Assessment of the carbon footprint of total hip arthroplasty and opportunities for emission reduction in a UK hospital setting

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Cite this article:
Bone Jt Open 2024;5(9):
742–748.

DOI: 10.1302/2633-1462.
59.BJO-2024-0027.R1

Aims
This study aimed to assess the carbon footprint associated with total hip arthroplasty (THA) in a UK hospital setting, considering various components within the operating theatre. The primary objective was to identify actionable areas for reducing carbon emissions and promoting sustainable orthopaedic practices.

Methods
Using a life-cycle assessment approach, we conducted a prospective study on ten cemented and ten hybrid THA cases, evaluating carbon emissions from anaesthetic room to recovery. Scope 1 and scope 2 emissions were considered, focusing on direct emissions and energy consumption. Data included detailed assessments of consumables, waste generation, and energy use during surgeries.

Results
The carbon footprint of an uncemented THA was estimated at 100.02 kg CO2e, with a marginal increase to 104.89 kg CO2e for hybrid THA. Key contributors were consumables in the operating theatre (21%), waste generation (22%), and scope 2 emissions (38%). The study identified opportunities for reducing emissions, including instrument rationalization, transitioning to LED lighting, and improving waste-recycling practices.

Conclusion
This study sheds light on the substantial carbon footprint associated with THA. Actionable strategies for reducing emissions were identified, emphasizing the need for sustainable practices in orthopaedic surgery. The findings prompt a critical discussion on the environmental impact of single-use versus reusable items in the operating theatre, challenging traditional norms to make more environmentally responsible choices.

Take home message
- This study calculated the carbon footprint of a total hip arthroplasty within a UK hospital.
- It also serves a starting point for tackling the environmental global impact of surgery and healthcare.

Introduction
The escalating concern over global climate change necessitates a comprehensive evaluation of carbon emissions across various sectors, including healthcare.[1–3] As societies strive to transition to a sustainable future, it is imperative to examine the environmental impact of healthcare practices and identify areas where improvements can be made.[4] Within the realm of healthcare, joint arthroplasty surgery has gained considerable attention due to its widespread use and potential for significant carbon emissions.[5]

Hailed as the operation of the century, total hip arthroplasty (THA) has witnessed an exponential growth over the years.[6,7] The ageing population, coupled with the rising prevalence of musculoskeletal conditions, has led to an increased demand for these surgeries.[8] While joint arthroplasty surgeries undoubtedly improve patients' quality of life, there is growing recognition that the

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environmental consequences associated with these procedures must be considered.[9] There is, however, a lack of comprehensive data pertaining to the carbon footprint of this commonly performed orthopaedic procedure.

Understanding the environmental impact of joint arthroplasty surgery is crucial for healthcare professionals, policy-makers, and patients alike.[10,11] It allows us to make informed decisions and implement sustainable strategies within the orthopaedic community. By quantifying and evaluating the carbon footprint associated with these procedures,[12] we can identify areas for improvement and propose sustainable interventions without compromising patient outcomes.

This study aims to evaluate the carbon footprint of THA by adopting a life-cycle assessment approach. By understanding the environmental consequences of these procedures, we can drive the adoption of sustainable orthopaedic practices, reduce carbon emissions, and contribute to the global effort to combat climate change.

Methods

This study evaluted the carbon footprint associated with a THA patient's journey from anaesthetic room to transfer to recovery room. Data were collected prospectively during ten primary hybrid (Stryker Trident and Exeter; Stryker, USA) and ten uncemented R3 and Polar stem; Smith & Nephew, UK) THAs from June to August 2023 at a single hospital (Wrexham Maelor Hospital, Wrexham, UK) under spinal anaesthesia supplemented with sedation. The carbon emissions were divided into different components, including anaesthesia, surgical instruments, and consumables.

We focused on scope 1 and scope 2 emissions,[13] which encompass direct emissions and energy consumption. Scope 3 emissions, which include manufacturing, transport, and waste management, were not included due to the unavailability of accurate manufacturing cost information from the industry.

