) with second- and third-year anaesthesia students (n=150) at Université Centrale, using an anonymous online quiz comprising 13 items covering bio-cleaning, waste management, air treatment, and greenhouse gas emissions. Results indicated that while a majority of students were familiar with certain eco-responsible practices such as bio-cleaning procedures and the labelling of yellow waste bags, substantial deficiencies persisted. Only 44% recognized that waste sorting must occur at the source, and less than 20% identified desflurane as the anaesthetic agent with the highest global warming potential. Knowledge of air treatment systems and greenhouse gas management also remained limited, reflecting a need for targeted training. To translate these findings into practical action, a 3D prototype of a "Green Operating Room" was developed using 3DS MAX software and aligned with international guidelines. The prototype integrates concrete eco-responsible solutions, including a color-coded waste sorting system with automated chutes, awareness posters on anaesthetic gas emissions, and environmentally friendly architectural design. Serving as both an educational and awareness-raising tool, this prototype provides a replicable model that connects theoretical knowledge with real-world application. In conclusion, the study underscores the necessity of incorporating sustainability modules into anaesthesia curricula and demonstrates how a digital prototype can bridge knowledge gaps while fostering eco-responsible behaviour among future healthcare professionals. By linking environmental education with practical innovation, the project contributes to advancing sustainable practices in healthcare and offers a pathway for developing greener operating rooms.

Keywords

Knowledge Assessment, Ecology (Green), Anaesthesia, Sustainable Development, Prototype

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1. Introduction

Sustainable development was defined in the 1987 Brundtland Report as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". So, to establish this balance and design a well-crafted sustainable development project, it is imperative to respect the three pillars: economic, social and environmental. The theme of sustainable development is becoming a matter of concern for many national (Tunisian Association for the Protection of Nature -ATPNE) and international associations (World Wide Fund for Nature, World Organization for Environmental Protection, National Federation of Environmentalists, Nature Conservation Union Germany). They believe that a coordinated and unified approach is needed to face any risk that could have a negative impact on the climate and the environment.

Paradoxically, the medical and paramedical sector that cares about our health is also the one that presents a real ecological danger. Worldwide, the healthcare sector is responsible for around 4.4% of global greenhouse gas emissions [1]. Our planet is undergoing fairly threatening climate change, and there is no denying that greenhouse gases are responsible for this. The healthcare sector must necessarily become involved in eco-friendly practices [2]. Indeed, several studies have estimated that greenhouse gas emissions in the healthcare sector in the UK and Australia represent 3-4% and 7% respectively of national emissions. In the United States, the figure is closer to 10%. The operating room is considered to be the "nerve center" of any hospital or clinic, but it is also a considerable source of environmental pollution and energy consumption, even using 3 to 6 times more energy per square meter than any other area of the hospital [1].

Several countries have implemented strategies to improve eco-responsibility in operating rooms, such as French Society of Anesthesia and Intensive Care (SFAR's) sustainable development committee, created in 2016. This committee published the operating room development guide in 2017 [3] and the SFAR-Green sheets in 2020 [4, 5] to help anaesthetists design their care techniques in an environmentally friendly way.

Given the current alarming state of our planet and the worldwide renaissance of eco-friendly concepts supporting the environment, we asked ourselves the following questions: What is the situation in Tunisia? How far have eco-responsible practices been adapted in operating rooms? What Green concepts and strategies need to be integrated to improve environmental sustainability?

In order to provide the best possible response to these issues, this project involves assessing the knowledge of students enrolled in anaesthesia and intensive care, who will be responsible for management and sustainable development in the future. Considered as an eco-responsible awareness-raising strategy, the aim is to assess their degree of acquisition of a few theoretical notions on the anaesthesia-environment relationship. Finally, we propose to initiate new designs that meet ecological standards in order to develop a prototype that translates the elements and practices required for a 'Green' operating room and that will be shared to raise awareness among students and health professionals.

2. Materials and Methods

2.1. Type and Duration of the Study

This was a prospective and analytical study. It ran from 30 January to 30 March 2023, i.e. eight weeks. As part of the development of an awareness-raising strategy, a form was carried out using Microsoft Forms. This anonymous online quiz comprised 13 questions (see supplementary data 1) including definitions, ecological management concepts, and the environmental impact of anaesthesia. It was aimed strictly at students enrolled in the 2nd and 3rd year of anaesthesia and intensive care at the Central University (a total of 205 students).

