ERAS wrong turn: each step costs carbon

Charles Moret, Diana Kabanova

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ERAS WRONG TURN: EACH STEP COSTS CARBON

THÈSE

POUR LE DIPLÔME D'ÉTAT DE DOCTEUR EN MÉDECINE

SPÉCIALITÉ : ANESTHÉSIE - RÉANIMATION

Par M. **Charles MORET**

[Données à caractère personnel]

Et Mlle **Diana KABANOVA**

[Données à caractère personnel]

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LE SERMENT D'HIPPOCRATE

« Au moment d'être admis(e) à exercer la médecine, je promets et je jure d'être fidèle aux lois de l'honneur et de la probité.

Mon premier souci sera de rétablir, de préserver ou de promouvoir la santé dans tous ses éléments, physiques et mentaux, individuels et sociaux.

Je respecterai toutes les personnes, leur autonomie et leur volonté, sans aucune discrimination selon leur état ou leurs convictions. J'interviendrai pour les protéger si elles sont affaiblies, vulnérables ou menacées dans leur intégrité ou leur dignité. Même sous la contrainte, je ne ferai pas usage de mes connaissances contre les lois de l'humanité.

J'informerai les patients des décisions envisagées, de leurs raisons et de leurs conséquences.

Je ne tromperai jamais leur confiance et n'exploiterai pas le pouvoir hérité des circonstances pour forcer les consciences.

Je donnerai mes soins à l'indigent et à quiconque me les demandera. Je ne me laisserai pas influencer par la soif du gain ou la recherche de la gloire.

Admis(e) dans l'intimité des personnes, je tairai les secrets qui me seront confiés. Reçu(e) à l'intérieur des maisons, je respecterai les secrets des foyers et ma conduite ne servira pas à corrompre les mœurs.

Je ferai tout pour soulager les souffrances. Je ne prolongerai pas abusivement les agonies. Je ne provoquerai jamais la mort délibérément.

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RESUME

Objectif

Déterminer l'empreinte carbone de la déviation à un protocole de RAAC après une chirurgie orthopédique lourde du membre inférieur type PTH/PTG ou après une chirurgie colorectale.

Méthode

Notre revue narrative a été construite à partir d'articles référencés dans la base PubMed. Nos recherches ont été basées sur l'impact environnemental d'un protocole de RAAC dans le cadre de la chirurgie colorectale et d'arthroplastie de hanche ou de genou. Chaque point des recommandations françaises et internationales a été étudié. Pour nos recherches, nous avons utilisé les termes "empreinte carbone", "durabilité", "coût énergétique", "empreinte environnementale", "évaluation du cycle de vie" ET un mot clef de chaque sous partie des recommandations RAAC.

Résultats

Durant la période péri-opératoire, les écarts à un protocole de RAAC, dans le cadre d'une chirurgie colorectale ou d'une arthroplastie lourde du membre inférieur, sont très coûteux en équivalent carbone. Le surcoût est estimé à environ 2500 Kg CO2/patient pour une chirurgie colorectale. La part la plus importante se produit durant la période peropératoire. Le surcoût est estimé à environ 1400 Kg CO2/patient dans le cadre d'une chirurgie orthopédique majeure. La part la plus importante se produit durant la période postopératoire. Ceci est un argument supplémentaire à l'application d'un protocole RAAC lorsque celui-ci est recommandé. Il existe des leviers supplémentaires, en dehors des protocoles de RAAC, pour réduire notre empreinte carbone dans notre pratique de l'anesthésie. Celle-ci devra probablement s'adapter à l'urgence du réchauffement climatique.

Conclusion

Le non-respect des recommandations RAAC est très coûteux en termes de carbone. Notre étude montre un argument supplémentaire de la nécessité de mettre en place des parcours RAAC pour le patient, qui devrait être considéré comme la norme éco responsable d'une prise en charge chirurgicale. Des considérations plus globales et organisationnelles sont également à mettre en place pour réduire les émissions de CO2 dans le secteur de la santé.

ABSTRACT

Objective

The aim of this study is to evaluate the carbon footprint of deviations from ERAS pathway applied to a joint replacement surgery and to a colorectal surgery.

Design, settings

This narrative review was designed to collect articles related to the environmental impact of deviations from the ERAS protocol in colorectal and joint replacement surgery. We decided to deal with each point of interest included in recent international and French recommendations. We based our search on the data base PubMed by including relevant references. Our search was oriented on available articles with the terms “carbon footprint”, “sustainability”, “ecology”, “energy cost”, “environmental footprint”, “life cycle assessment” or “climate” AND a keyword from each subpart of the ERAS recommendation.

Results

The non-compliance to the ERAS protocol is costly in terms of carbon footprint in almost all the steps in perioperative time. The balance between benefits and costs in terms of the carbon footprint is strongly positive. The total cost for a colorectal surgery (from the admission to the hospital leave) is about 2 500 KgCO2e/patient, the main part during the intraoperative period. In a joint replacement surgery, the total cost is about 1 400 KgCO2e/patient, the main part during the postoperative period.

Conclusion

Regarding ecological balance, our study shows an additional argument to follow the current ERAS guidelines for the colorectal and joint replacement surgery. Additional actions beyond the ERAS pathway are strongly efficient on carbon savings.

INTRODUCTION

After the Brundtland Commission of 1987, the concept of sustainable development implicates public institutions, and, in particular, the health care system. It represents between 3% to 8% of the annual CO2 production for European countries [1, 2], about 2.7% for China [3] and up to 9.8 % for the USA [2]. French authorities recommend that health care institutions should meet criteria regarding the environment and waste recycling. Since 2010, private and public institutions have to publish their annual carbon emissions [4].

Climate change is one of the major issues of modern times. Anthropogenic pollution is slowly becoming part of our daily considerations, and is challenging our professional habits. Burrel even proposed to extend the concept of the medical ethic “first do not harm” to the environment [5] since it impacts our patients. We may find ourselves in the paradox of providing care with a system that is itself harmful for health [6].

In this context, we aimed to explore the role of an Enhanced Recovery After Surgery (ERAS) pathway in the context of eco sustainability. ERAS refers to evidence-based multidisciplinary care pathways for a surgical specialty [7, 8, 9, 10] that aim to reduce surgical stress response, optimize physiologic function, and facilitate recovery.. The significant clinical benefits for the patient and the cost-effectiveness of ERAS are now well established [8, 9, 11, 12]. We focus our analysis on the environmental aspect with the aim of this article being to evaluate the cumulative carbon impact of deviations from the ERAS pathway applied to colorectal surgery and major joint replacements.

METHODS

This narrative literature review was designed to collect articles related to the environmental impact of deviations from ERAS protocols in colorectal and major joint replacement surgery.

Recent international and French recommendations [7, 8, 9, 10] served as reference documents for the PubMed literature search performed. There was no limit in the publication date, since the ecological cost of healthcare is a relatively recent concern.

Our research was based on available articles including the terms “carbon footprint”, “sustainability”, “ecology”, “energy cost”, “environmental footprint”, “life cycle assessment” or “climate” AND a keyword from each subpart of the ERAS recommendations, for example “chronic disease optimization” or “target thermic control”. In the case of data pertaining to a keyword that was not specific to ERAS, the selection of articles was narrowed by adding a third inter-related term like “anesthesia”, or “operating room”.

