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Original Research

The Environmental Impact and Sustainability of Total Hip and Knee Arthroplasty

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A B S T R A C T

Background: Operating room waste is disposed of in landfill sites, recycled, or undergoes costly, energy-intensive incineration processes. By assessing the quantity and recyclability of waste in primary hip (THA) and knee arthroplasty (TKA), we aim to identify strategies to improve sustainability.
Methods: A prospective waste audit of 15 primary THA and 16 primary TKA cases was conducted at a tertiary orthopedic hospital between April and July 2022. Waste was categorized into nonhazardous, hazardous, recycling, sharps, and linens. Each category was weighed. Items disposed as nonhazardous waste were cataloged for a sample of 10 TKA and 10 THA cases. Recyclability of items was determined using packaging.
Results: Average total waste generated for THA and TKA was 14.46 kg and 17.16 kg, respectively. TKA generated significantly greater waste ($P < .05$). Of all waste, 5.4% was recycled in TKA and just 2.9% in THA cases. The mean amount of recycled waste was significantly greater in TKA cases than that in THA cases, 0.93 kg and 0.42 kg, respectively.
Hazardous waste made up the largest proportion for both TKA (69.2%) and THA (73.4%). Nonhazardous waste made up 15.1% and 11.3% of total waste for TKA and THA, respectively. In the nonhazardous waste, only 2 items (scrub-brush packaging and towel packaging) were recyclable.
Conclusions: We estimate hip and knee arthroplasty generates over 2.7 million kg of waste in the United Kingdom annually. Currently, only a small percentage of waste is recycled in hip and knee arthroplasty, which could improve through increased use of recyclable plastics and clear labeling of items as recyclable by medical suppliers.

Introduction

Approximately 180,000 knee and hip replacements are performed in England and Wales each year [1]. With the number of arthroplasty procedures increasing annually, the sustainability of hip and knee arthroplasty procedures has come into focus. It is from our observation that each procedure generates a large amount of waste, which is not recycled or treated for re-use. In North America, health care generates 4 billion pounds of waste annually, which equates to almost one-tenth of greenhouse gas emissions nationally [2]. The National Health Service (NHS) produces in excess of 500,000 tonnes of waste and 25 megatonnes of CO_2 annually [3,4] and currently emits over one-third of the United Kingdom's public sector emissions; it has been found that surgery is 3-6 times more energy intense than any other department within a hospital [5]. As of July 2022, the NHS has cemented its commitment to achieving a "net zero" carbon footprint by 2045 through the Health and Care Act (2022), making the need for greener surgery ever more pressing [6].

Operating room waste is segregated into different streams which are either recycled, disposed of in landfill sites, or undergo costly and energy-intensive incineration processes [3]. The additional processes involved in disposing of potentially hazardous waste increases the cost by 10-20 times compared to general waste

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[7]. Currently very limited data on waste generation from lower-limb arthroplasty exist although the available data highlight a disappointingly low proportion of waste being recycled, despite a large proportion of waste generated being potentially recyclable plastics including sterile surgical tray wrapping [8-10].

With the Glasgow Climate Pact highlighting the need for urgent action to reduce waste generation, we seek to quantify the waste generated and sustainability of a total knee and hip replacement. By assessing the recyclability of waste generated from primary hip and knee arthroplasty cases at our institution, we aim to identify strategies to reduce the carbon footprint of primary hip and knee arthroplasty in the United Kingdom.

Material and methods

Data were collected prospectively at a single tertiary orthopedic hospital, in the theaters of 6 lower-limb arthroplasty surgeons between April and July 2022. Fifteen primary total hip arthroplasty (THA) cases and 16 primary total knee arthroplasty (TKA) cases were included; all revision and complex primary cases were excluded. Waste was categorized into dry nonhazardous (general) waste, hazardous (infectious) waste, recycling, sharps, and linens. General waste should include domestic waste and nonhazardous items such as packaging. Hazardous/infectious waste should include infectious clinical waste, such as infectious personal protective equipment and dressings.

Each waste category produced in the operating theater was weighed using a digital weighing scale accurate to 0.01 kg. Items disposed as dry nonhazardous waste were recorded and cataloged in real time for a sample of 10 TKA and 10 THA cases, and recyclability of each item was determined using packaging labels.

For each case, data collection began as soon as preparation for the case in the operating room commenced, which coincided with the opening of new waste bags and concluded once the patient had been transferred off the operating table, coinciding with closure and removal of waste bags. Waste produced in the anesthetic room and anesthetic gases were not recorded in our study. Fluid from suction tubing was also excluded. Institutional review board approval was not required.