In order to ensure the reliability of the results, three conditions had to be met:

1) Only one response to the entire form per participant.
2) All questions had to be answered.
3) Compliance with the cut-off date (after the study date, no participant could respond to the link).

To ensure the robustness of the results, the questionnaire was subjected to a pilot testing phase with a representative sample of students and professionals (N=5, allowing identification and correction of ambiguous items to improve clarity and comprehension before the full study.

At the end of the study, the results and a report containing the correct answers were shared anonymously with each participant.

2.2. Presentation of a Proposal for a Green Operating Room Prototype

In order to bring the “Green Operating Room” project to life and make it more visible and closer to reality, a 3D prototype was produced using 3DS MAX (2021) software, with rendering by V-Ray3D and video editing using Adobe Premiere Pro.

This prototype was not an end in itself but a step in the development of eco-responsible strategies and concepts aimed at raising awareness among young people. It was designed in accordance with international standards and regulations, while also drawing inspiration from architecture and green design principles, to achieve an environmentally respectful outcome.

Three stages were followed to ensure an efficient result:

1) Data collection: based on published international rec-

ommendations and guidelines [4-8], as well as the evaluation of theories acquired from a panel of students.

2) Idea development: by adding depth to the collected data and anticipating new developments in the field of green anaesthesia.
3) Digital transformation: by creating a 3D prototype incorporating all the essential elements of an operating room with reduced environmental impact.

3. Results

3.1. Evaluation of Pre-acquired Knowledge of the Green Operating Room

This evaluation was anonymous, and targeted students enrolled in the 2nd and 3rd years of the anaesthesia-intensive care section at the central university. 150 responses were collected, including 71 forms obtained from 2nd year students and 79 from 3rd year students (Figure 1). It is important to acknowledge potential biases affecting the generalizability of these results, as the study population may not fully represent all anesthesia training contexts or geographic regions, which could limit the applicability of findings to different settings.

3.1.1. Bio-cleaning

73% of all anaesthesia licence students gave the correct answer, mentioning that bio-cleaning is carried out at the beginning, between two interventions and at the end. By level, 69% of 2nd year students gave a correct answer and 77% of 3rd year students.

3.1.2. Waste Management

63% of all students and by level know the meaning of the abbreviation (DASRI): Healthcare Waste with Infectious Risk.

54% of students know the meaning of the abbreviation (DAOM): Waste Assimilated to Household Waste. By level, 57% of 2nd year students gave a correct answer, compared with 51% of 3rd year students.

50% of students know the meaning of the abbreviation (OPTC): Sharp Cutting Objects. Note that by level, 52% of 2nd year students compared to 49% of 3rd year students answered correctly.

70% of all students responded correctly, mentioning that the yellow bags are labelled with a date of installation and exit. Note that by level, 76% of 2nd year students mentioned a correct answer and 65% for 3rd year.

73% of students know the filling limit for yellow bags which is 2/3. Note that by level, 81% of 2nd graders and 65% of 3rd graders mentioned a correct answer.

44% of students marked the correct answer regarding waste sorting which must be done at the source.

82% of students know that waste disposal must be carried out in controlled public landfills.

3.1.3. The Air Treatment System

The majority (61%) think that nitrous oxide has the highest global warming potential. However, 17% of students answered correctly by mentioning Desflurane. By level, 14% of 2nd graders and 20% of 3rd graders checked the correct answer.

Nitrous oxide has the longest atmospheric lifespan. This result was mentioned by 53% of all the targeted students, and in particular by level 59% of 2nd and 48% of 3rd.

62% of students answered correctly indicated that the limit flow rate for halogens not to be exceeded 3L/min. By level, 69% of 2nd and 55% of 3rd know the flow limit value.