The focus was on lower-limb joint replacement surgery and colorectal surgery in adults. When the publications available concerned other types of surgery, it is mentioned in the text.

For each item developed in ERAS recommendations, direct data of carbon cost were searched. If not available, carbon cost was approximated indirectly.

RESULTS

Results are presented for the major orthopedic surgery and colorectal surgery during the pre operative, intraoperative, and postoperative periods.

A. Before Surgery

1. Information and counseling

Communication has a certain cost, related not only to transport and human resources necessary for consultation, but also to internet use.

An important part of the ERAS pathway is the quality of patient information and education, and furthermore, patient adherence to the protocol. One option is to promote targeted information by text messages or email (about 0.3 g of CO2 per email [13]), or even by individualized calls to patients at considerable risk of cancellation. Such patients could be identified during the anesthesiologist's appointment [14]. However, it remains difficult to assess the carbon impact of the quality of patient information and education.

2. Preoperative Fasting

Current preoperative fasting guidelines are not associated with increased anesthesia risk or any modification of length-of-stay (LOS) after surgery but do provide more patient comfort [7]; The carbon balance of this measure is neutral.

3. Preop evaluation and optimization

As a general principle, prevention of any postoperative complications by thorough and evidence-based preoperative evaluation will decrease the costs (financial and environmental) related to a surgical procedure. The ERAS Society Guidelines strongly recommend optimizing medical conditions prior to surgery. However, the cost of invasive investigations is often significant. For example, interventional radiology or coronarography produces 243 000 g CO2e/procedure and 8.28 kg of waste [15]. Each kilogram is equal to 3000 g of C02, thus 24 840 g of C02 secondary to waste must be added to the global cost (including energy, medical devices and human resources) [16].

Diabetes is one of the chronic medical diseases that needs to be diagnosed and treated. The principal perioperative complication of chronic hyperglycemia is susceptibility to infections. The risk is multiplied by 5.29, if the preoperative HbA1c is higher than 7.8% [32, 33, 34]. For each 1% increase in HbA1c above 7%, the risk of infectious complications increases by 40% [35]. Every 1% increase in HbA1c above normal adds 6 480 g C02 per patient, considering the risk for patients without risk factors of 0.72% [35] (Figure 1 and 2, detailed in Appendix 2, 3 and 4).

In terms of substance use and addiction, tobacco cessation is a major challenge because of its role in perioperative morbidity and mortality. The most effective interventions are intensive interventions using a nicotine substitute such as varenicline that start at least 4 weeks before surgery [17, 18, 19, 20]. Stopping cigarette smoking could help avoid 2 millions of complications in the USA per year.

The proportion of surgical patients who smoke is estimated to be 25.9% [21]. Smokers have a two-fold risk of surgical site complications. The risk of pulmonary complications is multiplied by a factor up to 4 [22]. The overall risk of complications for active smokers is between 31% and 45%, and LOS is increased by up to 3 days [21].

According to the French National Authority for Health, the odds ratio (OR) for complications does not return to zero after stopping tobacco. Interventions for smoking cessation implemented 6 to 8 weeks before hip or knee arthroplasty can however, significantly reduce up to 83% [23] the complication rate.

Stopping smoking represents a reduction of carbon costs of 140 063 g of C02 due to lower risk surgical complications.

The carbon cost of implementing various tobacco cessation services can be integrated into the above calculation. This ranges from 8.1 to 16.3 kg CO2e/patient depending on whether it is by text messages or individual counseling (Figure 1 and 2, detailed in Appendix 2, 3 and 4). If one considers the long term savings in carbon emission of a person who stops smoking, their carbon footprint will be reduced by a factor of more than 1:1000 [24].

Of note, the cradle-to-grave life cycle of a cigarette costs 14 g of C02 [25]. This may be a further argument to motivate ecologically-minded smokers.

Excessive alcohol consumption can be identified by the preoperative assessment. A simple questionnaire like AUDIT (Alcohol Use Disorder Test) can be useful. It can predict the perioperative risk of delirium and a risk of decompensation of an asymptomatic cirrhosis or cardiac dysfunction. This latter condition can recover within 4 weeks of alcohol withdrawal [26]. Up to 15% of patients in France have alcohol related problems and 5% will develop a delirium tremens during a hospital stay [27]. These patients are 50% more likely to develop postoperative complications, which rises to 200% if they are heavy drinkers [26]. However, alcohol cessation programs do not appear to decrease LOS, thus LOS is not a factor that can be taken into account when estimating carbon cost [28].

A delirium can occur 24 to 48 hours after stopping or reducing alcohol intake and can be prevented by benzodiazepines, correct hydration and analgesia. A short LOS is less likely to be complicated by a delirium. Once symptoms start, the LOS is likely to be prolonged and can even require an ICU admission. Correct management entails considerable human resources and availability of consumables (oxygen, IV hydration, specific medicaments). The mean carbon cost of an ICU stay is between 178 000 to 624 000 g of C02 per day [29]. The quantity of Propofol needed for general anesthesia (GA) is increased by 30% in chronic alcoholic patients [30]. Its carbon footprint is lower compared to anesthetic gasses, nonetheless the cradle-to-grave carbon cost of Propofol is about 10 g of CO2 for 20mL [31] and it exerts a significant impact on aquatic life. Propofol is not biodegradable in water, thus possessing a high potential for bioaccumulation. It is toxic to aquatic organisms which may result in long-term adverse effects in aquatic environments. Propofol has a Persistence Bioavailability Toxicity (PBT) index of 6 (9 being the most toxic) [32].

4. Patient blood management

PBM consists in combining a number of strategies to avoid transfusion of blood products, including increasing preoperative hemoglobin, reducing blood loss during surgery and respecting current guidelines about restrictive transfusion according to lower hemoglobin (Hb) thresholds.

Anemia is a frequent state in elderly patients and can be responsible for worse outcomes after surgery. Iron administration for a month before a surgery can correct 79% of anemias, raises hemoglobin levels by 1 g/L, reduces by 20-22% the risk of transfusion and the LOS by 24 hours [43, 45]. Patients who benefit from a PBM program are 27% more likely to be discharged directly to their domicile (rather than needing an interim stay in a rehabilitation facility) However the cost of a PBM program is not neutral: a physician visit can cost 66 kg of C02 [42], and up to 3 out-patient admissions may be necessary for the intravenous iron administration and EPO injection. This can entail a relatively high carbon cost: 198 kg of C02 (Figure 1 and 2, detailed in Appendix 2, 3 and 4).

Major orthopedic surgery carries a significant hemorrhagic risk : between 25% to 32% of patients will often require transfusion [46, 47].

Some studies [39, 40] show that 20% to 25% of transfusions are still undertaken above the current recommended Hb thresholds. Lowering transfusion thresholds can save 250kg of CO2 by patient by reducing LOS and saves 325g of CO2 after each major orthopedic surgery [37]. A recent study that quantified the carbon footprint of transfusions showed that 3000 tons of C02 are wasted each year in the UK by transfusing patients above a Hb of 7-8 g/L. A single blood transfusion was responsible for the production of 6,5kg of CO2 [36].

