sustainability

Article

Sustainable Waste Management in Orthopedic Healthcare Services

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Abstract: It is estimated that globally medical surgical specialties, including orthopedics, produce large amounts of hospital waste. However, the possibilities of recycling materials are not well highlighted. Orthopedic hospitals can collect larger volumes of recyclables that could be kept out of landfills. The general objective of this study is to identify the categories and related amounts of waste and recyclable materials produced by the main types of medical interventions in orthopedics. The specific objective is to evaluate the amounts of waste produced in the preoperative and intraoperative periods, but also their recycling potential. For one month, we analyzed eight types of orthopedic medical interventions, of which five were surgical and three were nonsurgical. These were performed at the County Emergency Clinical Hospital of Targu Mures in Romania. For surgical interventions, the waste was collected separately in the preoperative and intraoperative periods. Waste was divided into recyclable, nonrecyclable, and biological categories. The waste bags were weighed with a portable scale. The main results are the average amounts of recyclable waste produced per case in the eight types of medical interventions. The secondary results show the average amounts per case of nonrecyclable, biological, and total waste. To test for statistically significant differences between the types of medical interventions, we performed an analysis of variance. Seventy-four cases were included in the study. An amount of 466.2 kg of waste was collected, with an average mass of 6.3 kg per case. During the preoperative period, 130.3 kg of waste was produced, of which 78% was recyclable. During the intraoperative period, 303.8 kg of waste was produced and only 11% was recyclable. Trauma surgery produced the largest amount of waste, followed by arthroplasty. A quarter of orthopedic waste is recyclable, and the greatest potential for recycling is preoperative waste, which can be effectively recycled at three-quarters. Through effective recycling programs, the ecological footprint of orthopedic–traumatology interventions can be reduced.

Keywords: sustainability; waste; recycling; healthcare; orthopedics

Citation: Moldovan, F.; Moldovan, L. Sustainable Waste Management in Orthopedic Healthcare Services. *Sustainability* **2024**, *16*, 5214. https://doi.org/10.3390/su16125214

Academic Editors: Rita Khanna, Shaundeep Sen, Yury Konyukhov and Abhilash (Abe) Chandra

Received: 30 April 2024
Revised: 10 June 2024
Accepted: 18 June 2024
Published: 19 June 2024

1. Introduction

Hospitals, especially in operating rooms, carry out high-yield activities that require intensive resources. Surgical procedures use several substances and materials that, through the waste generated, harm the personnel and the environment [1]. Consequently, protecting public health requires efficient and sustainable medical waste management systems [2]. This desire is amplified because of the annual increase in the amount of waste generated in the healthcare sector, an industry in continuous growth [3].

In Greece, public hospitals produced 10,000 tons of hazardous waste in 2020, an amount that will double by 2030 [4]. In a university hospital in Brazil, it was estimated that each bed generates daily 4.09 kg of waste of all categories. Of these, general waste has a percentage of 55.6%, followed by infectious waste 39.1%, sharp waste 2.9%, and chemical waste 2.4% [5]. The extreme values of waste produced per day by a hospital bed have maximum values in Ethiopia of 6.03 kg and minimum values in India of 0.24 kg [6]. From this, it follows that there is a great variety in the volume of waste generated by a hospital bed in different countries, and this can be extrapolated to medical specialties. It is estimated that around 15% of healthcare waste poses risks. These can be infectious, toxic, or radioactive, and if not treated properly pose risks to human health and the environment. Microorganisms in healthcare waste can cause serious illness if spread among healthcare workers, patients, and the public [7]. Among the solid wastes that pose dangerous risks to health and the environment are dioxin and furan that require control and management under policies and programs based on sustainable development [6]. Sadiq et al. [8,9] indicate the use of antimicrobial tools built from multifunctional nanomaterials.

Improper practices in the separation, collection, storage, transport, and treatment of hospital waste in developing countries can lead to occupational and environmental risks. These are due to limited resources, knowledge, and awareness of proper waste management due to lack of staff training [10]. Care for the environment needs to be included among the health professional's primary ethical obligations. In this way, they can contribute to increasing the awareness of the importance of environmental issues among medical personnel, but also among patients. Health professionals must direct the system towards designing green healthcare practices that integrate the principles of sustainable health [11]. They must appreciably reduce the material aspects of the most advanced healthcare procedures.

