Journal of Carcinogenesis
Covering Genesis to Therapeutics

Journal of Carcinogenesis, ISSN: 1477-3163
2025; Vol 24: Issue 4s, https://carcinogenesis.com/

Quantitative and Qualitative Analysis of Surgical Waste in TKA and THA at Kolar Tertiary Care Center : Its Effect on Environment

Dr. Rahul Thapa[1], Dr. Vinod Kumar K[2], Dr. Arun Kumaar S P[3]

[1]junior Resident, Dept. Of Orthopaedics, Sri Devaraj Urs Medical College, Kolar, India

Email ID: rahulthapa@icloud.com

[2]Dept. Of Orthopaedics, Associate Professor, Sri Devaraj Urs Medical College, Kolar, India

Email ID: vinodkgowda@gmail.com

[3]Assistant Professor, Dept. Of Orthopaedics, Sri Devaraj Urs Medical College, Kolar, India

***Corresponding Author:**

Dr. Arun Kumaar S P

Email.ID: drarunkumaar1394@gmail.com

ABSTRACT

Background and Objective: Total knee arthroplasty (TKA) and total hip arthroplasty (THA) procedures produce considerable amounts of surgical waste, which have notable environmental consequences. This prospective observational study was conducted to quantitatively and qualitatively analyze the surgical waste generated during TKA and THA surgeries at a tertiary care center in Kolar. The study focused on evaluating the composition of the waste, the practices of waste segregation, and the associated environmental impact.

Methods: This prospective observational study examined surgical waste generated from primary arthroplasty procedures conducted at R L Jalappa Hospital and Research Center, Kolar, between March 2024 and January 2025. A total of twenty primary arthroplasty procedures, comprising ten total knee arthroplasties (TKA) and ten total hip arthroplasties (THA), were evaluated for waste generation and composition. Data collection involved the prospective quantification of waste by category—general, hazardous, recyclable, sharps, and linens—in accordance with the Biomedical Waste Management Rules 2016. Additionally, waste composition analysis and calculation of environmental impact, including carbon emissions, were performed. A qualitative assessment of staff practices and awareness regarding waste segregation was also conducted. Statistical analyses were carried out using SPSS version 22, with significance defined at $p < 0.05$.

Results: The average total waste generated per procedure was 48.3 ±7.2 kg for total knee arthroplasty (TKA) and 42.1 ± 5.8 kg for total hip arthroplasty (THA), with the difference reaching statistical significance ($p = 0.048$). Waste composition was distributed as follows: hazardous waste constituted 42% (20.3 kg for TKA, 17.6 kg for THA), general waste accounted for 35% (16.9 kg for TKA, 14.7 kg for THA), and recyclable materials comprised 23% (11.1 kg for TKA, 9.8 kg for THA). Single-use items represented 78% of the total waste generated. The carbon emissions associated with waste were 82.4 ± 12.3 kg CO_2-equivalent for TKA and 71.6 ±9.7 kg CO_2-equivalent for THA. Compliance with appropriate waste segregation protocols was 75%, whereas only 30% of staff exhibited adequate awareness of the environmental impact. Economic analysis revealed that waste management costs were ₹11,850 per TKA and ₹10,420 per THA.

Conclusions: Total knee arthroplasty (TKA) and total hip arthroplasty (THA) procedures generate substantial surgical waste, thereby contributing significantly to environmental impact. The prevalent reliance on single-use items, coupled with insufficient recycling practices, underscores opportunities for waste reduction. Implementing improved waste segregation protocols, transitioning to reusable alternatives where feasible, and delivering comprehensive staff training could potentially decrease waste production by 30–40% without compromising patient safety.

Keywords: *surgical waste, total knee arthroplasty, total hip arthroplasty, waste management, environmental impact, biomedical waste, Kolar, tertiary care*

How to Cite: Anusha PK, (2025) Quantitative and Qualitative Analysis of Surgical Waste in TKA and THA at Kolar Tertiary Care Center : Its Effect on Environment, *Journal of Carcinogenesis*, *Vol.24, No.4s*, 847-856

1. INTRODUCTION

Surgical procedures generate substantial amounts of waste, presenting significant challenges for healthcare institutions and environmental management systems. Within orthopedic surgery, total knee arthroplasty (TKA) and total hip arthroplasty (THA) are high-volume operations that produce considerable waste due to the extensive use of disposable materials, packaging, and specialized equipment [1,2]. A comprehensive understanding of the volume and composition of surgical waste is crucial for devising effective waste management strategies and mitigating environmental impact.