Transfusions are linked to a longer LOS [40, 41], so a restrictive strategy could shorten by 2 days the hospital stay. Additionally, 5.2% of new hospitalizations (75 kg CO2e per ambulance emergency response, 125 kg of C02 per day) could be avoided [41] in this study by applying a restrictive transfusion strategy in spinal surgery. Thus, by respecting the transfusion thresholds guidelines, a practitioner can save 10kg of C02 of LOS per patient receiving IV Iron [42] (Figure 1 and 2, detailed in Appendix 2, 3 and 4).

For colorectal surgery, we consider an average transfusion rate of 50% [60]. The impact of preoperative management of anemia and of the respect to the transfusion threshold is about 387 026 gCO2e/patient (Figure 1 and 2, detailed in Appendix 2, 3 and 4). We decided to extrapolate the findings in spinal surgery [41] about the risk of new hospitalization of 5,2% to the colorectal surgery.

The use of tranexamic acid is now recommended to reduce transfusion requirements during and after joint replacement, which will impact on LOS in this particular surgical context. Since antifibrinolytic drug administration results in one-third less transfusion and shortening of LOS by up to 0,67 LOS [10, 37], failure to give Tranexamic acid accounts for approximately 84 179 g CO2e/patient (Figure 1 and 2, detailed in Appendix 2, 3 and 4). The precise carbon impact for tranexamic acid manufacture is not available, but can be estimated at 340 g CO2e/g per drug dose administration during surgery [31, 38].

5. Prehabilitation

The potential benefits of increasing a patient's capacity to cope with surgical stress by following a prehabilitation program is appealing. In reality, there appears to be little proof of

benefits, especially in terms of LOS. Some studies [44, 48] involving patients with denutrition and sarcopenia undergoing major abdominal surgery have reported a shortened LOS (up to 2 days) with implementation of a preoperative nutrition program. It proved especially effective in diminishing pulmonary morbidity [49]. These programs were not beneficial for surgical specialties other than major abdominal and thoracic surgery, and recommendations are assigned a low grade of evidence. One study found similar results between intensive bike and aerobic activities at home on pulmonary complications [50]. Translated into carbon gain, these interventions represent a maximum of 250 kg C02 per malnourished patient (the carbon footprint of immunonutrition and protein supplementation remains unknown).

Only a few patients could benefit from these costly programs [51]. Proposing specific prehabilitation protocols to all other ERAS patient can be considered as an additional carbon cost without obvious clinical benefit. A physical reeducation program in a specialized center, costly in both electricity and transport, could be replaced by home exercises. If the patient travels 10 km twice a week for a physiotherapy session using a private car or taxi, this will equal 19.2kg of CO2 without a specific benefit for the patient [52] (Figure 1 and 2, detailed in Appendix 2, 3 and 4).

6. Other preoperative issues in colorectal surgery

According to recent recommendations in colorectal surgery [7], two nutritional interventions can each reduce LOS by 24 hours: carbohydrate loading for ASA 1-2 patients and immunonutrients for carcinologic surgery (Figure 1 and 2, detailed in Appendix 2, 3 and 4).

A considerable proportion of patients suffer from anxiety before a surgery (11 to 80%). All the ERAS societies agree that anxiolytic medication is not an effective way to prevent preoperative anxiety. It is also associated with certain side effects, including delayed time to extubation and cognitive recovery [53]. In terms of calculating carbon costs, there is no benefit pharmacological treatment of such anxiety, which it will simply generate more carbon because of medication itself and the longer time to extubation (4 min of extra time in the operating room is equivalent to roughly 160g of CO2) (Appendix 1). The delayed cognitive recovery after a benzodiazepine (e.g. Lorazepam) is difficult to convert into carbon, but if the patient cannot return home after day-case surgery, the subsequent overnight stay will increase carbon costs.

A non-pharmacology approach, such as hypnosis, is an innovative way to reduce anxiety and pain [54, 55], which has shown good success rates for appropriate patients. Patients tend to be less anxious after a 30-minutes hypnosis session, and report less pain when a painful procedure is performed under hypnosis. Nevertheless, even a brief hypnosis session costs resources. Furthermore, hypnosis is not a large-scale solution, but rather an option that can be proposed to patients with high anxiety levels.

In terms of carbon expenditure, hypnosis can reduce the length of a painful procedure [55], but on the other hand, needs 30 minutes of work from a hypnotherapist, so it is unclear if the final carbon balance is worthwhile.

7. Other preoperative issues in orthopedic surgery

There is no perfect score to determine which patients will continue to experience pain and difficulty walking after major orthopedic surgery involving the spine, hip, or knee. If the predicted surgical outcome of a patient is poor consideration should be given to favoring conservative (non-interventional) therapy. A decision not to perform surgery in this context could save a lot of carbon.

Besides the benefit of ERAS for the patient, it is recognized to be useful in reinforcing teamwork. Since most recommendations of ERAS Society are about better organization and anticipation, each team member is a crucial element for success. As health workers are usually well-informed about climate change, adherence to ERAS can be strengthened by the evidence for carbon saving inherent to these protocols

Routine infectious screening before TJA surgery is not recommended. No specific data about such laboratory investigations could be retrieved, but some studies report about 50 to 100 g/CO2e per laboratory test, which is mainly due to the use of reagents [58] (Appendix 1).

B. During surgery

1. Goal directed fluid therapy

The carbon impact of GDFT leads to saving up to 250 000 g CO2e/patient with LOS shortened by 2 days in colorectal surgery [7] (Figure 1 and 2, detailed in Appendix 2, 3 and 4). No such effect is observed in orthopedic surgery [8, 10]. The carbon footprint of sophisticated hemodynamic monitoring was not available in the current literature, and its practice will also depend on professional habits.

2. Corticotherapy

Use of dexamethasone for nausea and vomiting prophylaxis, leads to shortening LOS by 24 hours in colorectal surgery. The same anti-emetic administered to orthopedic surgery patients results in improved analgesia and less nausea but does not influence LOS. No data was found regarding indirect effects of nausea, for example the wastes in each unconsumed meal tray. The carbon impact could be major, as almost 50% of orthopedic patients in 1 study consumed less than one quarter of their first post operative meal [57]: the incidence of nausea was 42%. An 8 mg ampoule of dexamethasone could be approximated to 2.7 g CO2e [31]. Failure to administrate dexamethasone during colorectal surgery costs 125 000 g CO2/patient (Figure 1 and 2, detailed in Appendix 2, 3 and 4).

3. Target thermic control

Failure to maintain normothermia perioperatively increases the risk of SSI in colorectal surgery by 13%/degree of hypothermia, increases LOS by 1-2.6 day [58, 59] and delays return of intestinal transit. In orthopedic surgery, there is a lower bleeding but no change in LOS. The most efficient way to maintain normothermia is forced air warming, so such devices (e.g. Bair Hugger) must be integrated into the carbon costs. Considering that 1kWh equals 74 g of C02, using the warming device set at 38° for 1 hour costs 1 225 g of C02 [61].