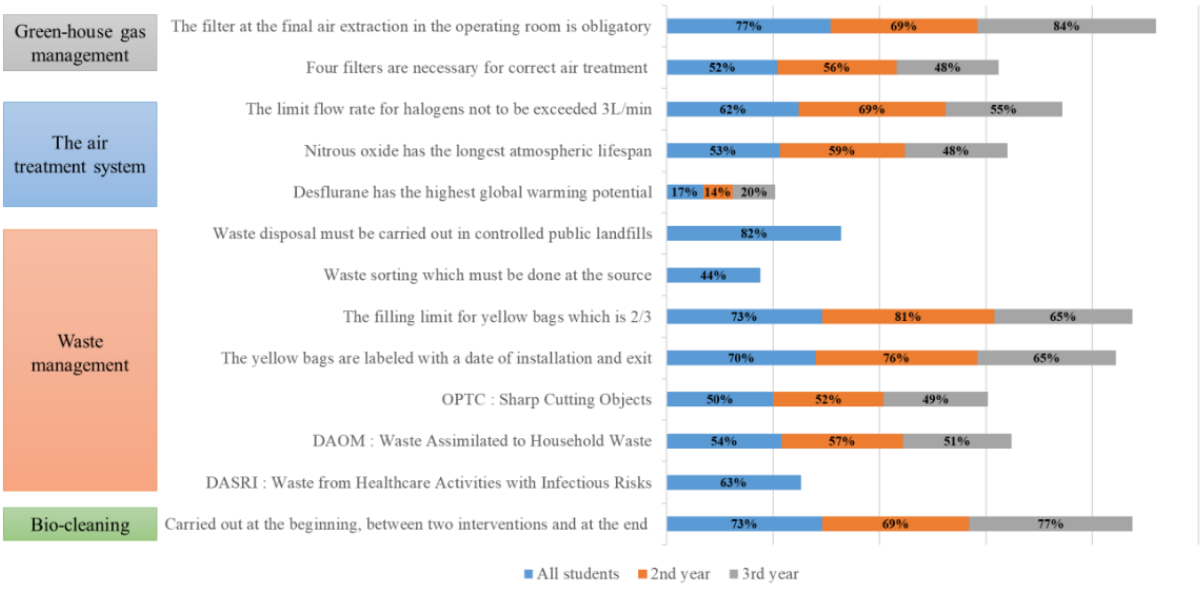

Figure 1. *Evaluation of the pre-acquired knowledge of anaesthesia licence students on the green operating room.*

3.1.4. Greenhouse Gas Management

52% of students mentioned that four filters are necessary for correct air treatment in the operating room. In particular, 56% by the 2nd and 48% for the 3rd.

77% of students, including 69% of the 2nd year and 84% of the 3rd year, correctly mentioned that the filter at the final air extraction in the operating room is obligatory.

3.2. Prototype Development

After collecting all the data from the knowledge assessment but also, through the international regulations followed [6-8], the prototype was developed. It presents a design of a green operating theatre with the necessary elements which offer practitioners, in particular the anaesthesiologist, a more adequate space to practice their care with the least ecological impact. The structure offers a well-organized space for easy circulation within the room (Figure 2).

The overall design of the green operating room prototype demonstrates a well-organized space for minimizing ecological impact, as shown below.

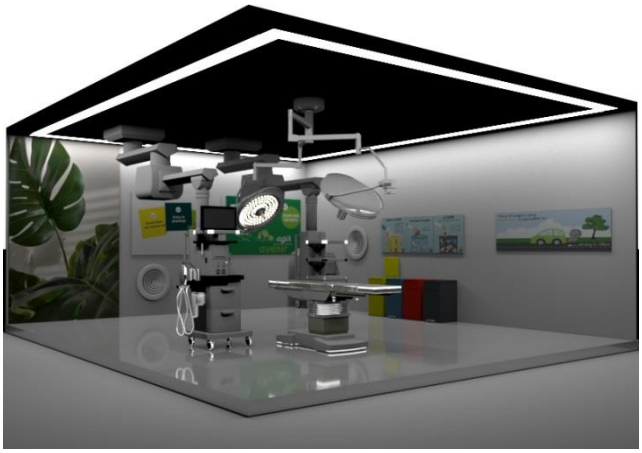

Figure 2. *Overall view of the 3D prototype.*

The sorting system is essential in order to apply waste management. This system was translated into the prototype (Figure 3), through different colours of the garbage chutes which must have automatic sensors to minimize infectious risks:

1) Yellow for DASRI
2) Blue for recyclable waste, cardboard/plastic
3) Red for recyclable glass bulbs
4) Gray for DAOM

To further facilitate the sorting task and minimize the rate of DASRI produced, the sorting protocol was displayed in posters.