A detailed inventory of each component involved in THA was created. The information for each item was based on the type of material used. Items such as surgical instruments, implants, and drapes were individually weighed using a calibrated digital weighing machine to obtain accurate measurements. The carbon factors for hip trays were divided by 2,040 to give an accurate estimate in line with a previous study.[14] Each case observed in this study was attended by three anaesthetic colleagues, three members of the surgical team who scrubbed in, and three more support staff, in a laminar airflow theatre situated within an orthopaedic theatre suite.

Scope 1 emissions for inventory items were calculated using life-cycle carbon factors,using life-cycle carbon factors, published by the Centre for Sustainable Healthcare.[15] Scope 2 emissions, linked to operating theatre energy consumption, included lights, ventilation, heating, water, and resterilization for each THA (Table I). The energy consumed from lights was estimated, combining the operating lights, and the ambient lights in operating, anaesthetic, and scrub rooms. The energy consumed for heating was estimated for a volume of 210 m^3 of theatre suite for 90 minutes (which was the average time taken to perform a THA). The water usage for each case was calculated by measuring scrub time with a full tap flow system by all the theatre scrub team. The laminar airflow (Howmedica

Fig. 1
Waste generated from packaging alone in a total hip arthroplasty.

(now Stryker, USA) ExFlow 90) use for the full day was divided by the number of cases per day to give an estimate of the energy use directly from the ventilation unit. The energy used during resterilization was estimated by multiplying the number of cycles required to complete the resterilizing of the hip trays. All this information was converted into CO2-equivalent emissions.

We measured the clinical waste generated after each case and divided this into recyclable and non-recyclable waste (Figure 1).

Results

The carbon footprint for a THA, categorized by different areas within the operating theatre, is as below.

The consumables used in the anaesthetic room included syringes, needles, cannulas, masks, and drugs administered for anaesthesia induction. The cumulative carbon footprint of these consumables for each THA amounted to 3.05 kg CO2e (Table II). This did not include the carbon footprint from the manufacturing of the anaesthetic drugs.

In total, 77 out of 78 items in the operating theatre excluding surgical trays were single-use items. This included scrub brushes, gowns, covers, and various ancillary items required for surgical preparation. Four scrub gowns were used per THA, one by the anaesthetist while performing spinal anaesthetic and three by the surgical team (surgeon, assistant, and scrub nurse). These preparatory consumables for each

Table I. Scope 2 calculations in this study.

Variable	Watts	Number	Duration, mins	kwH	Footprint kg CO2e
Operating light					
Halogen (ALM X ten)	100	128		12.8	2.98
LED (KLS Matrin marLED)	24	104		2.496	0.58
Non-operating lights T5 Longlast GE F49W	49				
Theatre		44		3.234	0.75
Anaesthetic room		12		0.882	0.2
Prep room		4		0.294	0.06
Ventilation					
Howmedica ExFlow 90			90	13	3.03
Heating (British Thermal Unit calculation)					
Volume	210 m^3		90	24	5.59
Water consumption					
Handwash					
First case	14 l				
Subsequent	8 l				
Average per case	9.5 l	X 3 people	28.5 l		8.49
			1 l = 0.298 Co2		
Sterilization cost					
11 trays - 2 cycles	1.531	X11			16.84
Total					37.7

THA contributed to a total carbon footprint of 3.46 kg CO2e (Table III).

Intraoperative consumables such as drapes, draping materials, surgical instruments, sutures, dressings, and gloves were required for the surgical procedure. Their collective carbon footprint for each THA was 17.24 kg CO2e (Table IV).

The hip pack, including drapes, bowls, needles, syringes, and other necessities, made a substantial contribution to the carbon footprint for each THA at 21.41 kg CO2e (Table V).

Reusable instrument sets – comprising basic hip sets, R3 instruments, and Polar stem instruments in an uncemented THA – make a minimal contribution, with a combined carbon footprint of 0.02 kg CO2e (Tables V to VII). This was 0.03 kg CO2e in hybrid THA, using the Trident Exeter for each case. We found that 112 (66%) out of 170 instruments were not used regularly during THA.

We could not accurately calculate the emissions related to manufacturing of the implants and cement due to a lack of information available from the industry.