The estimation of blood loss for a patient with mild hypothermia is about 54mL. Approximately 50% of patients undergoing colorectal surgery will require transfusion [60] which corresponds to 650 g CO2e/patient [36]. Combined with the increased LOS associated with hypothermia, the carbon cost of non respect of appropriate temperature control is about 330 300 g CO2e/patient (Figure 1 and 2, detailed in Appendix 2, 3 and 4).

4. Prophylactic antibiotic treatment

Antibioprophylaxis reduces the risk of surgical site infection (SSI) by up to 50%, as consistently stated in current guidelines of ERAS [7, 10]. In case of lack of, or inappropriately-timed administration of antibiotics [36], there is a major risk of complications notably need for antibiotic treatment, a prolonged LOS and possible reoperation. We used actual risk of an SSI [36], the rate of unanticipated further surgery during the initial admission and the additional LOS incurred [62, 63, 67] have been taken into account for our

calculations. The total amount of carbon is 60 335 (colorectal surgery) and 194 469 g CO2/patient (TJR) each time antibiotic prophylaxis did not conform to standards. In terms of absolute risk, the rate of non-compliance with prophylactic antibiotics did not influence the carbon emission calculations (51.2% in digestive surgery and 60.8% in orthopedics surgery respectively) (Figure 1 and 2, detailed in Appendix 2, 3 and 4).

5. Choice of surgical technique

In colorectal surgery, there are known advantages to using minimally invasive surgery. The main benefits concern the recovery for the patient, with the impact in terms of LOS being accentuated when an ERAS program is implemented. After a laparoscopy, the LOS is shorter by 2 days compared to a laparotomy, and shorter by 5 days if the ERAS program is followed [7]. The cost of the total CO2e emission necessary for an hour-long laparoscopy [64] is reported to be about 100 000 g CO2e. In addition, the extra cost in terms of energy and wastes of laparoscopic techniques [65] is certain - about 6 500 g CO2. The carbon cost gap by not using laparoscopy could be as high as 518 500 g CO2e/patient (Figure 1 and 2, detailed in Appendix 2, 3 and 4).

There is no clinical effect of the type of incision for TJA in terms of complication or LOS. The fixed cost for joint prosthetic surgery was not included in our final calculations (an estimated 190 000 g CO2e/patient) [66].

6. Type of anesthesia

A “standard anesthetic protocol” is proposed [9] without clear recommendation for either anesthetic gasses or total intravenous anesthesia (TIVA). In order to avoid wasting anesthetic drugs without any adverse effects for the patient, a simple change in clinical practice could achieve a great deal. Using a lower fresh gas flow for halogenated anesthetics or TIVA during GA, a lower oxygen flow during regional anesthesia (RA) and avoiding desflurane and nitrous oxide are some of the eco-responsible strategies to implement. For TJA, these steps could lighten the carbon expenditure by 20-25% [38]. Between 2000-3000 g CO2e/patient can be saved depending on the modality of anesthesia (Figure 1 and 2, detailed in Appendix 2, 3 and 4). The carbon cost of a GA is estimated at 12 kg CO2e and 10 kg CO2e for a RA using European energy sources.

7. Other intraoperative issues in orthopedic surgery

Application of a tourniquet in TKA is not recommended [10]. Tourniquet use is associated with contradictory results for the post-operative pain, carries a major risk of distal deep venous thrombosis (DVT) and shows no significant influence on transfusion requirements or LOS. This last point was not found in a recent review [68], this is the reason why we did not include any impact in terms of carbon related to the use of tourniquet.

C. After surgery

1. Multimodal analgesia

Beside the modality of anesthesia itself, a strategy of multimodal analgesia is an important limiting factor LOS after surgery [7, 8, 9, 10]. For colorectal surgery, up to 88 750 g CO2e can be saved per patient using IV lidocaine for laparoscopy or thoracic epidural analgesia for a laparotomy in addition to perioperative multimodal analgesia. This figure increases up to 125 000 g CO2e saved by a multimodal analgesia in TJA (Figure 1 and 2, detailed in Appendix 2, 3 and 4).

2. Venous thromboembolism prevention

A number of surgical operations are identified as high risk for DVT, including major orthopedic surgery and cancer surgery. Strict DVT prophylaxis is mandatory in these cases. Non-pharmacological prophylaxis consists of wearing compression stockings during and after surgery, and if the patient's condition permits, early mobilization, which can start as early as the PACU. These are virtually carbon free measures, which makes them very attractive (the carbon footprint of compression stockings remains unknown).

For some types of surgeries, patients will also require pharmacological prophylaxis, for example, injectable low molecular weight heparin (LMWH) or non-fractionated heparin in carcinologic surgery. Without prophylaxis, colorectal surgery has a 1.2% incidence of venous thromboembolic disease [7, 69]. For major abdominal cancer surgery, the incidence can rise to 35-45%, with a 3% of cases experiencing fatal pulmonary embolism [70].

Major orthopedic surgery also necessitates thromboprophylaxis which will reduce the risk of DVT by 50% [10]. Three options are possible: injectable heparin, oral prophylaxis using new oral anticoagulants (NOA) or aspirin alone. Despitewidespread availability and evidence of efficacy for NOA, some clinicians are still reluctant to use this oral medication due to fear of hemorrhagic complications. Studies have clearly documented the safety profile of these NOA [69, 71, 72, 73]. Besides the patient comfort afforded by an oral medication compared to daily injections, using the oral route is relatively a green option. Heparin injections often need to be administered by a nurse, and furthermore, regular monitoring of platelet count is obligatory. The carbon footprint of a patient receiving injectable heparin after TJA (35 days for hip prosthesis, and 14 days for knee prosthesis) is as follows : 20km roundtrip by car for the nursing visit plus 2 blood tests per week equals 85.16 kgC02 for the hip and 34.06 kg C02 for the knee (Figure 1 and 2, detailed in Appendix 2, 3 and 4). Some types of surgeries (e.g. knee ligamentoplasty) for low risk patients do not need DVT prophylaxis, or can be managed by aspirin alone. This can help save 24.5 kg of C02 per patient.

3. Drains

Intraoperative gastric decompression for colorectal surgery with a nasogastric tube does not significantly impact LOS significantly. The impact of this intervention on postoperative ileus and bronchopulmonary complications lacks sufficient precision to be converted into carbon cost.

There is a risk of catheter associated urinary tract infection (CAUTI) with a urinary probe left in-situ more than 24 hours after colon surgery. The basal risk of CAUTI is about 5% [74, 75].

This complication entails an increase in LOS of around 11 days according to recent literature [76]. Between 17 to 70% of CAUTIs can be prevented by removal or avoidance of a urinary catheter [74]. In total, the carbon cost of CAUTI related to unjustified prolonged urinary catheterization may reach 47 438 g CO2e/patient.

Orthopedic surgery does not require drains in the postoperative course: inappropriate drainage is estimated to cost 125 000 g CO2e/patient (Figure 1 and 2, detailed in Appendix 2, 3 and 4). There is insufficient data about the carbon footprint of the avoided catheter or urinary probes.