Statistical analysis

Data were stored and analyzed using Excel 2019 (Microsoft Corp., Redmond, WA) and IBM SPSS (Armonk, NY). Mean waste production for each waste category and overall waste production were calculated for hip and knee arthroplasty cases. An unpaired *t*-test was used to calculate the significance of differences between the 2 groups, with a significance level of 0.05.

Results

A total of 16 TKA cases and 15 THA cases were included in the study. All TKA cases used cemented prostheses. Five THA cases were hybrid with cemented femoral components; 10 cases used uncemented prostheses. No intraoperative complications were recorded.

Tables 1 and 2 illustrate the quantity of waste generated in the different waste streams for all THA and TKA cases. Average total waste generated for THA and TKA were 14.46 kg (12.25-18.15 kg) and 17.16 kg (14.05-23.05 kg), respectively, with TKA cases generating a significantly greater total amount of waste ($P < .05$).

The mean recycled waste was significantly greater in TKA cases than in THA cases, 0.93 kg and 0.42 kg, respectively ($P < .05$). On average, only 5.4% of waste was recycled in TKA cases, and just 2.9% in THA cases.

Hazardous waste made up the largest proportion of the waste streams for both TKA (69.2%) and THA (73.4%), and on average, TKA generated a significantly greater amount of hazardous contaminated waste (11.87 kg) than THA (10.61 kg), $P < .05$.

Nonhazardous waste made up 15.1% and 11.3% of total waste for TKA and THA, respectively. TKA generated on average a significantly greater quantity of nonhazardous waste (2.59 kg) than THA (1.63 kg), $P < .05$.

Linens and sharps represent the smallest of the waste stream categories, and no significant difference in the quantities of linen or sharps waste generated was observed between TKA and THA cases. In TKA cases, on average, 1.46 kg and 0.31 kg of linens and sharps waste was generated, respectively. In THA cases, the average amount of linen waste generated was 1.50 kg, while the mean amount of sharps waste was 0.31 kg.

Tables 3 and 4 are examples of the itemized breakdown of nonhazardous waste generated in a TKA and THA case, respectively.

Of all the items discarded in the nonhazardous (general) waste, only 2 items (scrub brush packaging and sterile towel packaging) were labeled as recyclable. Surgical instrument tray wrapping sheets and sterile glove packaging were the items most frequently disposed of in the nonhazardous (general) waste.

Table 1
Waste generated from total knee arthroplasty.

Procedure	Patient	Implant/system choice	Recycling waste (kg)	Hazardous (contaminated) waste (kg)	Dry nonhazardous waste (kg)	Linens (kg)	Sharps (kg)	Total waste (kg)
TKA	1	Persona[a]	3.1	15.15	2.5	2.1	0.2	23.05
	2	Vanguard[a]	1.55	11.3	4.65	1.2	0.05	18.75
	3	Vanguard[a]	0.7	11.65	2.85	0.75	0.05	16.00
	4	Vanguard[a]	1.05	13.6	2.95	0.8	0.1	18.50
	5	Vanguard[a]	1.95	11.95	2.35	1.85	0.05	18.15
	6	Vanguard[a]	0.75	14.8	2	0.8	0.4	18.75
	7	Vanguard[a]	1	11.55	1.5	1.35	0.2	15.60
	8	Vanguard[a]	0.6	10.85	2.55	1.65	0.9	16.55
	9	Vanguard[a]	0.35	11.9	3.65	1.5	0.3	17.70
	10	Triathlon[b]	0.9	10.75	2.45	2.45	0.3	16.85
	11	Triathlon[b]	0.3	11.3	2.55	0.5	0.1	14.75
	12	Vanguard[a]	0.6	10.6	1.95	0.8	0.1	14.05
	13	Triathlon[b]	0.5	11.1	1	1.25	1.3	15.15
	14	Vanguard[a]	0.4	11.45	4	2.4	0.1	18.35
	15	Persona[a]	0.1	10.95	2.3	1.4	0.05	14.80
	16	Persona[a]	1.1	11.05	2.15	2.6	0.7	17.60
	Mean		0.93	11.87	2.59	1.46	0.31	17.16

TKA, total knee arthroplasty.
[a] Zimmer-Biomet (Warsaw, IN).
[b] Stryker Ltd (Kalamazoo, MI).