Healthcare systems worldwide contribute approximately 4.4% of total global greenhouse gas emissions. Within hospitals, operating rooms (ORs) are among the most resource-intensive areas, accounting for up to 30% of total hospital waste and between 20% and 33% of energy consumption [3,4]. Total knee arthroplasty (TKA) and total hip arthroplasty (THA) procedures encompass multiple stages—pre-operative preparation, surgical intervention, and post-operative care—each generating distinct waste streams. A single joint replacement surgery is estimated to produce between 20 and 50 kilograms of waste and to result in 40 to 85 kilograms of CO_2-equivalent emissions [5,6].

The Biomedical Waste Management Rules of 2016 in India require the appropriate segregation, treatment, and disposal of healthcare waste [7]. Nevertheless, implementation is often inconsistent, especially in surgical environments where time constraints and infection control priorities frequently take precedence over environmental concerns. The extensive use of single-use disposable instruments and drapes, initially introduced to ensure sterility and infection control, has contributed to increasing volumes of waste [8]. The COVID-19 pandemic has further intensified this trend toward disposable items, despite limited evidence supporting their superiority in infection control compared to reusable alternatives [9].

In India, the number of joint replacement surgeries has increased by more than 200% over the past decade, with projections indicating continued exponential growth [10]. Studies conducted in high-income countries have reported that each joint replacement surgery generates between 20 and 50 kilograms of waste [11,12]. However, there is limited data available from Indian healthcare settings, where resource limitations, differing surgical practices, and variable waste management infrastructures may lead to distinct waste generation profiles.

This prospective observational study was conducted from March 2024 to January 2025 to quantify and characterize the surgical waste generated during total knee arthroplasty (TKA) and total hip arthroplasty (THA) procedures at a tertiary care center in Kolar, Karnataka. The primary objectives were to measure the total amount of waste produced, analyze its composition by category, assess existing segregation practices, and evaluate the environmental impact of surgical waste. Secondary objectives included identifying opportunities for waste reduction and assessing the economic implications of current waste management practices.

2. MATERIALS AND METHODS

Study Design and Setting

This prospective observational study was conducted at R L Jalappa Hospital and Research Center, Kolar, Karnataka, India, from March 2024 to January 2025. The study protocol was approved by the Institutional Review Board and Ethics Committee. Written informed consent was obtained from all patients and participating staff members.

Study Population

Inclusion Criteria:

- Adults (≥40 years) undergoing elective primary TKA or THA for degenerative joint disease
- Procedures performed by the regular arthroplasty team
- Complete waste data collection possible

Exclusion Criteria:

- Revision arthroplasty procedures
- Bilateral procedures
- Emergency surgeries
- Complex primary cases requiring additional instrumentation

Sample Size

Sample size was calculated prior to study initiation based on previous studies showing mean waste generation of 45±10 kg for joint replacement surgeries. With expected difference of 5 kg between TKA and THA, the required sample size was calculated as 10 procedures per group (α=0.05, β=0.20, power=80%).

Data Collection Protocol

Data was collected prospectively for each procedure during the study period using the following protocol:

Waste Quantification:

1. **Pre-operative phase:** All packaging materials, preparation items
2. **Intra-operative phase:** Surgical drapes, gowns, disposable instruments, suction canisters, irrigation fluids containers
3. **Post-operative phase:** Dressing materials, cleanup items

Each waste category was collected in color-coded bins as per Biomedical Waste Management Rules 2016:

- **Yellow bins:** Infectious/pathological waste
- **Red bins:** Contaminated recyclable waste
- **White/Blue bins:** Sharps and metallic waste
- **Black bins:** General non-hazardous waste

Waste was weighed immediately post-procedure using calibrated digital scales (accuracy ±0.01 kg).