4. Early mobilization and feeding

One of the key points of ERAS is to maintain the patient as close as possible to a normal physiological state. Early mobilization, reduction in bed-rest and early oral refeeding are all strongly promoted to avoid deleterious effects such as muscle loss and insulin resistance. All ERAS guidelines [7, 10] recommend standing, or even better walking on the day of surgery, which can reduce LOS by 1 to 2 days, equivalent to 125-250 kg of CO2.

Early intensive physiotherapy can allow patients to return home 2 to 3.5 days sooner after TJA. The carbon cost of healthcare workers such as physiotherapists is directly linked to the carbon footprint of their mode of transport. If the physiotherapist treats multiple patients in the same day at the hospital, this is more eco-sustainable than if the patients visit the physiotherapist separately. This translates to 437.5 kg of C02 savings because of the work patterns of nurses and physiotherapists.

Physical exercises can be started in the PACU. This high-intensity care-zone offers reassurance for patients by allowing them to re-start oral fluids and mobilize in their bed in total security. The PACU should play a specific role in improving the patient's immediate postoperative care as needed; but should be avoided for those who don't. A shortened PACU stay can be achieved thanks to a better prevention of PONV (each vomiting patient stays at least 20min more in the PACU, consuming plastic and energy) [77], or by avoiding hypnotics when using loco regional anesthesia. The energetic cost of a PACU is hard to determine because of a large variety of different types and sizes of PACU.

Early feeding in colorectal surgery can be linked to a shorter LOS (0.89 day, or 111kg of C02) (Figure 1 and 2, detailed in Appendix 2, 3 and 4).

5. Other postoperative issues in colorectal surgery

One interesting measure could be allowing patients to chew gum as soon as they arrive in the PACU, helping to restore a bowel transit sooner, but the impact on LOS is not certain [7]. Education of patients after colorectal surgery about how to deal with a stoma can be done by stomatherapists. Besides helping patients to cope with this, it helps shorten the hospital stay by 2.5 days [78]. We will not take into account this in our calculation because of the lack of information about the carbon cost of this human resource.

6. Other postoperative issues in orthopedic surgery

Cryotherapy reduces pain, but does not significantly reduce surgical bleeding and does not impact on LOS [10]. Some devices use compressive cryotherapy (e.g. Game ready) but are consuming a lot of energy, by needing ice to be filled with. Probably these devices are more carbon costing than efficient for the patient, but precise carbon costs are difficult to obtain.

7. Post discharge

With the development of same day surgery, surgical and anesthesia teams need to use solid scores in their practice to avoid complications due to patients who would have gone home too early. Besides, useless time spent in the hospital while waiting before heading home can be shortened by using these scores. A 12 item score can allow a patient to leave the PACU without waiting a minimum time thanks to the Aldrete score [79, 80], which helps saving about 24min per patient in the PACU. The carbon cost of PACU is not known, but there is a clear gain of time and this can allow more patients to have surgery. The final carbon price would be divided by more patients, and so it would be lower. Same opportunity with the Chung score with 9 items which allow the patient to leave the hospital after surgery. This is a good way to shorten the LOS without spending any carbon and just completing a physical examination.

How to determine which patient can go home, and who needs a rehabilitation center?

Some functional surgeries benefit patients who can cope with the changes and efforts to give to recover. Another partly subjective assessment has to be done by the surgeon before

performing the surgery. If the patient appears to be skilled to do his rehabilitation at home, it can help save a lot of carbon, by not using a high electricity consuming health center. But if the patient is not well surrounded by friends or family, and cannot find physiotherapists and nurses around his home, the praticien should notice this before planning the surgery, because an unplanned need for a rehab center will delay the rehab and will cost some carbon with useless hospitalization days. There is a need for stronger scores to find out the needs of the patients for rehab after surgery.

While the patient is back home, he can call back to the hospital if he needs to ask a question or if he has an issue like pain or ileus. Sometimes, a nurse is in charge of calling the patients to make sure they make it through the postoperative period. Some studies propose a post discharge text message instead of a telephone call: the results are good with less than 10% of non-response and a high satisfaction.

These calls usually last for 6 min with a rate of response of 87% and cost 342g of C02 [81]. A text message is also less consuming carbon, with a cost of 0.014g C02, and it divides by 4 the need of being called, so it costs 85.5g of C02 per day [13] (Figure 1 and 2, detailed in Appendix 2, 3 and 4).

D. Additional issues : ERAS and optimized hospital stay: time is carbon

Beyond all recommendations about ERAS pathway, one should consider a global vision of the healthcare system. During our research, we found some clues to reduce and prevent waste of carbon by saving time at all steps of a patient's hospital stay.

First of all, a simple prevention of patient cancellation could help reducing carbon costs by just calling the patient the day before the surgery [82, 14, 83, 84] and by collecting some information with an entry checklist by a nurse : cancellations are responsible for 7% of time of OR wasted because of canceled cases [85]. Considering one minute of OR costs 40g of C02, and that a day lasts 600min, 7% of that corresponds to 42min wasted and 1,680g C02 per day (Appendix 1). A D-1 day call could help dividing by 2 or even 4 this waste of time.

A large point to develop is the use of tele counseling. Indeed, the scope 3 of the greenhouse gas emissions characterized by the costs for goods, services and travels, account for a wide part of the total emissions, from 12% [86] to 92% [87], depending on countries. Tele counseling could help to divide by ten the CO2 emission based on European standards of car emissions, with a carbon footprint for a 15min appointment of 450 to 2,100 gCO2e [88, 89].

Lean management is an interesting approach of optimization OR time [90, 91, 92]. By using some Lean programs like Sigma method, by reducing late starts by 5 min could save 200g C02 per patient, and up to 640g with a better OR organization, reducing the whole turn over time by 16min (Appendix 1).

In the same way of calculating carbon by considering that time is carbon, time spent in the PACU gains to be optimized. By using discharge criteria, time in PACU can be shortened by 24%. As we didn't find the carbon footprint of PACU, we cannot calculate these costs. The optimization of the OR schedule so that PACU is not overloaded can lead to 7% of time available for surgery [91], which can be converted into a 42 min and 1680g C02 (Appendix 1).

To go further in our topic, more actions could be used as levers to lower carbon emissions of the healthcare system. The widespread isolation of buildings [42], improved gas scavenging system with halogens [93], generalized water sparing scrubs techniques [94] or sorting domestic and clinical waste in OR [16].

DISCUSSION

Even if the attention for carbon footprint and greener solution within the healthcare system is growing, there is a need for more studies to assess carbon costs of all steps of the patient pathway. The literature is heterogeneous, as previously described [96]. One of the weaknesses of our study are the unknown costs and the approximations of the calculations performed. One classic example of this conundrum is the missing life cycle assessment for pharmaceuticals due to proprietary nature of drug synthesis, thus only limited data is available [95]. Missing data also proved to be a problem in evaluating energy consumption for monitoring device, involved in volemia optimization for example. It is also difficult to include the total repercussions of an event: in particular, the professional and social impacts are hard to translate in terms of carbon and financial costs [97].

Our calculations mainly assume that a patient consumes no more than 125kg of C02 at home per day, and that a day at hospitalization is producing more C02 than a personal dwelling.