A continuously growing field is environmental sustainability in orthopedics. It has a high potential for significant change and requires thorough research into carbon foot printing and the impact of environmentally sustainable change [12]. Operating rooms produce up to half of all hospital waste and, in orthopedic surgery, arthroplasty is the largest producer of waste with the highest material recycling potential [13]. In the operating room, there are several high-value materials that can be recycled, while substantially reducing the residual mass. These opportunities have been used with difficulty in Germany, although they do not delay the processes in the operating rooms and do not require special effort [14].

Many studies have been conducted on hospital waste management. Although the contribution made to the generation of medical waste by the various medical specialties and related medical techniques is intensively studied, due to the appearance of new materials that have recycling potential, this requires additional studies [6]. The most common procedures in orthopedic surgery are fracture operations, and hip and knee arthroplasties. They are the largest producers of waste and have the greatest potential for material recycling [15]. In the United Kingdom, knee arthroplasties generate over 2.7 million kg of waste annually, of which only a small percentage is recycled [16]. The total life cycle carbon footprint of a knee arthroplasty is estimated at 190.5 kg of CO_2 [17]. This has important consequences for the environment and the health of the population, and requires detailed or comparative studies. Reducing the volume of contaminated waste after total hip arthroplasty and total knee arthroplasty can reduce hospital overheads and environmental impact.

The general context of how hospital waste management is carried out is regulated at the national level. For example, in Romania, the supervision of waste management resulting from medical activity is carried out by the Ministry of Health [18]. The waste resulting from the medical activity must go through all the stages of management, to minimize the risks attributed both to the staff of the health unit and to the environment. In this regard, there are provisions regarding the collection and separation by category, packaging of waste, internal transport, temporary storage in the space of the sanitary unit, the transport of hazardous medical waste to the place of final disposal, methods of disposal of medical waste by incineration, treatment, and the costs regarding medical waste management.

Considering the controversies identified in the specialized literature indicating that an insufficient knowledge of the structure of the generated waste can lead to its inappropriate selection, with health risks and unnecessary expenses, in the present study we formulated several research questions:

RQ1: What are the representative categories of waste and what items make them up in orthopedics?

RQ2: What are the types of medical interventions that generate the largest amounts of waste?

RQ3: What are the medical interventions with the greatest waste recycling potential?

RQ4: What ecological sustainability measures can be adopted in orthopedics?

With the support of these research questions, we formulated the general objective of our study. This consists of identifying the categories and related amounts of waste and recyclable materials produced by the main types of medical interventions in orthopedics. The specific objective of the study consisted of evaluating the amounts of waste produced in the preoperative and intraoperative periods, but also their recycling potential.

With the support of the findings of the study, we proposed to formulate measures to reduce the environmental footprint related to the orthopedics–traumatology specialization.

2. Materials and Methods

The steps of the research methodology we have used in this pilot study are presented in Figure 1.

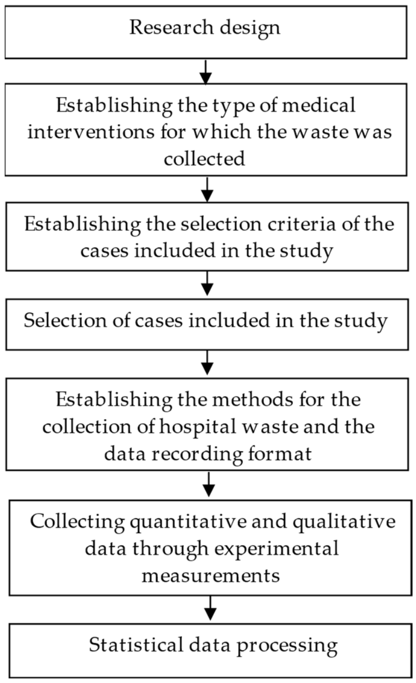

Figure 1. Flowchart with the steps of the research methodology.

2.1. Study Design and Participants

In March 2024, a pilot study was carried out regarding the volumes of waste generated at the Orthopedics–Traumatology Department of the County Emergency Clinical Hospital of Targu Mures in Romania. Medical activities are carried out in the four compartments: operating room, outpatient, ward, orthopedics emergency room. They have recycling programs established and implemented in current practice.

The research tool consisted primarily of establishing the type of medical interventions for which the waste was collected:

- Arthroplasty: total knee replacement surgery—code O14902; total hip replacement surgery—code O12104 (type of fixation: cemented total hip arthroplasty, uncemented total hip arthroplasty, hybrid, and reverse hybrid total hip arthroplasty); revision knee arthroplasty—code O15501; revision hip arthroplasty—code O12401.