Waste Composition Analysis:

Detailed inventory of items in each waste category including:

- Material type (plastic, paper, textile, metal)
- Single-use vs potentially reusable items
- Recyclability based on manufacturer specifications
- Contamination status

Environmental Impact Assessment:

Carbon footprint calculated using:

- Emission factors for different waste treatment methods (incineration: 0.9 kg CO_2/kg, landfill: 0.47 kg CO_2/kg)
- Energy consumption for waste processing
- Transportation emissions

Qualitative Assessment:

Structured observations and surveys assessed:

- Staff compliance with segregation protocols
- Knowledge of waste categories
- Awareness of environmental impact
- Barriers to proper waste management

Statistical Analysis

This prospective observational study was conducted at R L Jalappa Hospital and Research Center, Kolar, Karnataka, India, from March 2024 to January 2025. The study protocol received approval from the Institutional Review Board and Ethics Committee. Written informed consent was obtained from all patients and participating staff members. Data analysis was performed using SPSS version 22.0. Descriptive statistics included means, standard deviations, and percentages. Comparisons between total knee arthroplasty (TKA) and total hip arthroplasty (THA) were conducted using independent t-tests for continuous variables and chi-square tests for categorical variables. Correlation analysis was employed to examine the relationships between procedure duration and waste generation. Statistical significance was defined as $p < 0.05$.

3. RESULTS

Baseline Characteristics

Twenty primary arthroplasty procedures, comprising 10 total knee arthroplasties (TKA) and 10 total hip arthroplasties (THA), were analyzed during the study period from March 2024 to January 2025. Patient demographics and procedural characteristics are presented in Table 1.

Table 1: Patient Demographics and Procedure Characteristics

Parameter	TKA (n=10)	THA (n=10)	p-value
Age (years), mean ± SD	68.4 ± 7.2	65.2 ± 8.6	0.382
Female, n (%)	7 (70%)	4 (40%)	0.178
BMI (kg/m²), mean ± SD	28.3 ± 3.4	26.7 ± 3.1	0.291
Surgery duration (min)	112.5 ± 18.3	98.4 ± 15.7	0.078
Blood loss (ml)	285 ± 75	320 ± 85	0.342

Quantitative Waste Analysis

The total waste generated was significantly greater in total knee arthroplasty (TKA) procedures compared to total hip arthroplasty (THA) procedures (see Table 2).

Table 2: Total Waste Generation by Procedure Type

Waste Category	TKA (kg)	THA (kg)	p-value
Hazardous waste (Yellow)	20.3 ± 3.8	17.6 ± 3.1	0.098
General waste (Black)	16.9 ± 3.2	14.7 ± 2.8	0.116
Recyclable waste (Red/Blue)	11.1 ± 2.4	9.8 ± 2.1	0.214
Total	**48.3 ± 7.2**	**42.1 ± 5.8**	**0.048**

Waste Composition Analysis

A detailed analysis of the waste composition revealed a predominance of single-use items (see Table 3).

Table 3: Waste Composition by Material Type

Material Type	Weight (kg)	Percentage	Items Examples
Plastics	22.4 ± 4.2	46.4%	Drapes, packaging, syringes
Textiles	11.8 ± 2.3	24.4%	Gowns, gauze, cotton
Paper/Cardboard	8.2 ± 1.8	17.0%	Packaging, sterile wraps
Metals	3.4 ± 0.9	7.0%	Instrument packaging, blades
Glass	1.2 ± 0.4	2.5%	Medicine vials
Others	1.3 ± 0.5	2.7%	Rubber, foam

Single-use vs Reusable Items Analysis

Table 4 presents an analysis of single-use items that could potentially be replaced.

Table 4: Single-use Items and Reusable Alternatives

Item Category	Current Practice	Weight per Case (kg)	Reusable Alternative Available
Surgical drapes	100% disposable	4.8 ± 0.6	Yes
Surgical gowns	100% disposable	3.2 ± 0.4	Yes
Instrument wraps	100% disposable	2.1 ± 0.3	Yes (containers)
Suction canisters	100% disposable	1.8 ± 0.3	Yes
Patient positioning	100% disposable	1.5 ± 0.2	Yes
Cautery accessories	100% disposable	0.8 ± 0.1	Partial

Waste Segregation Compliance

The observational assessment of waste segregation practices demonstrated varying levels of compliance, as detailed in Table 5.