It is hard to approximate the distance traveled by a nurse or a physiotherapist, especially in countries with geographical heterogeneity like France or those where long distances may be traveled. To simplify our calculations, the distance to provide care to a patient was approximately 20km round trip. The fact that we chose to include the carbon cost of distance traveled for nursing home visits for LMWH injections could also be criticized, because both LMWH and alternative oral prophylaxis match current recommendations. We included this carbon cost to indicate that an alternative process, namely oral medications, exists.

Furthermore, some professional practices during a GA are very carbon costly, and are mentioned as “standard anesthetic protocol” [9]. One of our objectives would be to define a standard protocol with ecological concerns.

The type of energy source is another factor that can modify carbon costs by a factor from 1 to 8, limiting the external validity of our results. An important factor with a profound impact is the extraction of carbon dioxide for which open access is rarely available from companies. Secondly, there are possible important variations in carbon footprint depending on energy sources available in a particular country. Better transparency is needed about the sources of energy for all healthcare facilities.

Finally, some carbon balances were not quantified in the existing literature, for example, the carbon costs of time spent in the recovery room or staff overtime accrued in managing patient anxiety. We also exclude data with divergent clinical results such as tourniquet usage in orthopedic surgery.

CONCLUSION

The non-compliance to the ERAS protocol is costly in almost all the steps in perioperative time. The balance in terms of carbon footprint is strongly positive. Indeed, the total cost for a colorectal surgery is about 2,500,000 gCO2e/patient, the major part involved is during the intraoperative time. In joint replacement surgery, the total cost is about 1,400,000 gCO2e/patient, the major part involved is during the postoperative time. Results are summarized in Figure 3.

Regarding the ecological balance, our study shows an additional argument to respect the current ERAS guidelines for colorectal and joint replacement surgery. Additional actions beyond ERAS pathway are strongly efficient on carbon savings, and the future of our practices in anesthesia will have to face the global warming emergency.

All these points must be part of a general dynamic, sometimes hard to implement in the hospital where the so-called “environmental numbness” [98] could limit carbon transition. It can correspond to the temporal justification of the medical staff being too busy to pay attention to short term concerns, the presupposed expensiveness of green practices or even the “moral offset” in which working in healthcare is already enough. Transition to a new model of care in which human and environment health is both promoted and rewarded must be considered [99].

FIGURES

Figure 1: Carbon costs of perioperative actions based on ERAS recommendations

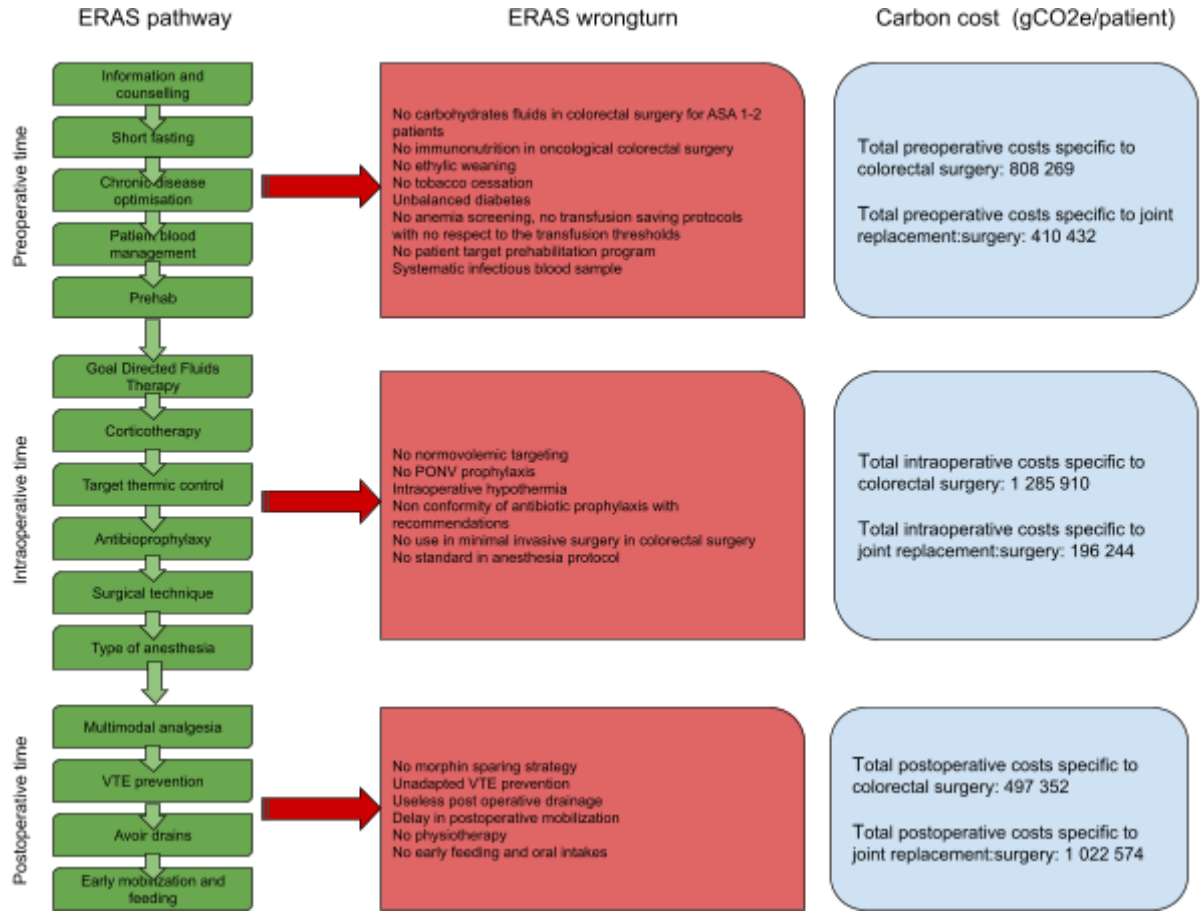
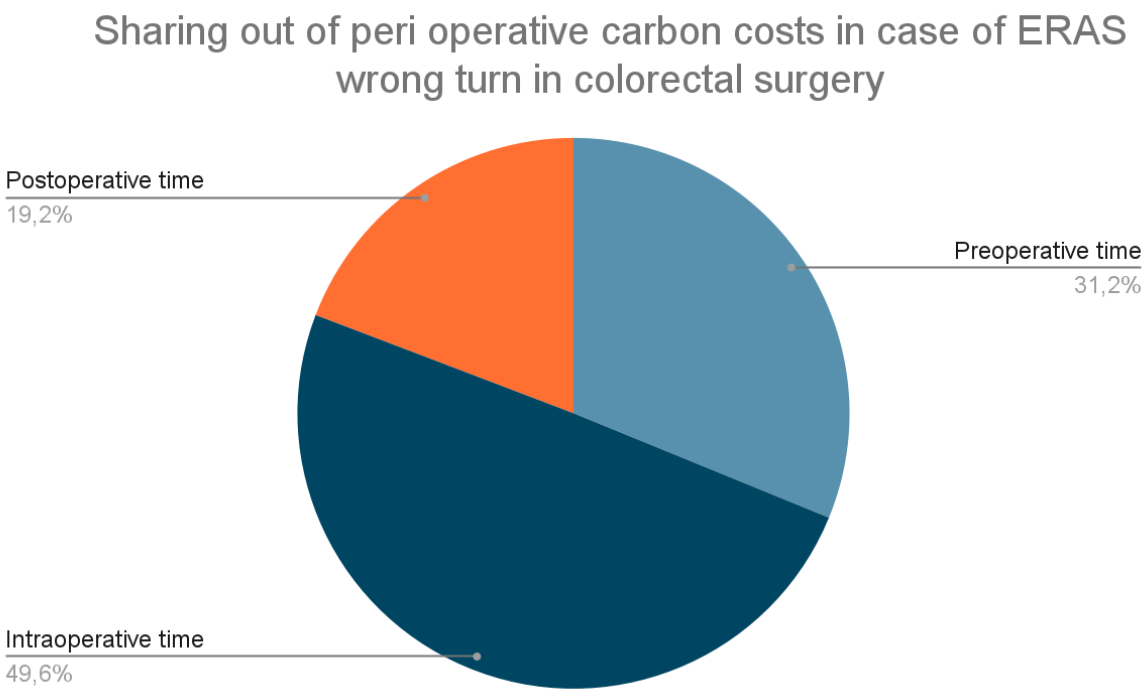
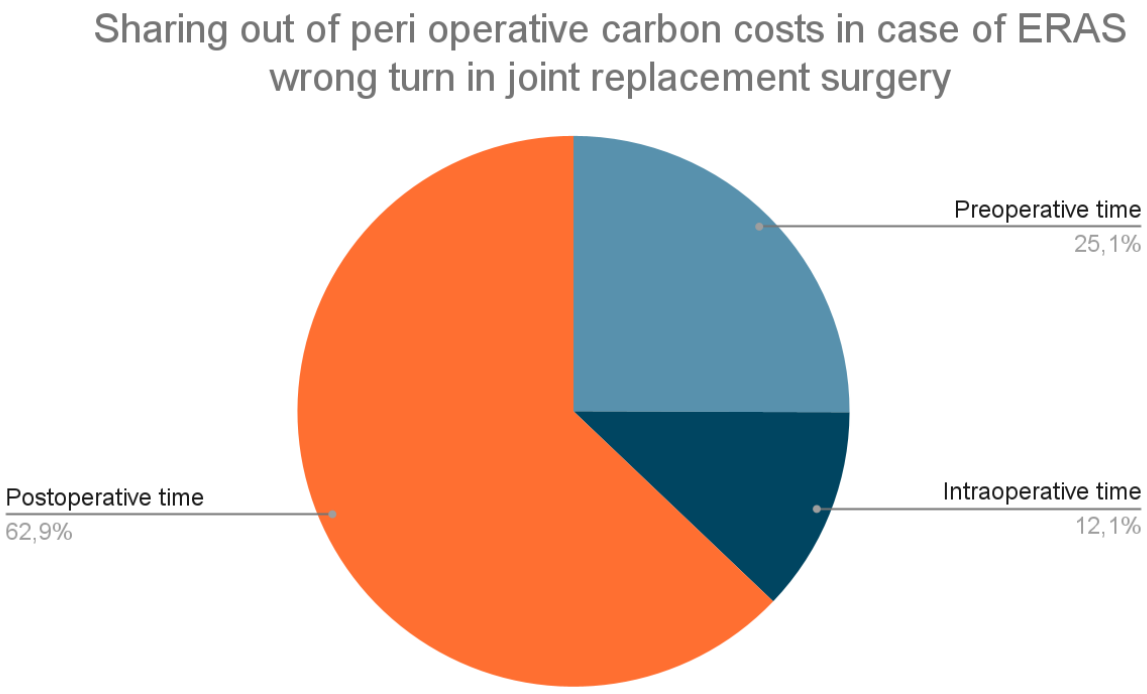