- Trauma: operated fractures including the following: femoral neck fractures treated by unipolar hemiarthroplasty (Moore type) and bipolar hemiarthroplasty—code O12101; proximal humeral fracture treated by shoulder hemiarthroplasty—code O04103; internal fixation of the intra-articular fracture of the femoral condyle—code O13101; closed reduction of the tibial diaphysis fracture with internal fixation—code O14002; open reduction of proximal humerus fracture with internal fixation—code O05002; open reduction of the fracture of the distal epiphysis of the radius with internal fixation—code O06302.
- Upper limb: plate or nail removal—code O18106; shoulder stabilization for multidirectional instability—code O04106; arthroscopic debridement of the shoulder—code O03402; arthroscopic release of elbow contracture—code O04609.
- Lower limb: removal of the plate or nail from the femur—code O18107; ankle arthrodesis—code O17201; meniscectomy of the knee—code O13604; arthroscopic reconstruction of the cruciate ligament of the knee with meniscus repair—code O15303; arthroscopic chondroplasty of the knee with multiple drilling or implant—code O15108.
- Bone tumors: en bloc resection of malignant bone tumor with anatomically specific autograft—code O19706; marginal excision of malignant bone tumor with cementation of the defect—code O19605; marginal excision of malignant bone tumor with defect allograft—code O19604; en bloc resection of the malignant long bone tumor of the lower limb with arthrodesis of the adjacent joint—code O19703.
- Outpatient interventions: chronic cases, trauma controls.
- Ward procedures: extraskeletal immobilization procedures, periodic postoperative dressing, medication administration, hygienic maintenance, nutrition.
- Orthopedics emergency room procedures: cast immobilization, immobilization in bandages, anesthesia.

In the period 1–31 March 2024, among the previously listed treatments performed in the four compartments of the Orthopedics–Traumatology Department, we selected a variable number of 5–15 cases that we considered representative as having a medium–high degree of complexity and requiring for treatment all the requirements established by the specific medical procedures and protocols of orthopedics–traumatology approved at the hospital level [19].

Thus, for the reference period, in the case of arthroplasty interventions from a total of 78 cases, we selected 15 interventions; trauma (out of 104 cases/we selected 12 cases); upper limb (6/6); lower limb (14/10); bone tumors (2/2); outpatient interventions (623/8); ward procedures (204/9); and orthopedics emergency room procedures (817/12). In summary, for all interventions, the most representative 74 interventions were selected from a total of 1848 cases. Pediatrics cases were not treated because they constitute a distinct medical specialty.

The personnel involved in waste collection were trained on the categories of collected waste, how to sort and store, the portable scale, and how to weigh and record in the database of the pilot study. The project manager continuously followed the way in which these operations were carried out to ensure good reliability and validity of the data collected.

At the time of admission, the hospital obtained the consent of the patients. According to the provisions of the Ministry of Health, for this study, it was not necessary to obtain separate consent of the patients or the consent of the ethical committee of the hospital. This is because the study is classified as an environmental improvement project that does not directly involve human subjects.

2.2. Evaluation Variables and Methodologies

The strategy for the generation and collection of hospital waste adopted in this research was the most representative of the generation of hospital waste because it respects the national requirements formulated by the Ministry of Health—the National Institute of Public Health—the National Center for Monitoring Risks from the Community Environment through the guide Waste resulting from medical activity—legal requirements and good practices [18]. With this support, the European legislative framework is respected: Directive 2008/98/EC [20], Council Regulation (EU) 2017/997 [21], Council Directive 1999/31/EC [22], Directive (EU) 2018/850 [23], as well as the national legislative framework: Law no. 211/2011 [24], Government Decision no. 856/2002 [25], Government Decision no. 870/2013 [26]. The legislation regarding the categorization of waste resulting from medical activities [18] was complied with: sharps waste (code 18 01 01), anatomical–pathological waste and anatomical parts (18 01 02), infectious waste (18 01 03), waste considered non-hazardous, which does not require special infection prevention measures (18 01 04), chemical waste consisting of or containing dangerous substances (18 01 06), other chemical waste (18 01 07), cytotoxic and cytostatic drug waste (18 01 08), and other medicinal waste (18 01 09).

With the support of the research questions, we defined the variables and developed the evaluation methodologies corresponding to the following aspects explored: the average amounts of waste collected in each type of orthopedic intervention in the phases of their implementation, the average total amounts of waste collected in each type of orthopedic intervention, and the total and percentage amounts of waste that fall into the recyclable, nonrecyclable, and biological categories during the reference period of the study.

