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Orthopedic Surgery Environmental Sustainability Recommendations: A Literature Review

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Abstract Environmental sustainability is a topic that continues to grow in importance throughout the world as climate change continues to progress. It has been noted that healthcare, in particular, is a great contributor to climate change due to the immense amount of materials utilized and energy consumed on a daily basis. The materials and energy consumption in hospitals, mostly due to the operating room and critical care management of patients, have implications on the environment. The demanding nature of orthopedics inevitably leads to a detrimental amount of waste, leading to unfavorable environmental impacts. These negative outcomes on the environment ultimately lead to public health concerns due to pollutants in both the air and soil. To limit the progression of climate change and decrease public health concerns, it is necessary for waste in orthopedic surgery to be reviewed. Recent studies within orthopedics have explored methods to improve environmental impacts. There have been studies conducted trialing various methods to become more environmentally adept while maintaining quality health care. Outcomes of these studies are reviewed in this paper with the goal to use evidence-based medicine to benefit public health. This literature review carries a more narrow focus as it examines recommendations to decrease waste in orthopedic surgery.

Keywords: *orthopedic surgery, sustainability, waste, conservation, surgical waste, carbon footprint*

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1. Introduction

Environmental sustainability is emerging as a pressing issue in healthcare, particularly in surgical disciplines, where significant opportunities exist to reduce the environmental footprint. Environmental sustainability can be defined as the responsible use of resources leading to outcomes that benefit future generations. The medical field generates substantial waste, which leads to significant environmental challenges. A study exploring the environmental impact of orthopedic surgery discovered that ACL Repairs leave a substantial carbon footprint with carbon dioxide emissions equal to 47 kg [1]. The study noted that these greenhouse gas emissions were equivalent to the emissions of a gas-fueled car traveling 120 miles [1]. As more attention has been brought to this issue, one study reports several medical center quality improvement teams have suggested to utilize the "5 Rs of sustainability: refuse, reduce, reuse, repurpose, and recycle" [2]. Among the various approaches to mitigating this impact, waste reduction, reusing instruments, and recycling seem to be some of the most effective strategies.

Orthopedic surgery is a large contributor to medical waste and energy use. McAleese et al. reports the amount of healthcare waste produced by orthopedic surgery is "60% higher than any other surgical specialty" [3]. Studies indicate that joint arthroplasty procedures generate more medical waste than any other subtype of orthopedic surgery, underscoring the significant environmental burden of this field [4]. While orthopedic arthroplasty procedures cause a vast amount of medical waste, it has been estimated that 33.5% of the currently generated waste could be recycled [5]. Given its prominent role in healthcare, orthopedic surgery has a unique opportunity to adopt sustainable practices and reduce its ecological impact. Smith et al. reiterates the essential nature of

environmental sustainability and economic viability stating, "embedded sustainability efforts improve business performance" [6]. Orthopedic surgery has an opportunity to lead in reducing carbon emissions and costs [6]. Becoming environmentally conscious has beneficial short-term effects due to the reduction in costs for hospitals and outpatient facilities. This review aims to identify the negative effects of orthopedic surgery on the environment, identify recent methods to decrease environmental waste, and recommend evidence-based solutions for a more environmentally conscious future in orthopedic surgery.

2. Environmental Waste in Orthopedic Surgery

Waste Outside of the Operating Room

Climate change has become an increasingly relevant topic globally. The health system is a major contributor, especially considering surgeries like hip and knee arthroplasty. A multidisciplinary approach is necessary to address environmental sustainability in fields like orthopedic surgery as it remains a significant contributor to environmental waste within healthcare [3]. However, contributions are not limited to the operating room. Treatment for orthopedic conditions often requires care outside of the orthopedic surgeon's facility. Traveling to and from appointments by patients, such as outpatient physical therapy or other subspecialists, can contribute to negative environmental impacts [7]. McAleese et al. identified another contributor to environmental waste as the "production, procurement, and transportation of medical equipment," also suggesting the contribution of travel to environmental consequences of healthcare [3]. Furthermore, gases utilized for anesthesia including nitrous oxide and halogenated compounds are potent contributors to greenhouse gases. Building materials for surgery including stainless steel and concrete products contribute to the carbon footprint due to electricity usage and off gassing carbon dioxide in the fabrication process. The utilization of telehealth could help reduce gas emissions due to decreased need for travel.