Segregation Parameter	Compliance Rate	Common Errors
Correct bin usage	75%	Mixing general and hazardous waste
Proper labeling	82%	Incomplete waste tags
Timely disposal	68%	Delays in waste removal
Sharp safety	95%	Occasional overfilling
Documentation	70%	Incomplete waste registers

Table 5 : Waste Segregation Compliance

Assessment Environmental Impact

The environmental impact of surgical waste is detailed in Table 6.

Table 6: Environmental Impact of Surgical Waste

Impact Parameter	TKA	THA	Calculation Method
Total CO_2 emissions (kg)	82.4 ± 12.3	71.6 ± 9.7	LCA methodology
From incineration (kg)	18.3 ± 3.4	15.8 ± 2.9	0.9 kg CO_2/kg waste
From landfill (kg)	7.9 ± 1.5	6.9 ± 1.3	0.47 kg CO_2/kg waste

From production (kg)	56.2 ± 8.4	48.9 ± 7.3	Cradle-to-gate emissions
Water footprint (L)	285 ± 42	248 ± 38	Direct measurement

Economic Analysis

The cost implications associated with current waste management practices are presented in Table 7.

Table 7: Economic Analysis of Waste Management

Cost Component	TKA (₹)	THA (₹)	Annual Cost (200 procedures)
Single-use items	8,450 ± 980	7,320 ± 850	15,54,000
Waste disposal	1,850 ± 220	1,610 ± 190	2,92,000
Segregation supplies	680 ± 85	680 ± 85	1,36,000
Labor costs	870 ± 110	810 ± 95	1,68,000
Total	**11,850 ± 1,425**	**10,420 ± 1,180**	**21,50,000**

Staff Awareness and Practices

A survey conducted among 20 members of the surgical team identified several knowledge gaps (see Table 8).

Table 8: Staff Awareness Assessment

Awareness Domain	Score (%)	Staff Category Most Aware	Training Received
Waste categories	45 ± 12	Nurses	30%
Environmental impact	30 ± 8	Surgeons	15%
Segregation protocols	72 ± 15	OR technicians	65%
Cost implications	25 ± 7	Administrators	20%
Waste reduction strategies	18 ± 5	None	5%

Correlation Analysis

Significant correlations were observed among various parameters, as detailed in Table 9.

Table 9: Correlation Analysis of Waste Parameters

Variable 1	Variable 2	Correlation (r)	p-value
Surgery duration	Total waste	0.68	<0.001
Total waste	CO_2 emissions	0.74	<0.001
Single-use items	Total cost	0.81	<0.001

Staff awareness	Segregation compliance	0.52	0.021

4. DISCUSSION

This prospective observational study, carried out between March 2024 and January 2025, provides comprehensive data on the generation of surgical waste during total knee arthroplasty (TKA) and total hip arthroplasty (THA) procedures at a tertiary care center.

center in Kolar reports significant waste generation, with averages of 48.3 kg for total knee arthroplasty (TKA) and 42.1 kg for total hip arthroplasty (THA), highlighting the considerable environmental impact associated with these common orthopedic procedures.

Waste Quantity and Composition

The total waste generation observed in this study exceeds the amounts reported by European centers (30–35 kg) but is comparable to figures from other Asian facilities [13,14]. The 14.7% increase in waste associated with total knee arthroplasty (TKA) compared to total hip arthroplasty (THA) likely reflects the use of additional instrumentation, tourniquets, and longer operative durations. The predominance of hazardous waste (42%) presents significant challenges for disposal and environmental management, as such waste necessitates energy-intensive treatment methods, including incineration [15].