The healthcare staff in the departments of the Orthopedics–Traumatology Department manually separated the generated waste items into streams suitable for distinct categories and deposited each waste item in the appropriate container. In the case of arthroplasty, trauma, upper limb, lower limb, and bone tumor surgical interventions, the waste from the preoperative, intraoperative, and postoperative phases was selected and analyzed. For the other types of interventions, outpatient interventions, ward procedures, and orthopedics emergency room procedures, the total amounts of waste collected were selected and analyzed.

The preoperative phase was delimited between the preparation of the rolling bed for the surgical case and when the patient's skin was prepared for the intervention. At the end of this period, the surgical waste generated was weighed and separated into two categories of recyclable and nonrecyclable waste.

The next, intraoperative phase continued from the preparation of the patient's skin for the intervention and was completed by cleaning the operating room in the postoperative phase. At the end of this period, the waste items generated were divided into four categories: recyclable waste, nonrecyclable waste, linen, and biological waste. In the category of recyclable materials were included cardboard and uncontaminated plastic materials, but also other materials used for packaging. The category of nonrecyclable materials included surgical gloves, disposable gowns made of materials other than cloth, and all soiled and contaminated waste items. The category of biological waste included resections of bone tissues and soft tissues, as well as any other human remains. These were collected in separate waste streams. The waste that had the potential for injury/infestation and that required operational control was excluded from the analysis: sharp objects (syringes with needles, needles, scalpel blades), biopsy material from operating rooms, infectious waste that contained or met blood or other biological fluids, as well as viruses, bacteria, parasites, and/or microorganism toxins. The waste packed in labeled bags was weighed in a uniform and standardized manner using a portable scale model SBS-LW-7500A, which has an accuracy of 10 g.

In this study, we used the following notations: mass (m), preoperative (e), intraoperative and postoperative (t), recyclable (R), nonrecyclable (N), and biological (B). With this support, we defined the following primary variables of the study:

- Type of medical orthopedic intervention o_i (i = 1–8), where i = 1 denotes arthroplasty, i = 2 trauma, i = 3 upper limb, i = 4 lower limb, i = 5 bone tumors, i = 6 outpatient interventions, i = 7 ward procedures, and i = 8 emergency procedures.
- Mass amounts of recyclable waste produced per case in orthopedic medical intervention o_i (i = 1–5) in the preoperative period $mRe(o_i)$, and intraoperative and postoperative period $mRt(o_i)$.

- Mass amounts of nonrecyclable waste produced per case in orthopedic medical intervention o_i (i = 1–5) in the preoperative period $mNe(o_i)$, and intraoperative and postoperative period $mNt(o_i)$.
- Mass amounts of biological waste produced per case for the orthopedic medical intervention o_i (i = 1–5) in the preoperative period $mBe(o_i)$, and intraoperative and postoperative period $mBt(o_i)$.

The secondary variables of the study are as follows:

- Total quantities of recyclable waste $mR(o_i) = mRe(o_i) + mRt(o_i)$, nonrecyclable waste $mN(o_i) = mNe(o_i) + mNt(o_i)$, and biological waste $mB(o_i) = mBe(o_i) + mBt(o_i)$ produced in the same period for the studied surgical interventions (o_i = 1–5). For medical interventions without a surgical component, the mass of recyclable, nonrecyclable, and biological waste is determined directly without highlighting the preoperative and intraoperative and postoperative periods under the notations $mR(o_i)$, $mN(o_i)$, and $mB(o_i)$, where (o_i = 6–8).
- Total amounts of waste produced in the same period for each medical intervention (o_i = 1–8) is $m(o_i) = mR(o_i) + mN(o_i) + mB(o_i)$.
- Total amount of waste produced in the same period by all medical interventions $m = \sum_{i=1}^{8} m(o_i)$ (o_i = 1–8).
- The total weights of recyclable waste produced for each studied medical intervention (o_i = 1–8) is $mR(o_i)/m(o_i)$, and for surgical medical interventions (o_i = 1–5) the weights of recyclable waste produced in the preoperative phase $mRe(o_i)/m(o_i)$, and intraoperative and postoperative phases $mRt(o_i)/m(o_i)$.
- Waste weights for all types of interventions in recyclable $\sum_{i=1}^{8} mR(o_i) / \sum_{i=1}^{8} m(o_i)$; nonrecyclable $\sum_{i=1}^{8} mN(o_i) / \sum_{i=1}^{8} m(o_i)$; and biological $\sum_{i=1}^{8} mB(o_i) / \sum_{i=1}^{8} m(o_i)$ categories.
- Recyclable and nonrecyclable waste weights for all types of interventions collected in the preoperative $\sum_{i=1}^{5} mRe(o_i) / \sum_{i=1}^{5} m(o_i)$, and intraoperative and postoperative $\sum_{i=1}^{5} mRt(o_i) / \sum_{i=1}^{5} m(o_i)$ phases.