The waste sorting system includes color-coded chutes and posters to facilitate eco-friendly practices.

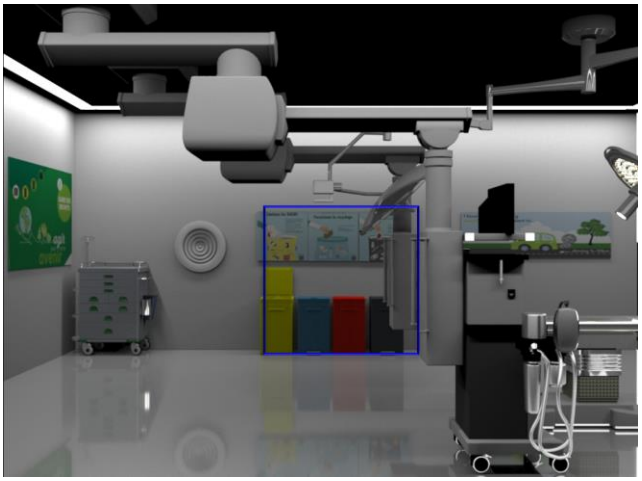

Figure 3. *Sorting system with poster protocol.*

Raising awareness within the operating room about the harmful impact of greenhouse gases used during anaesthesia is a fairly important starting point for minimizing their exploitation. For this reason, a poster, showing the polluting effect of using sevoflurane for one hour, was added for example (Figure 4).

And finally to integrate the Green and eco-friendly spirit into the operating room, posters raising awareness of the practice of sustainable management have been added. They show the importance of respecting the environment, and applying some practical notions that will help our planet (Figure 5).

Awareness posters on greenhouse gases and sustainable management are integral to the prototype.

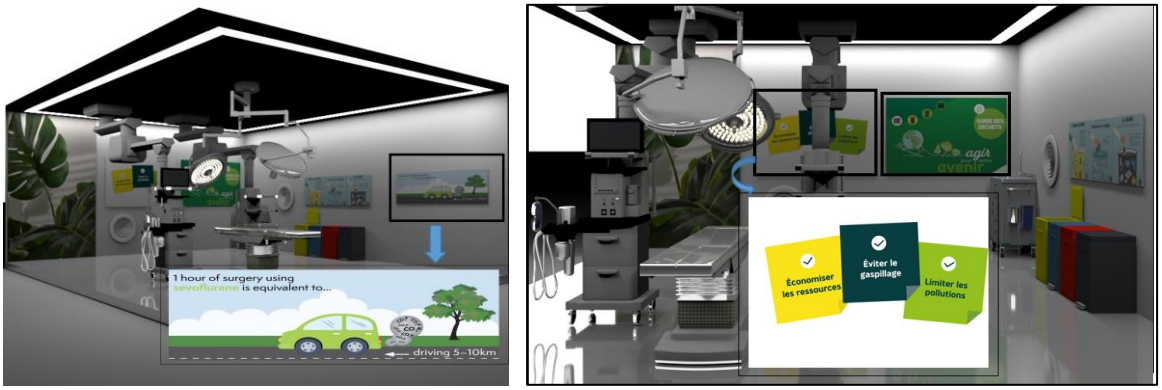

Figure 4. *Raising awareness of the impact of greenhouse gases and sustainable management practices.*

4. Discussion and Conclusions

Through this project, the problem linked to the lack of knowledge of the impact of anaesthesia on the environment was addressed, given the critical situation of the environment causing climate change and to initiate an eco-responsible development strategy by carrying out 'a prototype specific to a green operating room.

Global warming, the environment and the duty to protect it are among the subjects that we have heard so much about since our childhood and whose magnitude will only increase in our future. In this context, and in order to develop eco-responsible strategies, we targeted anaesthesia-resuscitation students, enrolled in the 2nd and 3rd year of the central university. The goal is to evaluate their degree of theoretical knowledge on basic notions of some eco-responsible practices. This step involves the principles of ecologically sustainable anaesthesia, including the Green bloc, where the student should be made aware and trained on environmental sustainability.