Plastic materials accounted for 46.4% of the total waste, predominantly originating from single-use drapes, packaging, and disposable instruments. This observation corresponds with global trends indicating increased utilization of disposable items, a phenomenon intensified by infection control measures implemented during the COVID-19 pandemic [16]. Nevertheless, current evidence supporting the superior efficacy of disposable products over reusable ones in infection prevention is limited [17]. The exclusive use of disposable drapes and gowns at our facility, despite the availability of reusable alternatives, presents a substantial opportunity for waste reduction.

Environmental Impact

The calculated carbon emissions of 82.4 kg CO_2-equivalent for total knee arthroplasty (TKA) and 71.6 kg for total hip arthroplasty (THA) represent a considerable environmental burden. When extrapolated to the approximately 500,000 joint replacement procedures performed annually in India, these emissions correspond to over 38,500 tons of CO_2 released solely from surgical waste [18]. The majority of these emissions (68%) originate from the production and transportation of single-use items rather than from waste disposal processes, indicating that source reduction through the adoption of reusable materials could substantially mitigate the environmental impact [19].

Previous research has demonstrated that transitioning to reusable surgical textiles can reduce carbon emissions by up to 60% while maintaining sterility standards [20]. Our analysis suggests that the adoption of reusable drapes and gowns alone could eliminate approximately 8 kg of waste per procedure, corresponding to a 17% reduction in total waste generation.

Segregation Practices and Compliance

The 75% compliance rate with proper segregation protocols suggests that there is considerable potential for improvement. Improper segregation not only elevates disposal costs but also hinders recycling efforts and exacerbates environmental risks. Similar challenges have been documented in other developing countries, where compliance rates range from 60% to 80% [21]. The observed mixing of general and hazardous waste in 25% of cases leads to the unnecessary treatment of non-hazardous materials as infectious waste, thereby increasing both financial costs and environmental impact.

Effective waste segregation has been shown to reduce the volume of hazardous waste by 20-30%, as evidenced by quality improvement initiatives implemented at other tertiary care centers [22]. Our finding that only 30% of staff possess adequate awareness of the environmental impact indicates that targeted educational programs could substantially enhance segregation practices.

Economic Implications

The economic analysis indicates that waste-related costs amount to ₹11,850 per total knee arthroplasty (TKA) and ₹10,420 per total hip arthroplasty (THA), with single-use items accounting for 71% of these expenses. The adoption of reusable alternatives for drapes and gowns could result in savings of ₹6,000 to ₹7,000 per procedure. For a hospital conducting 200 joint replacement surgeries annually, this translates to potential savings of ₹12 to ₹14 lakhs. International studies have demonstrated that the initial investment in reusable systems typically achieves a return within 12 to 18 months [23].

The significant correlation between waste generation and cost ($r = 0.81$, $p < 0.001$) suggests that waste reduction initiatives can concurrently yield environmental and economic advantages. This dual benefit is especially pertinent in resource-limited healthcare systems, where cost-effectiveness is a primary factor influencing decision-making [24].

Opportunities for Waste Reduction

Our analysis identifies several evidence-based interventions for waste reduction:

1. **Immediate interventions:**

- Improved segregation training could reduce hazardous waste by 20%
- Optimizing packaging and inventory management
- Implementing recycling programs for uncontaminated plastics

2. **Medium-term strategies:**

- Transitioning to reusable drapes and gowns (potential 8 kg reduction per case)
- Reusable instrument containers replacing disposable wraps
- Reprocessing of single-use devices where approved

3. **Long-term initiatives:**

- Collaboration with manufacturers for reduced packaging
- Preference for reusable instruments over disposables
- Circular economy approaches with take-back programs

Studies conducted in high-income countries have successfully implemented these interventions, achieving a 30–50% reduction in waste without compromising patient safety [25, 26]. The key to successful implementation involves addressing staff concerns regarding infection control through education and demonstrating that reusable alternatives provide equivalent safety outcomes.

5. LIMITATIONS

This study presents several limitations. The single-center design restricts the generalizability of the findings to other healthcare settings. Although the sample size was sufficient to address the primary objectives, it may not encompass the full range of variability in surgical practices. The 11-month duration of the study may not adequately capture seasonal fluctuations in surgical volume or practices. Additionally, long-term clinical outcomes following potential waste reduction interventions were not evaluated. The environmental impact assessments were based on published emission factors, which may not accurately represent local conditions.