Unused Materials

There are many areas of waste contribution in orthopedic surgery. While surgical materials used during procedures are a large contributing factor to waste, it is also necessary to consider the role of unused materials that are disposed of every year. As patient specific implants increase, there will be a direct increase in environmental waste due to the excessive use of disposable products. In the United Kingdom, knee arthroplasty surgeries generated over 2.7 million kg of waste annually, with only a small fraction recycled [8]. In the United States, about 4 billion pounds of hospital waste was reported with 70% being from the operating room [7]. In another study, researchers found that the estimated cost of the surgical supplies required oscillated around 2 million dollars per year [9]. The 2 million dollars did not include dropped implants and unused materials, which was estimated to be $634,000 per year at a single institution [9]. This issue extends to other surgical specialties like neurosurgery, where a group of researchers found that in 58 procedures that were investigated, they estimated that $968 is wasted per case, with $242,968 per month, and an outstanding $2.9 million per year in their department [10]. In Canada, arthroplasty surgeries were estimated to produce 341.0 kg of waste, estimating about 6.2 kg of waste per case in a month [4]. Establishing efficiency in materials used for surgeries is a requirement to reduce waste. Instruments and materials that can be used repeatedly typically have less waste generation, such as processing surgical gowns. Another relevant finding was that up to 95% of waste events were caused by human factors, such as opening instruments onto that sterile field that were not needed [11]. Orthopedic surgical waste can also be from opened but unused implants. Training orthopedic surgery residents on the proper use of instruments needed for the cases they are performing may translate to decreased waste of resources.

Disposable Materials

The widespread use of single-use devices and the extensive reliance on surgical instruments necessitating cleaning and sterilization procedures contributes heavily to water and energy consumption. In addition to single-use devices contributing to waste, instrument trays that must be sterilized after each procedure also contribute to environmental impacts. A study trialing optimization of instrument trays attempted to minimize waste through including only necessary instruments for the procedure on the tray [12]. They found that this option offered both environmental and economic benefits for hospitals and clinics [12].

Cost Considerations

Introducing new habits that decrease unnecessary costs may be a key to improving environmental outcomes. Many solutions, such as turning the lights off and altering the ventilation when the operating room is not in use, can have profound effects on energy usage and provide cost saving measures. Smith et al. highlights the intertwined nature of reducing the carbon footprint and driving down costs stating "financial and environmental efforts align" [6]. Costs may be accrued to help operating rooms become more environmentally conscious, which could lead to an overall reduction of annual costs for a hospital. For example, in the article *The Business Case for Greening the OR*, a hospital in Olympia, Washington, was able to "reduce energy use by 25,000 kWH and annual costs by $4,000" by having an occupancy sensor set up in their operating room HVAC system [13]. Further investigation is required to assess the impact of different measures to reduce waste from both the environmental and cost perspectives.

3. Recommendations for Environmental Sustainability in Orthopedic Surgery

Maximizing Surgical Tray Efficiency

While there are no universal guidelines for improving environmental sustainability in orthopedic surgery, recent research has demonstrated positive interventions. One method that can significantly reduce environmental waste is optimizing surgical instrument tray composition. Stockert & Langerman reported that trays often contain a high percentage of unused instruments, with usage rates as low as 13%, which contributes to excess waste in the

operating room [14]. This inefficiency, by leading to unnecessary instruments being discarded or sterilized, underscores the potential for reducing both costs and environmental impacts by aligning tray contents more closely with procedural needs. Lunardini et al. further supported this idea, emphasizing that standardizing tray configurations based on specific procedural requirements minimizes unnecessary variation, reducing both waste and environmental impact [15]. By streamlining tray contents, surgical teams can reduce the use of excess instruments, which directly decreases waste from unused items and their associated packaging materials.