Table 2
Waste generated from total hip arthroplasty.

Procedure	Patient	Implant/system choice	Recycling waste (kg)	Hazardous (contaminated) waste (kg)	Dry nonhazardous waste (kg)	Linens (kg)	Sharps (kg)	Total waste (kg)
THA	1	POLARSTEM[a]/R3[a] (Uncemented)	0.5	9.7	1.8	1.5	0.3	13.80
	2	Exeter[b]/ R3[a](Hybrid)	0.1	10.45	1.5	0	0.2	12.25
	3	POLARSTEM[a]/R3[a] (Uncemented)	0.4	7.55	2.55	1.95	0.25	12.70
	4	POLARSTEM[a]/R3[a] (Uncemented)	0.1	10.55	1.05	1.15	0.1	12.95
	5	CPCS[a]/ R3[a](Hybrid)	0.7	9.5	1.5	4.7	0.7	17.10
	6	POLARSTEM[a]/R3[a] (Uncemented)	0.35	11.85	1.7	1.7	0.3	15.90
	7	POLARSTEM[a]/R3[a] (Uncemented)	0.25	11.15	1.35	1.15	0	13.90
	8	POLARSTEM[a]/R3[a] (Uncemented)	0.45	12.7	2.15	0.55	0.2	16.05
	9	POLARSTEM[a]/R3[a] (Uncemented)	0.55	9.4	1.95	0.85	0.85	13.60
	10	Exeter[b]/ R3[a](Hybrid)	0.65	12.4	1.15	0.35	0.35	14.90
	11	Exeter[b]/ R3[a](Hybrid)	0.5	10.75	2.4	1.9	0.2	15.75
	12	POLARSTEM[a]/R3[a] (Uncemented)	0.3	10.95	0.85	1.55	0.35	14.00
	13	Exeter[b]/ R3[a](Hybrid)	0.5	9.6	1.65	1.3	0.1	13.15
	14	POLARSTEM[a]/R3[a] (Uncemented)	0.45	13	1.05	2.95	0.7	18.15
	15	POLARSTEM[a]/R3[a] (Uncemented)	0.45	9.65	1.75	0.9	0	12.75
	Mean		0.42	10.61	1.63	1.50	0.31	14.46

THA, total hip arthroplasty.
[a] Smith and Nephew (Andover, TX).
[b] Stryker Ltd (Kalamazoo, MI).

Discussion

Over 180,000 hip and knee arthroplasty procedures are performed annually in the United Kingdom [1], and our findings suggest that each year, over 2.7 million kg of waste is being generated from THA and TKA.

Hazardous waste made up the largest proportion of waste generated although previous studies on operating room waste management highlight that greater than 90% of the waste in hazardous waste bags is misallocated [11,12] and in fact should be disposed of in alternative waste streams. The energy-intensive processes by which hazardous waste is disposed of, including high-temperature incineration, have significant economic and environmental consequences. Rizan et al. assessed the carbon footprint of different waste streams in 3 hospitals and estimated per ton of waste, hazardous waste generates 569-1074 kg of CO_2e, compared to 21-65 kg of CO_2e for recyclable waste [13]. According to our local hospital policy, the cost of disposing of 1 bag of hazardous waste is three times that of 1 general waste bag; thus, the potential environmental and financial benefits of diligent waste segregation cannot be overemphasized.

Our study found 69.2% and 73.4% of waste in TKA and THA procedures, respectively, was being disposed as hazardous waste. This mirrors the results of Lee and Mears who performed a waste audit of 10 TKA and 10 THA cases in Baltimore, USA, and found hazardous waste comprised 70% and 69.7% of their waste streams,

Table 3
Inventory of waste generated in a TKA case.

Item	Number
Gloves outer packaging	13
Surgical tray wrapping (blue polypropylene sheets)	8
Gloves inner packaging	7
Scrub brush packaging	6
Scrub brush	6
Ioban inner packaging	5
Drape adhesive paper	5
Sheets of paper associated with surgical trays	5
Suture packaging	5
Other paper and plastic packaging	5
Needle packaging	4
Cement packaging	4
Surgical gown outer packaging	3
Saw blade packaging	3
Nail pick	3
Ioban outer packaging	2
Unsterile pouch	2
Syringe packaging	2
Femoral cement restrictor packaging	1
Mayo table cover packaging	1
Skin stapler packaging	1
Single basin liner packaging	1
Intravenous fluid packaging	1
Pulsed lavage packaging	1
Surgical marker packaging	1
Scalpel blade packaging	1
Mask	1
Visor	1
Optivac packaging	1

Table 4
Inventory of waste generated in a THA case.