6. FUTURE DIRECTIONS

Building upon this baseline data, future research should focus on evaluating the safety and cost-effectiveness of specific waste reduction interventions through controlled trials. Conducting multi-center studies across diverse healthcare settings in India could facilitate the establishment of national benchmarks for surgical waste. Furthermore, the development of India-specific guidelines for sustainable surgery, which incorporate waste reduction targets into hospital accreditation standards, would promote systematic improvements. Long-term follow-up studies are also necessary to assess the impact of waste reduction interventions on both environmental and clinical outcomes.

7. CONCLUSIONS

This prospective observational study, conducted from March 2024 to January 2025, reveals that total knee arthroplasty (TKA) and total hip arthroplasty (THA) procedures produce considerable surgical waste, resulting in notable environmental and economic consequences. The predominance of single-use items, accounting for 78% of the waste, combined with suboptimal waste segregation practices—demonstrated by a 75% compliance rate—and limited staff awareness regarding environmental impacts (30%), highlight significant opportunities for enhancement.

The implementation of targeted interventions, including the transition to reusable alternatives where feasible, enhanced segregation protocols, and comprehensive staff education, has the potential to reduce waste generation by 30–40% while maintaining patient safety. These reductions could result in annual savings of ₹12–14 lakhs for a typical tertiary care center and decrease carbon emissions by approximately 15 tons of CO_2 equivalent.

The findings underscore the necessity for systematic reforms in surgical practice, encompassing the revision of procurement policies to prioritize reusable alternatives, the incorporation of waste metrics into quality indicators, and the formulation of specialty-specific guidelines for waste reduction. Given the increasing volume of surgical procedures, addressing surgical waste is imperative not only for environmental sustainability but also for enhancing healthcare system efficiency and cost-effectiveness.

8. ADDITIONAL INFORMATION

Disclosures

Human subjects: The study protocol was approved by the Institutional Ethics Committee of R L Jalappa Hospital and Research Center . Written informed consent was obtained from all participants.

Animal subjects: All authors have confirmed that this study did not involve animal subjects or tissue.

Conflicts of interest: All authors declare no conflicts of interest.

Financial relationships: All authors declare no financial relationships with any organizations that might have an interest in the submitted work.

9. ACKNOWLEDGEMENTS

The authors thank the surgical team members and waste management staff of R L Jalappa Hospital and Research Center for their cooperation in data collection.

REFERENCES

[1] MacNeill AJ, Lillywhite R, Brown CJ. The impact of surgery on global climate: a carbon footprinting study of operating theatres in three health systems. Lancet Planet Health. 2017;1:e381-e388. 10.1016/S2542-5196(17)30162-6

[2] Rizan C, Steinbach I, Nicholson R, Lillywhite R, Reed M, Bhutta MF. The carbon footprint of surgical operations: a systematic review. Ann Surg. 2020;272:986-995. 10.1097/SLA.0000000000003951

[3] Health Care Without Harm. Health care's climate footprint. 2019. Available from: https://noharm-global.org/climateFootprintReport

[4] Morris DS, Wright T, Somner JEA, Connor A. The carbon footprint of cataract surgery. Eye (Lond). 2013;27:495-501. 10.1038/eye.2013.9

[5] Leiden A, Cerdas F, Noriega D, Beyerlein J, Herrmann C. Life cycle assessment of a disposable and a reusable surgery instrument set for spinal fusion surgeries. Resour Conserv Recycl. 2020;156:104704. 10.1016/j.resconrec.2020.104704

[6] Phoon A, Lim A, Yuen A, Zhang D, Yan Pincus J, Hey HWD. Environmental sustainability in orthopaedic surgery: a scoping review. Bone Jt Open. 2022;3:628-640. 10.1302/2633- 1462.38.BJO-2022-0067.R1

[7] Central Pollution Control Board. Guidelines for Management of Healthcare Waste as per Biomedical Waste Management Rules, 2016. Ministry of Environment, Forest and Climate Change, Government of India, New Delhi; 2022.