Toor et al. developed a mathematical inventory optimization model using 80 surgical procedures designed to identify underutilized instruments more effectively, demonstrating a direct path to environmental waste reduction [16]. The model works by analyzing usage patterns to predict the instruments most likely to be needed for specific procedures, ensuring only the essential instruments are included in trays. This leads to less waste of unused equipment and the materials required to sterilize them, resulting in cost and labor savings. Importantly, this model achieved a 47% reduction in tray size, translating into substantial environmental benefits, such as fewer instruments being discarded and less sterilization material used [16]. Collectively, these strategies demonstrate how optimizing instrument tray composition and standardizing tray configurations are key to reducing waste in surgical settings.

It is also important to recognize the impact of inventory organization. Vozzola et al. discussed how overstocking and inefficient use of surgical instruments and drapes contribute to unnecessary resource consumption [17]. Their findings indicated that optimizing inventory to align with procedural needs could reduce resource consumption by up to 15%, helping reduce waste while improving hospital resource management [17]. This could implicate a systemic change in surgical supply chain management, emphasizing just-in-time (JIT) inventory to limit excess and prioritize environmental responsibility. Optimizing inventory and introducing protocols based on conservation, highlights the importance of an orthopedic surgeon assessing how many disposable items they truly require.

Reusable Materials

Another method that has shown to significantly reduce environmental waste is transitioning from disposable surgical drapes, gowns, and linens in the operating room to reusable alternatives made from washable materials. Erbay et al. reported that reusable surgical drapes were approximately five to six times more cost-effective than disposable drapes, with an average cost per use for reusable drapes calculated at 57.31 Turkish Lira (TRY) compared to 261.01 TRY for disposable drapes, and 378.24 TRY for two separate companies [18]. Optimizing the use of reusable surgical materials cuts down the need for constant procurement while reducing medical waste and disposal costs.

Studies have shown that the greater the number of cycles a drape is used, the more economical and sustainable it becomes. Baker et al. demonstrated this principle at both Carilion Clinic and UCLA Medical center over their multi-year programs. Carilion Clinic saved $851,984 over the first three years of implementing reusable gowns while eliminating 514,839 pounds of waste during their nine-year program. Similarly, at UCLA medical center, their four year program saved over $1.1 million and diverted 297 tons of waste from landfills [19]. Both programs also highlighted the durability of their reusable linens having lifespans of 75-100 washes, similar to the results Erbay et al. reported [18,19]. This highlights the importance of cycle tracking to show the cost savings and environmental benefits of reusable linen implementation. These studies demonstrate the importance of minimizing single-use items, which has the potential to incentivize hospitals toward more sustainable practices by integrating long-term cost efficiency, and reduced environmental impact into their procurement strategies.

Another study by Chang et al. reported that the transition to reusable linens led to a 30% reduction in waste compared to disposable alternatives [20]. This 1,400 bed study conducted over 100 operating rooms further reinforces the benefits of reusable gowns, drapes, linens in the operating room, suggesting that similar strategies could be applied to other surgical materials to achieve broader sustainability goals [20].

Differences in Surgical Procedures

While the majority of conservation efforts regarding minimizing waste have a clear positive outcome, it is important to explore the differences in resource consumption and environmental influence of the different surgical procedures of choice for a given injury. In a randomized clinical trial, waste produced by five different anterior cruciate ligament reconstruction techniques were compared in terms of various levels of ecotoxicity, land use, resource scarcity, and water consumption [21]. The findings showed that selection of an iliotibial band graft produced 104% less of a carbon footprint than the next most efficient graft [21]. This procedure uses less resources, produced 200% less waste, and had no difference in re-rupture rates in 15-year follow up in comparison to bone-patella-tendon-bone autograft, another commonly used graft [21,22]. This highlights the need for further investigation in the waste generation of different orthopedic procedures and their clinical benefits among other options.

In addition to comparison analysis of waste produced by various procedures, one study by Munn et al. introduced a novel outpatient needle arthroscopic (NA) procedure [23]. These patients met the criteria of atraumatic knee pain without mechanical symptoms, but had chronic soft tissue injury or early degenerative disease of the knee [23]. They evaluated the economic cost, efficiency, and waste measures of this procedure relative to conventional arthroscopy (CA), the gold-standard for treatment of intra-articular knee pathology [23]. The findings of this study showed that outpatient NA is both technically and economically viable [23]. Although it utilizes more single-use equipment than CA, this procedure still produced less than one-third of the non-recyclable waste, required less hospital resources and energy required for resterilization, and saved over £600 per patient for diagnostic procedures [23]. Patients were also shown to recover sooner and required one less hospital visit, opening up an extra space for obligate inpatient procedures for every one patient [23]. This highlights the benefit of comparing orthopedic procedures

targeted towards the same pathology with similar outcomes.