Surgical waste assessment revealed distinct categories: unclean, non-recyclable clinical waste; recyclable waste; and biological waste. For uncemented THA cases, the average waste was 13.5 kg (73% non-recyclable, 12% recyclable, 15% biological), resulting in a carbon footprint of 20 kg CO2e. Hybrid THA cases had an average waste of 14.8 kg, contributing to a carbon footprint of 22 kg CO2e (Table VIII).

Scope 2 emissions attributable to energy consumption during THA arise from various sources, including water usage, resterilization, electricity consumption, ventilation (inclusive of laminar airflow), and heating. The total scope 2 emissions were 37.7 kg CO2e for each THA (Table I). Among these, resterilization and water usage stood out as the primary contributors, accounting for 45% (16.84 kg CO2e) and 22% (8.50 kg CO2e) of scope 2 emissions, respectively. We found that change from halogen to LED operating theatre lights reduced the energy consumption by 81% (from 2.98 to 0.58 kg CO2e).

When considering all the components mentioned above, the cumulative carbon footprint associated with an uncemented THA amounted to 100.02 kg CO2e and this increased marginally to 104.89 kg CO2e in a hybrid THA. This can be compared to driving 600 miles in a diesel car. It requires five trees for one year to capture 100 kg CO2e.

Discussion

In this study, we have reported the carbon footprint of a THA inside an operating theatre. These findings not only shed light on the immediate carbon emissions associated with surgery, but also serve as a starting point for considering the broader ecological consequences of orthopaedic healthcare practices.

The carbon footprint of joint arthroplasty surgery extends beyond the operating theatre, encompassing various stages along the surgical pathway. These include preoperative activities such as diagnostic tests, consultations, and pre-surgical planning, as well as intraoperative procedures,

Table II. Anaesthetic consumable related carbon footprint during a total hip arthroplasty.

Variable	Weight, kg	Conversion factor	Footprint kg CO2e
Anaesthetic room			
50 ml syringe (plastic)	0.036	4.49	0.16
20 ml syringe (plastic)	0.016	4.49	0.07
10 ml syringe (plastic)	0.007	4.49	0.03
Blunt needle × 2	0.002	6.145	0.01
Spinal needle (plastic + metal)	0.002	6.145	0.01
20 G cannula (plastic + metal)	0.007	6.145	0.04
Spinal anaesthesia administration set	0.15	4.49	0.67
ChloraPrep wand	0.013	4.49	0.06
Cannula dressing	0.001	4.49	0.01
Hudson mask and tubing (plastic)	0.063	4.49	0.28
Y connector (plastic)	0.048	4.49	0.22
IV fluids 500 ml (plastic bag)	1.08	4.49	0.17
Prefilled metaraminol syringe	0.002	4.49	0.01
200 mg propofol vial (glass)	0.034	0.1277	0.01
10 ml 0.5% levobupivacaine (plastic)	0.017	4.49	0.07
5 ml 1% lidocaine (plastic)	0.01	4.49	0.04
1.5 gm cefuroxime (glass)	0.034	4.49	0.12
80 mg gentamicin × 3 (glass)	0.006 × 3 = 0.018	4.49	0.08
500 mg TXA × 4 (glass)	0.006 × 4 = 0.024	4.49	0.1
30 mg ketorolac (glass)	0.006	4.49	0.02
100 ml paracetamol infusion (plastic)	0.13	6.145	0.79
20 mmol MgSO4 (plastic)	0.014	6.145	0.08
Total			3.05

IV, intravenous; TXA, tranexamic acid.

Table IV. Intraoperative consumables related carbon footprint in total hip arthroplasty.