4.1. Knowledge Gaps Identified

Certain essential basic notions related to green practices are not well acquired. Generally, for all questions, 2nd year students have more correct answers than 3rd year students, this can be explained by the fact that these definitions and these notions begin with the course objectives given in 2nd year.

Regarding bio-cleaning, 27% of students do not know the steps. The assimilation of different types of waste is important in order to reduce their production, ensure good management and apply a good sorting protocol. About 40% of students do not know the meaning of the abbreviations DAOM, DASRI and OPTC. Around 30% did not answer correctly regarding the labelling of yellow bags and their 2/3 filling volume limit. Although 82% are aware of the concept of controlled public landfills, 50% of students think that waste sorting is done at the end of the intervention and not at the source, which can directly affect the recycling of waste in the operating room.

Regarding greenhouse gases, some basic concepts are important to know [9]:

1) The global warming potential (GWP): is a conversion factor which gives an idea of the relative impact of greenhouse gases on global warming.
2) Atmospheric life: is the average duration during which a polluting molecule remains in the atmosphere, from the moment of its emission until its disappearance.
3) Desflurane is the gas which has a higher GWP of around 2720.
4) Nitrous oxide has the longest atmospheric lifespan which is equal to 120 years.

Most of the students who participated in our questionnaire responded that Protoxide has the highest atmospheric life and Global Warming Potential (GWP). Thus, capturing this information on Greenhouse Gas (GHGs) can play an important role in choosing the least polluting halogen during anaesthesia. The majority of students are aware that low flow rates must be used, which can reduce harmful effects. About half mentioned the number of filters as four and a majority that the final extraction filter is mandatory for correct treatment.

In France, a survey carried out by REFEED (French Student Network for Sustainable Development) showed that 66% of students are concerned about their future by thinking about climate change, 52% are not properly trained ecologically and 65% find it necessary for university programs to offer courses on this subject [10].

In this context, integrating ecology and sustainable development regulations into the university curricula of paramedical and medical professionals is increasingly necessary. Universities are encouraged to adopt formal educational policies to better prepare future healthcare professionals for eco-responsible practices and to promote continuing education in this area. Educators play a key role in fostering ecological awareness among students so that they can contribute positively to the planet [8, 14]. More broadly, the integration of digital simulations, such as the prototype developed in this study, represents an innovative pedagogical approach that enhances both learning and ecological awareness [11]. Furthermore, continuing professional education in anesthesia should include training on environmental sustainability at

both individual and institutional levels [11]. This study highlights significant gaps in anesthesia students' knowledge regarding sustainable practices in the operating room, notably a low awareness of the global warming potential of certain anesthetic agents, such as desflurane. These findings underscore the need to make sustainability and eco-responsibility modules mandatory in anesthesia training programs. Such training should combine theoretical input on the environmental impact of medical practices with practical tools, such as digital prototypes and simulations, to improve knowledge retention. Healthcare institutions, in collaboration with universities, must develop pedagogical and organizational strategies to strengthen this knowledge at all training levels and within continuing education. Moreover, implementing institutional policies aimed at reducing the carbon footprint of operating rooms, such as those proposed by the SFAR [5] or operational training initiatives on eco-responsible anesthesia [5] is essential to translate theory into concrete action.

4.2. Green Operating Room Prototype

The operating room, in our life as a resuscitator anaesthetist, represents our second home, so practicing our anaesthesia while respecting a green environment in the operating room would be totally beneficial for our planet.

Green architecture is a true philosophy which aims to reduce the harmful consequences of construction, by drawing inspiration from the environment to create healthy regions. It is a complex approach that places respect for nature at the heart of its approach. These green constructions are mainly focused on energy conservation and the use of sustainable and ecological materials to minimize their environmental footprint [7, 12]. There is no single way to build an ecological building as long as the building complies with these characteristics:

1) Optimization of water and energy use.
2) Use of renewable energy sources.
3) Implementation of a recycling strategy to optimize waste.
4) Use of materials that are both durable and non-toxic.