3D Printing

Another tool to help decrease implant waste has been from increasing innovation in 3D printing for orthopedic implants using biomaterials. Traditional materials used in these implants can be broadly classified as either bio-inert or bio-active [24]. While these materials have yielded excellent outcomes over the past few decades, they eventually corrode within the body, leading to increased discomfort and often necessitating a secondary surgery for removal. In contrast, biodegradable materials offer a promising solution by gradually absorbing into the host bone and surrounding tissue. For instance, while stainless steel and titanium implants are known for their high tensile strength in treating fractures, 3D printable magnesium-based alloys, with their resorptive properties, provide enhanced conditions for osseous healing [25]. These materials reduce the need for secondary surgeries, thereby minimizing patient discomfort and associated waste. The circular economic nature of 3D printing can promote sustainability and shortening of the supply chain in manufacturing. Kreieger & Pearce's life cycle analyses comparing traditional manufacturing methods to 3D printing of biomaterials reveal significant reductions in financial and energy costs, as well as lower carbon dioxide emissions [26]. Moreover, the use of recyclable or synthetic materials further amplifies these benefits [26]. In light of these findings, transitioning to 3D printable biodegradable materials, alongside continued research into synthetic polymers for implants, offers a viable solution to the waste generated by traditional orthopedic implants.

Analysis of Orthopedic Procedures

Exploring the environmental impact of comparable orthopedic procedures with similar outcomes could be an untapped reservoir of potential regarding which procedures produce the least amount of waste without compromising patient outcomes. With such a significant reduction in waste (≥104%) with modifying the choice of an ACL reconstruction graft, it is imperative we expand on this type of analysis in hopes of finding similar differences across other procedures, such as graft selection for other ligament reconstructions [22]. Assessing differences in carbon footprints in different orthopedic subspecialties and common orthopedic surgeries could alter the landscape of environmental sustainability in the field of orthopedic surgery.

4. Limitations

This review highlighted recent literature related to environmental sustainability in orthopedic surgery, but there are significant limitations. For example, there are limited studies assessing multiple institutions with interventions to improve environmental sustainability, with many studies focusing on a single institution, which limits generalizability. There are different barriers to implementing surgical changes depending on the hospital location, contracts with suppliers, policies within facilities, and cost incentives. This field of research would benefit from further cost-benefit analysis investigations for the different interventions discussed in this review. There are limited studies focusing on orthopedic surgery recommendations for environmental sustainability with evidence-based guidelines.

5. Conclusion

Environmental sustainability is a topic that continues to grow of importance as climate change progresses. Orthopedic surgery contributes to environmental waste largely due to the nature of the operations and extensive tools required. This literature review assessed various methods that have been demonstrated to minimize environmental waste in orthopedic surgery. Optimizing instrument trays was shown to be an effective technique in diminishing environmental waste. Additionally, transitioning from disposable surgical gowns, drapes, and linens to reusable options was demonstrated as being effective at minimizing environmental waste in the operating room. Many interventions are outside of an individual orthopedic surgeon's control, such as whether the hospital uses reusable surgical gowns. However, some interventions, such as optimizing instrument trays for an individual orthopedic surgeon, may be feasible to implement without significant institution barriers. There are possible limitations to developing a more environmentally conscious form of practice due to financial costs to the surgeon and institution. Capitalizing on advancements in technology also allows orthopedic surgery to decrease its negative impacts on the environment, such as with the use of biodegradable orthopedic implants. There remains limitations in understanding how interventions to improve environmental sustainability in orthopedic surgery may impact different types of institutions, such as community versus academic hospital settings. There also remains limitations in understanding cost-benefit analysis for different interventions along with the logistical feasibility of implementing them. This review highlights environmentally sustainable interventions for orthopedic surgical practices, but further investigation is necessary, especially within different subspecialties within orthopedic surgery.

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