Variable	Material	Weight, kg	Conversion factor	Footprint kg CO2e
Green U drape	Polypropylene	0.16	4.49	0.72
Ioban × 2	Polypropylene	0.096 × 2 = 0.192	4.49	0.86
Saw blade	Metal	0.025	6.145	0.15
Pulse lavage	Polypropylene	0.842	4.49	3.78
Pulse lavage extension brush	Polypropylene	0.041	4.49	0.18
Diathermy tip	Metal	0.257	6.145	1.58
Diathermy pad	Polypropylene	0.016	4.49	0.1
Marker pen	Plastic	0.01	4.49	0.04
2.5 mm drill bit	Metal	0.011	6.145	0.1
Aqueos chlorhex wash		1.1	0.1277	0.96
Chlorherxidine	Plastic	0.559	4.49	2.51
Normal saline wash		3.198	0.1277	0.17
Mepliex surgical dressing	Plastic + cotton	0.018	4.49	0.08
Elective local (drugs + 3 needles and syringe)	Hard plastic+ stainless steel	0.22	4.49	0.99
Surgeon gloves × 15	Polypropylene	0.035 × 15 = 0.525	4.49	2.36
Cement restrictor	Plastic	0.223	4.49	1.0
Blue pressuriser	Polypropylene	0.043	4.49	0.19
Size 10 suction catheter	Polypropylene	0.012	4.49	0.05
Ribbon gauze	Cotton	0.029	6.78	0.20
Palacos R40 Cement	PMMA	0.34	8.43	2.86
Total				17.24

PMMA, polymethyl methacrylate.

Table III. Carbon footprint of preparatory consumables.

Variable	Material	Weight, kg	Conversion factor	Footprint kg CO2e
Scrub brush × 3	Polypropylene	0.016 × 3 = 0.048	4.49	0.22
Gowns × 4 (3 surgeons + 1 anaesthetist)	Non-woven polypropylene	0.282 × 4 = 1.128	0.905	1.02
Hood covers × 3	Plastic + polypropylene	0.125 × 3 = 0.375	4.49	1.68
Hair trimmer blade	Metal + plastic	0.005	4.49	0.22
Slide canvas	Polypropylene	0.205	4.49	0.92
ChloraPrep stick	Hard plastic + cotton	0.07	4.49	0.31
Total				3.46

postoperative care, and rehabilitation. Each stage contributes to the overall carbon emissions, resulting from energy-intensive processes, transportation, sterilization practices, anaesthesia administration, waste generation, and the sourcing of materials and implants.

Our study emphasizes the prevalence of single-use items in operating theatres, with 77 out of 78 items, excluding patient-monitoring equipment, designated for single use. This trend, initially driven by concerns about Creutzfeldt-Jakob disease transmission during adenotonsillectomy procedures,[16] led to the growth of a £3.7 billion disposable surgical device market by 2020.[17] Despite environmental concerns and proven advantages of reusable gowns in impact penetration,[18] water resistance, and a 93% reduction in solid waste production,[19] hesitations persist due to infection risk and adherence to established norms.

Streamlining preassembled hip packs to minimize unnecessary items can have a positive impact on both cost and environmental sustainability. We found that approximately 66% of surgical instruments in our hip trays were not routinely used. Collaboration among surgical teams is pivotal to formalizing these trays effectively. Several studies highlight that this can reduce the carbon footprint of a surgical procedure by approximately one third.[14,20] Considering

Table V. Constituents of a hip pack and their carbon footprint.