Figure 2: Sharing out of peri operative carbon costs





APPENDIX

Appendix 1 – Details in calculations

- **1min in operating room :**

Calculations from 3 hospitals in USA, UK and Canada

1min in OR = 500,000g CO2e/ 365d / 24h / 60min / 22 OR = 40 g C02e/min

Considering countries with carbon energy: 363 g CO2e/min

We chose countries with the least carbon energy (Canada, Vancouver) to meet with France consumption

Not included : wastes count

Sources: McNeil Lancet 2017

- **Carbon cost per bed day**

125 kg CO2E /bed-day and 76 kg CO2e /outpatient appointment for acute care

Estimation in NHS in England

Source: Tennison, 2021, Lancet

Appendix 2 - Formulas for carbon footprint calculations (time in minutes, carbon costs in grams of CO2e, length of stay in days, amount in grams, distance in kilometers)

Formula A	increase in length of stay x average carbon cost for additional bed-day in hospital
Formula B	wasted time in operating room x average carbon cost for additional minutes in operating room
Formula C	variation in complication rate x absolute risk for general population x average additional length of hospital stay per complication x average carbon cost for additional bed-day in hospital
Formula D	proportion of TJR surgeries transfused x variation in rate of transfusion x average carbon cost per transfusion
Formula D’	proportion of general surgeries transfused x variation in rate of transfusion x average carbon cost per transfusion
Formula E	absolute over risk of unnecessary blood test x average carbon cost per blood test
Formula F	amount of wasted involved x carbon cost per kilograms of wastes incinerated
Formula G	days of treatment x distance traveled by nurses x carbon cost per kilometer by car + number of blood test x carbon cost per CBC

Formula H	reoperative rate x carbon cost per surgery (1 hour long coelioscopy or TJR surgery) + 1 hour long anesthesia

Appendix 3 - Details in calculations for each ERAS wrong turn costs (results in gCO2e/patient)

ERAS points	Formula	Calculation	Results
Tobacco cessation	C	0,83 x 0,45 x 3 x 125 000	140 063
Diabetes balance	C	0,4 x 0.0072 x 18 x 125 000	6 480
Patient blood management ● Iron supply ● Tranexamic acid ● Restrictive transfusion strategy	 D A A D A A D	 0,25 x 0,2 x 6 500 1 x 125 000 0,67 x 125 000 0,2 x 0,33 x 6 500 0,052 x 200 000 2 x 125 000 0,25 x 0,2 x 6 500	470 229 (orthopedic surgery)
Patient blood management ● Iron supply	 D' A	 0,25 x 0,5 x 6 500 1 x 125 000	387 026 (colorectal surgery)

• Restrictive transfusion strategy	A A D’	0,052 x 200 000 2 x 125 000 0,25 x 0,5 x 6 500	
Prehab	A	2 x 125 000	250 000 (colorectal surgery)
Carbohydrates and immunonutrients	A	2 x 125 000	250 000 (colorectal surgery)
Routine infectious blood sample	none		50 - 100 (orthopedic surgery)
Goal directed therapy	A	2 x 125 000	250 000 (colorectal surgery)
Corticotherapy	A	1 x 125 000	125 000 (colorectal surgery)
TTC	C A D’	0,13 x 0,0159 x 18 x 125 000 2,6 x 125 000 0.2 x 0,5 x 6 500	330 300 (colorectal surgery)
Prophylactic antibiotic treatment	C H C	0,5 x 0,0157 x 18 x 125 000 0,381 x (100 000 + 12 000) 0,5 x 0,0135 x 21 x 125 000	60 335 (colorectal surgery)