[8] Rizan C, Mortimer F, Stancliffe R, Bhutta MF. Plastics in healthcare: time for a re-evaluation. J R Soc Med. 2020;113:49-53. 10.1177/0141076819890554

[9] Sharma HB, Vanapalli KR, Cheela VS, et al. Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic. Resour Conserv Recycl. 2020;162:105052. 10.1016/j.resconrec.2020.105052

[10] Pachore JA, Vaidya SV, Thakkar CJ, Bhalodia HKP, Wakankar HM. ISHKS joint registry: a preliminary report. Indian J Orthop. 2013;47:505-509. doi:10.4103/0019-5413.185604

[11] Thiel CL, Eckelman M, Guido R, et al. Environmental impacts of surgical procedures: life cycle assessment of hysterectomy in the US. Environ Sci Technol. 2015;49:1779-1786. 10.1021/es504719g

[12] Drew J, Christie SD, Tyedmers P, Smith-Forrester J, Rainham D. Operating in a climate crisis: a state-of-the-science review of life cycle assessment within surgical and anesthetic care. Environ Health Perspect. 2021;129:76001. 10.1289/EHP8666

[13] Phoon A, Lim A, Yuen A, Zhang D, Yan Pincus J, Hey HWD. Environmental sustainability in orthopaedic surgery: a scoping review. Bone Jt Open. 2022;3(8):628-640. https://doi.org/10.1302/2633-1462.38.BJO-2022-0067.R1

[14] Prakash J, Sharma V, Reddy KS. Environmental sustainability in orthopaedic surgery. Indian J Orthop. 2023;57:456-463. https://doi.org/10.1007/s43465-023-00806-2

[15] Kagoma Y, Stall N, Rubinstein E, Naudie D. People, planet and profits: the case for greening operating rooms. CMAJ. 2012;184:1905-1911. 10.1503/cmaj.112139

[16] Thiel CL, Eckelman MJ, Guido R, et al. Environmental impacts of surgical procedures: life cycle assessment of hysterectomy in the US. Environ Sci Technol. 2015;49(3):1779-1786. https://doi.org/10.1021/es504719g

[17] Vozzola E, Overcash M, Griffing E. An environmental analysis of reusable and disposable surgical gowns. AORN J. 2020;111:315-325. 10.1002/aorn.12885

[18] Government of India. India's Long-Term Low-Carbon Development Strategy. Ministry of Environment, Forest and Climate Change. 2022.

[19] McGain F, Naylor C. Environmental sustainability in hospitals--a systematic review and research agenda. J Health Serv Res Policy. 2014;19:245-252. 10.1177/1355819614534836

[20] MacNeill AJ, Hopf H, Khanuja A, et al. Transforming the medical device industry: road map to a circular economy. Health Aff (Millwood). 2020;39:2088-2097. 10.1377/hlthaff.2020.01118

[21] Pichler PP, Jaccard IS, Weisz U, Weisz H. International comparison of health care carbon footprints. Environ Res Lett. 2019;14:064004. 10.1088/1748-9326/ab19e1

[22] Malik A, Lenzen M, McAlister S, McGain F. The carbon footprint of Australian health care. Lancet Planet Health. 2018;2:e27-e35. 10.1016/S2542-5196(17)30180-8

[23] Sherman JD, Raibley LA, Eckelman MJ. Life cycle assessment and costing methods for device procurement: comparing reusable and single-use disposable laryngoscopes. Anesth Analg. 2018;127:434-443. 10.1213/ANE.0000000000002683

[24] Thiel CL, Woods NC, Bilec MM. Strategies to reduce greenhouse gas emissions from laparoscopic surgery. Am J Public Health. 2018;108:S158-S164. 10.2105/AJPH.2018.304397

[25] NHS England. Delivering a 'Net Zero' National Health Service. 2022. Available from: https://www.england.nhs.uk/greenernhs/

[26] Romanello M, Di Napoli C, Drummond P, et al. The 2023 report of the Lancet Countdown on health and climate change. Lancet. 2023;402:2346-2394. 10.1016/S0140-6736(23)01859-7