Variable	Material	Weight, kg	Conversion factor	Footprint kg CO2e
Hip Pack				
Drape 150 × 240 cm	Polypropylene	0.271	4.49	1.22
Hip drape	Polypropylene	1.133	4.49	5.09
Adhesive op sheet 260 × 175 cm	Polypropylene	0.334	4.49	1.50
Op sheet 90 × 150 cm x 4	Polypropylene	0.102 × 4 = 0.408	4.49	1.83
Table covers 150 × 190 cm x 3	Polypropylene	0.185 × 3 = 0.55	4.49	2.49
Bowls 500 ml × 2 (plastic)	Plastic	0.035 × 2 = 0.07	4.49	0.31
Hypodermic needle	Hard plastic + stainless steel	0.002	6.145	0.01
Bowls 250 ml × 5 (plastic)	Plastic	0.01 × 5 = 0.05	4.49	0.22
Blades 23 × 2	Stainless steel	0.001 × 2 = 0.002	6.145	0.01
Spinal needle	Hard plastic + stainless steel	0.002	6.145	0.01
60 ml syringe × 4	Plastic	0.033 × 4 = 0.132	4.49	0.59
Sharp holder set (plastic)	Plastic	0.049	4.49	0.22
Bandage 15 cm	Cotton	0.064	6.78	0.43
Suction cannula	Polypropylene	0.016	4.49	0.07
Suction tubing	Polypropylene	0.141	4.49	0.63
5 × gauze (7.5 × 10 cm)	Wool	0.004 × 5 = 0.02	6.78	0.14
10 × gauze (30 × 30 cm)	Wool	0.019 × 10 = 0.19	6.78	1.29
Light handle covers × 2	Plastic	0.004 × 2 = 0.008	4.49	0.04
Skin stapler	Stainless steel	0.07	6.145	0.43
Diathermy holder	Plastic	0.05	4.49	0.22
Kidney bowls 800 ml × 2	Plastic	0.034 × 2 = 0.068	4.49	0.31
Stockinette 31 × 122 cm	Polypropylene + wool	0.141	6.78	1.00
Mayo stand cover 79 × 145 cm reinforced × 3	Polypropylene	0.178 × 3 = 0.534	4.49	2.40
Tray wrap 130 × 150 cm plastic	Polypropylene	0.117	4.49	0.53
Plastic outer cover	Plastic	0.091	3.31	0.30
Blade size 23		0.001	6.145	0.006
Ethibond no. 5	Stainless steel + suture material	0.009	4.49	0.04
Vicryl no. 2 × 2		0.007	4.49	0.031
Vicryl 2/0		0.004	4.49	0.017
Prolene on straight needle		0.004	4.49	0.017
Monocryl 3/0		0.004	4.49	0.017
Skin glue	Plastic	0.004	4.49	0.017
Total				21.41

Table VI. Carbon footprint of the surgical instruments used in a hybrid total hip arthroplasty.

Variable	Material	Weight, kg	Conversion factor	Footprint kg CO2e	Divided by 2,040
Uncemented instruments					
Basic hip 1	Stainless steel	4.2	6.145	25.81	0.002
Basic hip 2	Stainless steel	4.7	6.145	28.89	0.002
Extra instruments	Stainless steel	3.15	6.145	19.36	0.001
Stryker drill	Stainless steel	4.8	6.145	29.50	0.002
R3 Instruments	Stainless steel	9.3	6.145	57.15	0.003
R3 reamers	Stainless steel	7.6	6.145	46.70	0.002
R3 trials	Stainless steel	7.9	6.145	48.54	0.002
Polar stem instruments	Stainless steel	13.6	6.145	83.58	0.004
Trial liner sets	Stainless steel	4.14	6.145	25.44	0.001
Mallet heavy	Stainless steel	1.08	6.145	6.34	0.001
Total					0.02

optional trial trays for acetabular shell and liners can contribute to inventory reduction. Familiarity with these systems plays a crucial role in their successful implementation. Preoperative templating can enhance surgical precision while minimizing waste. Innovative technologies such as patient-specific instrumentation and robot-guided surgery may have a carbon-intensive footprint, but their long-term benefits in reducing single-use instruments and improving surgical outcomes should be carefully considered. Evaluating the environmental impact of these technologies is critical in assessing their long-term sustainability benefits.

Addressing the issue of poor waste-recycling practices in the UK healthcare system is paramount. Several studies have highlighted the need for proper segregation of recyclable waste in the operating theatre.[20–23] We found that a THA case on average generated 14.1 kg of waste, of which only 12% was recyclable. Implementing separation at the source and providing dedicated spaces for different waste streams in the planning of new or existing operating theatre facilities can facilitate effective waste segregation.

Several important limitations must be acknowledged when interpreting the results of this study. One notable constraint lies in the exclusion of scope 3 emissions from the analysis. Emissions from implant manufacturing, transportation, and waste contribute considerably to the carbon footprint. The lack of precise manufacturing cost data hampered inclusion of scope 3 emissions in this study. Cappucci et al[24] reported 56.4 kg CO2e to be associated with the manufacturing of a titanium femoral stem prosthesis by an additive manufacturing process. Addressing this limitation would provide a more holistic view of the environmental impact and a much larger number of CO2 emissions associated with THA. Better engagement, transparency, and innovation focused on sustainability by leading industry partners is crucial to measure the real impact of this procedure.