	H	0,875 x (190 000 + 12 000)	194 469 (orthopedic surgery)
Choice in surgery technic: laparoscopy	A	5 x 125 000	625 000 (colorectal surgery)
Balanced anesthesia	none		2000 - 3000
Multimodal analgesia	A A	0,7 x 125 000 1 x 125 000	88 750 (colorectal surgery) 125 000 (orthopedic surgery)
Venous thromboembolism prevention	G G	35 x 10 x 2 x 120 + 10 x 116 14 x 10 x 2 x 120 + 4 x 116	85 160 (orthopedic surgery - THR) 34 064 (orthopedic surgery - TKR)
Drains	C A	0,69 x 0,05 x 11 x 125 000 1 x 125 000	47 438 (colorectal surgery) 125 000 (orthopedic surgery)
Early mobilization	A	2 x 125 000	250 000 (orthopedic surgery and colorectal surgery)

Physiotherapy	A	3,5 x 125 000	437 500 (orthopedic surgery)
Early feeding	A	0,89 x 125 000	111 250 (colorectal surgery)

Appendix 4 - Details in calculations for costs involved in each ERAS pathway subpart (in gCO2e/patient)

Tobacco cessation services	8 100 to 16 100
Tranexamic acid (gram)	340 (orthopedic surgery)
PBM: Physician visit for iron perfusion and EPO injection	198 000 (orthopedic surgery)
Prehab: physiotherapist transport	19 200 (colorectal surgery)
Laparoscopy	100 000 (per hour) (colorectal surgery)
Wastes and energy consumption difference (Laparoscopy 29 200 vs Laparotomy 22 700)	6 500 (colorectal surgery)
ABSW, active body surface warming (Bair Hugger)	1 225 (per hour) (colorectal surgery)
Post discharge call	86 to 342

LEXICON

- ERAS Enhanced recovery after surgery
- SSI Surgical site infection
- LOS Length of stay
- TJA Total joint arthroplasty

THÈSE SOUTENUE PAR : Charles MORET Et Diana KABANOVA

TITRE :

LA RAAC COMME NORME ÉCO-RESPONSABLE : CHAQUE ÉTAPE COÛTE DU CARBONE

CONCLUSION :

Objectif

Déterminer l'empreinte carbone de la déviation à un protocole de RAAC après une chirurgie orthopédique lourde du membre inférieur type PTH/PTG ou après une chirurgie colorectale.

Méthode

Notre revue narrative a été construite à partir d'articles référencés dans la base PubMed. Nos recherches ont été basées sur l'impact environnemental d'un protocole de RAAC dans le cadre de la chirurgie colorectale et d'arthroplastie de hanche ou de genou. Chaque point des recommandations françaises et internationales a été étudié. Pour nos recherches, nous avons utilisé les termes "empreinte carbone", "durabilité", "coût énergétique", "empreinte environnementale", "évaluation du cycle de vie" ET un mot clef de chaque sous partie des recommandations RAAC.

Résultats

Durant la période péri-opératoire, les écarts à un protocole de RAAC, dans le cadre d'une chirurgie colorectale ou d'une arthroplastie lourde du membre inférieur, sont très coûteux en équivalent carbone. Le surcoût est estimé à environ 2500 KgCO2/patient pour une chirurgie colorectale. La part la plus importante se produit durant la période peropératoire. Le surcoût est estimé à environ 1400 KgCO2/patient dans le cadre d'une chirurgie orthopédique majeure. La part la plus importante se produit durant la période postopératoire. Ceci est un argument supplémentaire à l'application d'un protocole RAAC lorsque celui-ci est recommandé. Il existe des leviers supplémentaires, en dehors des protocoles de RAAC, pour réduire notre empreinte carbone dans notre pratique de l'anesthésie. Celle-ci devra probablement s'adapter à l'urgence du réchauffement climatique.

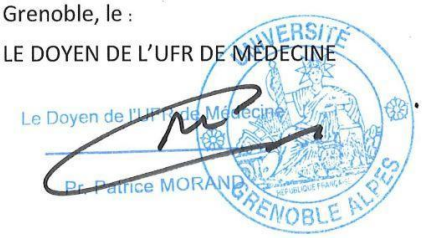
Conclusion

Le non-respect des recommandations RAAC est très coûteux en termes de carbone. Notre étude montre un argument supplémentaire de la nécessité de mettre en place des parcours RAAC pour le patient, qui devrait être considéré comme la norme éco responsable d'une prise en charge chirurgicale. Des considérations plus globales et organisationnelles sont également à mettre en place pour réduire les émissions de CO2 dans le secteur de la santé.

VU ET PERMIS D'IMPRIMER

Grenoble, le :

LE DOYEN DE L'UFR DE MÉDECINE



Pr. Patrice MORAND

LE PRÉSIDENT DU JURY

Pr. Pierre ALBALADEJO

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Le serment d'Hippocrate

Texte revu par l'Ordre des médecins en 2012

« Au moment d'être admis(e) à exercer la médecine, je promets et je jure d'être fidèle aux lois de l'honneur et de la probité.

Mon premier souci sera de rétablir, de préserver ou de promouvoir la santé dans tous ses éléments, physiques et mentaux, individuels et sociaux.

Je respecterai toutes les personnes, leur autonomie et leur volonté, sans aucune discrimination selon leur état ou leurs convictions. J'interviendrai pour les protéger si elles sont affaiblies, vulnérables ou menacées dans leur intégrité ou leur dignité. Même sous la contrainte, je ne ferai pas usage de mes connaissances contre les lois de l'humanité.

J'informerai les patients des décisions envisagées, de leurs raisons et de leurs conséquences.

Je ne tromperai jamais leur confiance et n'exploiterai pas le pouvoir hérité des circonstances pour forcer les consciences.
Je donnerai mes soins à l'indigent et à quiconque me les demandera.
Je ne me laisserai pas influencer par la soif du gain ou la recherche de la gloire.

Admis(e) dans l'intimité des personnes, je tairai les secrets qui me seront confiés. Reçu(e) à l'intérieur des maisons, je respecterai les secrets des foyers et ma conduite ne servira pas à corrompre les mœurs.

Je ferai tout pour soulager les souffrances. Je ne prolongerai pas abusivement les agonies. Je ne provoquerai jamais la mort délibérément.

Je préserverai l'indépendance nécessaire à l'accomplissement de ma mission. Je n'entreprendrai rien qui dépasse mes compétences. Je les entretiendrai et les perfectionnerai pour assurer au mieux les services qui me seront demandés.

J'apporterai mon aide à mes confrères ainsi qu'à leurs familles dans l'adversité. Que les hommes et mes confrères m'accordent leur estime si je suis fidèle à mes promesses ; que je sois déshonoré(e) et méprisé(e) si j'y manque. »

SECTEUR SANTÉ
Université Grenoble Alpes