Item	Number
Gloves outer packaging	16
Gloves inner packaging	15
Surgical tray wrapping (blue polypropylene sheets)	10
Paper towels	8
Scrub brush packaging	7
Scrub brush	6
Surgical gown outer packaging	5
Drape packaging	5
Other paper & plastic packaging	5
Inner gown packaging	4
Barrier drape packaging	4
Huck towel packaging	4
Sheets of paper associated with surgical trays	3
Mask	3
Dressing packaging	2
Pulsed lavage packaging	2
Crepe bandage packaging	2
Cement packaging	2
Syringe packaging	2
Saline bag packaging	2
Saw blade packaging	2
Ioban outer packaging	1
Drape adhesive paper	1
Local anesthetic packaging	1
Optivac packaging	1
Suction tubing	1
Marker pen packaging	1
Cannula packaging	1
Skin stapler packaging	1

respectively [8]. Such high proportions are almost certainly due to inappropriate segregation of waste, demonstrated by Stall et al. who categorized and segregated waste generated from 5 TKA procedures in Ontario, Canada, and found biohazardous waste to comprise 19.2% of total waste [9]. Recent quality-improvement initiatives focusing on accurate segregation of waste have shown that a reduction of up to 60% of operating room waste disposal costs is achievable with diligent segregation of waste [14].

As well as efforts to reduce the inappropriate disposal of items as hazardous waste, our data highlight the need for a concerted effort to recycle noncontaminated plastics and papers, which are routinely being thrown in the nonhazardous waste stream. This waste stream accounted for 15.1% and 11.3% of total waste for TKA and THA, respectively, and as illustrated in Tables 3 and 4, it contains large numbers of potentially recyclable plastic items. Of particular significance is the blue polypropylene sheets used to wrap surgical instrument trays. These are thought to contribute to 19% of operating room waste and are nonbiodegradable [3,15]. The material can be melted into pellet form and re-sold for use in reproduction of plastic items [15]. In their waste audit, Stall et al. found an average of 1.6 kg of sterile blue polypropylene wrap is used per TKA [9]. Recycling of the sterile sheets, commonly termed “blue wrap,” has become an important focus in recent times, and schemes are available worldwide to assist health care bodies with collection and recycling of this particular subset of hospital waste [16].

Of the different hospital waste streams, recycled waste has been shown to have the lowest carbon footprint [13]; however, our data suggest only a very small percentage of total waste generated is recycled; 5.4% and 2.9% in TKA and THA cases, respectively. Of the large number of plastic and paper items thrown in the nonhazardous waste stream (see Tables 3 and 4), only 2 were identified as recyclable from their packaging labels: the outer packaging of the scrub brush and sterile towels. This highlights two key barriers which must be overcome if the NHS is to honor its net-zero ambitions [6] and to significantly reduce the carbon footprint of not just lower-limb arthroplasty but surgery as a whole. First, medical suppliers must drive a global change toward using recyclable plastics for packaging. This will facilitate recycling of noncontaminated plastic wrapping, which in our study was often disposed of as clinical waste. Second, a greater awareness is required by the entire surgical team as to which items can and cannot be recycled, which requires clear labeling on the packaging of surgical items by medical suppliers. A survey of 554 participants analyzing barriers to greener surgery highlighted that 56.7% of participants were unclear which items in the operating room were recyclable [17].

Limitations

The authors acknowledge the limitations of this study. This study includes data collected from a single center, and such findings may not be generalizable given significant variations in practice both nationally and internationally.

Conclusions

Extrapolating the results from our study, we estimate that annually, THA and TKA cases generate over 2.7 million kg of waste in the United Kingdom alone, with this number set to rise as case numbers increase. There is increasing awareness of the need for greener surgery with recent surveys confirming that most surgeons are concerned about their environmental impact and are willing to make changes to their practice [18,19]. Through the increased use of recyclable plastics for packaging, combined with clear labeling of items as recyclable, medical suppliers can have a significant impact in reducing the carbon footprint of lower-limb arthroplasty surgery. Our data suggest only a very small percentage of waste generated is recycled in THA and TKA cases. Ultimately, to improve this, greater focus on the issue is required at a national level to provide the infrastructure and information to local health care organizations to enable long-lasting change.

Conflicts of interest

The authors declare there are no conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2023.101254.

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