Table VII. Carbon footprint of the surgical instruments used in a hybrid total hip arthroplasty.

Variable	Material	Weight, kg	Conversion factor	Footprint kg CO2e	Divided by 2,040
Uncemented instruments					
Basic hip 1	Stainless steel	4.2	6.145	25.8	0.002
Basic hip 2	Stainless steel	4.7	6.145	28.881	0.002
Extra instruments	Stainless steel	3.15	6.145	19.356	0.002
Stryker drill	Stainless steel	4.8	6.145	29.496	0.002
Exeter hip femoral Instruments	Stainless steel	7.3	6.145	44.858	0.004
Exeter modular rasps	Stainless steel	9.3	6.145	57.148	0.005
Trident reamers	Stainless steel	4.1	6.145	25.194	0.002
Trident instruments	Stainless steel	7.8	6.145	47.931	0.004
Trident liner impactor	Stainless steel	0.378	6.145	2.322	0.0001
Exeter plug trial sets	Stainless steel	4.162	6.145	25.575	0.002
Contemporary remaers	Stainless steel	7.14	6.145	43.875	0.003
Cement vaccum	Stainless steel	3.37	6.145	20.708	0.001
Cement gun extension	Stainless steel	0.149	6.145	0.915	0.0005
Mallet heavy	Stainless steel	1.08	6.145	6.636	0.0005
Charnley weight and chain	Stainless steel	1.475	6.145	9.063	0.0007
Total					0.03

Table VIII. Waste generated for each total hip arthroplasty in this study.

Case	Black (non-recyclable), kg	Black (recyclable), kg	Yellow (clinical waste), kg	Biological waste, kg	Sharps, kg	Suction canister, kg	Total, kg
1	2.8	1.28	5.5	0.32	0.38	0.85	11.13
2	4.5	1.92	10.3	0.17	0.46	0.88	18.23
3	3.9	1.56	6.4	0.23	0.96	0.58	13.63
4	3.0	1.8	5.1	0.33	0.89	1.1	12.22
5	2.4	1.28	8.8	0.34	0.25	0.64	13.71
6	2.4	1.58	7.7	0.55	0.59	0.45	13.27
7	2.5	2.03	7.3	0.12	0.36	1.22	13.53
8	3.4	2.02	6.8	0.2	0.43	0.68	13.53
9	1.7	2.18	6.8	0.46	0.47	0.51	12.12
10	3.7	1.54	7.2	0.3	0.53	0.84	14.11
11	1.2	0.99	8.9	0.7	0.48	0.30	12.57
12	3.7	1.4	7.3	0.4	0.27	0.73	13.80
13	5.6	3.13	9.3	0.6	0.63	0.87	20.13
14	3.8	1.71	7.1	0.4	0.38	1.2	14.59
15	3.1	1.8	9.1	0.3	0.31	0.83	15.44
16	2.9	1.7	8.0	0.4	0.54	0.9	14.44
17	3.8	1.61	6.0	0.6	0.55	1.2	13.76
18	5.2	1.74	5.9	0.4	0.56	1.07	14.87
19	3.0	1.52	7.4	0.4	0.45	0.53	13.30
20	3.5	2.4	8.8	0.2	0.13	0.77	15.80

Additionally, variations in energy consumption and cost data across different healthcare settings may influence the generalizability of the study's findings. Recognizing these variations is crucial, as it underscores the need for context-specific sustainability initiatives tailored to individual healthcare facilities.

The estimated carbon emissions for uncemented THA stand at approximately 100.02 kg CO2e, with a minor increase to 104.89 kg CO2e for hybrid THA. The study identifies actionable areas for reducing carbon emissions, including energy-efficient buildings, transitioning to LED lighting, instrument rationalization, improving waste-recycling practices, and educating healthcare teams on sustainability.

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Funding statement

The authors disclose receipt of the following financial or material support for the research, authorship, and/or publication of this article: Awyr Las North Wales Charity.

ICMJE COI statement

I. Malek discloses lecture fees from Bonesupport that are unrelated to this work.

Data sharing

The data that support the findings for this study are available to other researchers from the corresponding author upon reasonable request

Open access funding

The authors report that the open access funding for this manuscript was self-funded.