The inspiration we drew from the "Green Architecture" concept pushed us to design a prototype intended to raise awareness among practitioners about environmental preservation. We believed that prototyping was limited to specific areas, but in reality, it is totally possible to create a prototype in any sector.

Our prototype is simple, understandable, made up of:

1) The structuring of a room meeting standards: all the elements carried by arms, the rubber floor and waterproof PVC wall protection without joints for better cleaning.
2) A sorting system with a posted protocol to facilitate waste management.
3) Posters recalling the negative impact of the use of greenhouse gases on the environment.
4) Posters to raise awareness of sustainable management

This project comes from an ecological initiative, it was born from awareness and responds to a strategy of eco-responsible practices which will be shared on a larger scale (students, health professionals).

4.3. Recommendations for Eco-responsible Practices [4-8]

1) Regulatory Outfit of the Operating Room
2) Promote the use of single-use clothing to minimize the environmental impact.
3) Conduct a comparative study of different types of operating room outfits to evaluate both comfort and ecological footprint.
4) Prefer the use of reusable caps that can be regularly washed to reduce waste.
5) Avoid the use of overshoes, which may increase hand contamination and contribute to unnecessary waste production.
6) Optimization of Injectable and Effluent Management
7) Prevent the disposal of residual propofol in wastewater due to its high toxicity to soil and groundwater [13].
8) Dispose of drug residues via a treatment chain dedicated to incineration.
9) If opioid residues remain sterile, reuse them in the Post-Anaesthesia Care Unit (PACU).
10) Implement additional wastewater purification processes such as activated carbon.
11) Waste Management
12) Use induction and intubation trays made of cellulose pulp, which offer significant benefits: biodegradable, recyclable, and capable of undergoing new transformation processes after use [15].
13) Waste Sorting
14) Raise staff awareness of waste sorting protocols and display posters in the operating room.
15) Use color-coded bags for each type of waste.
16) Avoid mixing DASRI (infectious waste) and DAOM (household-like waste) to facilitate proper treatment.
17) Respect the filling threshold of waste bags to prevent leaks.
18) Recycling
19) Create dedicated spaces for recycling containers.
20) Recycle metals and plastics after disinfection of biological fluids and storage.
21) Exclude infectious waste from recycling to avoid the spread of contagious diseases.
22) Collaborate with associations and companies to ensure proper recovery of recyclable waste.
23) Incinerate non-recyclable plastics to recover energy.
24) Air Treatment System
25) Maintain optimal temperature and humidity.
26) Regularly monitor filter saturation alarms.
27) Continuously monitor air quality through dedicated

systems.

28) Keep operating rooms closed during surgical procedures to prevent external air contamination.

29) Management of Anaesthetic Gases

a) Nitrous Oxide (N_2O) [16]

1) Phase out existing N_2O infrastructures and prioritize alternative systems.
2) If its use is unavoidable, reduce GHG emissions by lowering fresh gas flow through respirators that provide concentration-based inhalational anaesthesia or by using carbon footprint calculation applications.
3) Restrict N_2O use to essential painful procedures only.
4) Discontinue the use of equimolar mixture cylinders (O_2/N_2O).
5) Prefer intravenous anaesthesia when clinically appropriate.
6) Consider non-pharmacological alternatives such as hypnosis.

b) Halogenated Agents [5]

1) Select the halogenated agent with the lowest greenhouse effect when clinical outcomes are equivalent.
1) Adjust administration based on continuous monitoring of anaesthesia depth.
2) When possible, use Target-Controlled Inhalational Anaesthesia (TCIA), which reduces gas consumption by 2–3 times.

Abbreviations

DASRI	Healthcare Waste with Infectious Risk
DAOM	Waste Assimilated to Household Waste
OPTC	Sharp Cutting Objects
GWP	The global Warming Potential
GHG	Greenhouse Gas
N2O	Nitrous Oxide
TCIA	Target-Controlled Inhalational

Supplementary Material

The supplementary material can be accessed at https://doi.org/10.11648/j.xxxx.2025xxxx.xx

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Author Contributions

All authors conceived and designed the project; AR and DS performed research and prototype; AR, DS, and MB wrote article which comes in part from their PFE project.

Conflicts of Interest

The authors declare no conflicts of interest.

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