After collection, all quantities of waste were properly treated and eliminated. Hospital-specific protocols approved by the public health authority were used.

2.3. Data Collection and Statistical Analysis

A spreadsheet was designed according to the categories of waste collected and the volumes of data estimated for registration. The data obtained after weighing each category of waste were recorded on this electronic document. These were primary analyzed and filtered in Excel 2021 (Microsoft 365) GNU PSPP and transferred to Matlab for further processing. We performed the statistical analysis with the support of Statistics and Machine Learning Toolbox Version 12.3 from Matlab R2022a (The MathWorks, Inc., Natick, MA, USA).

The statistical analysis consisted, as appropriate, of descriptive statistics, in the detection of differences between the categories of medical interventions with the support of one-way analysis of variance with post hoc Tukey testing. Significance was defined by p less than 0.005.

3. Results

A total of 74 medical procedures were included in this month-long study, of which 45 procedures were surgical. These are part of the eight types of medical interventions studied. The average values of the masses of waste collected per case are shown in Table 1.

At the end of the reference period, a total of 466.2 kg of waste was collected. The average mass of waste was 6.3 kg/case. Of this, 29% was recyclable waste (with a total of 137.6 kg of waste, 1.86 kg/case), 67% was nonrecyclable waste (310.8 kg of waste, 4.20 kg/case), and 4% was biological waste (18.5 kg of waste, 0.25 kg/case) (Figure 2).

Table 1. Waste mean mass per case.

Type of Medical Intervention	No of Cases	Mean Mass of Waste Per Case (95% CI) (g)				Recyclable Waste Percentage
		Recyclable Waste	Nonrecyclable Waste	Biological Waste	Total Waste	
Arthroplasty	15	3123.4 (2818.7–3428.1)	5343.2 (5128.6–5557.8)	423.4 (360.2–486.6)	8466.6 (8182.8–8750.4)	36.6 ‡
Trauma	12	3842.5 (3526.8–4158.2) *	6824.6 (6593.4–7055.8) †	516.2 (446.8–585.6) †	10667.1 (10,408.5–10,925.7) †	35.8 ‡
Upper limb	6	1214.3 (700.5–1728.1)	3217.0 (2639.0–3795.0)	61.0 (0–132.5)	4431.3 (3422.9–5439.7)	26.6
Lower limb	10	1024.0 (782.1–1265.9)	3812.1 (2288.8–5335.4)	19.4 (0–54.3)	4836.1 (3147.6–6524.6)	20.8
Bone tumors	2	1315.2 (974.4–1656.0)	3416.5 (2392.2–4440.8)	22.4 (0–64.9)	4731.7 (3450.8–6012.6)	27.0
Outpatient interventions	8	85.4 (64.5–106.3)	270.5 (188.3–352.8)	0.0 (0)	355.9 (259.1–452.7)	23.3
Ward procedures	9	124.9 (92.6–157.3)	319.2 (245.8–392.6)	12.3 (0–27.3)	444.1 (346.8–541.4)	26.6
Orthopedics emergency room procedures	12	100.7 (63.3–138.1)	474.3 (420.9–527.7)	3.2 (0–9.8)	575.0 (496.3–653.7)	17.2
All interventions	74	1862.8 (889.6–2896.2)	4207.3 (2785.9–5648.7)	253.8 (0–575.2)	6070.1 (3755.2–8385.0)	25.5

CI = confidence interval. * Trauma produced significantly more recyclable waste than all other types of medical interventions except arthroplasty ($p < 0.05$). † Arthroplasty produced significantly more nonrecyclable, biological, and total waste than all other types of medical interventions ($p < 0.05$). ‡ Trauma and arthroplasty produced a significantly greater percentage of recyclable waste than all other types of medical interventions. The difference between trauma and arthroplasty was not significant ($p < 0.05$).

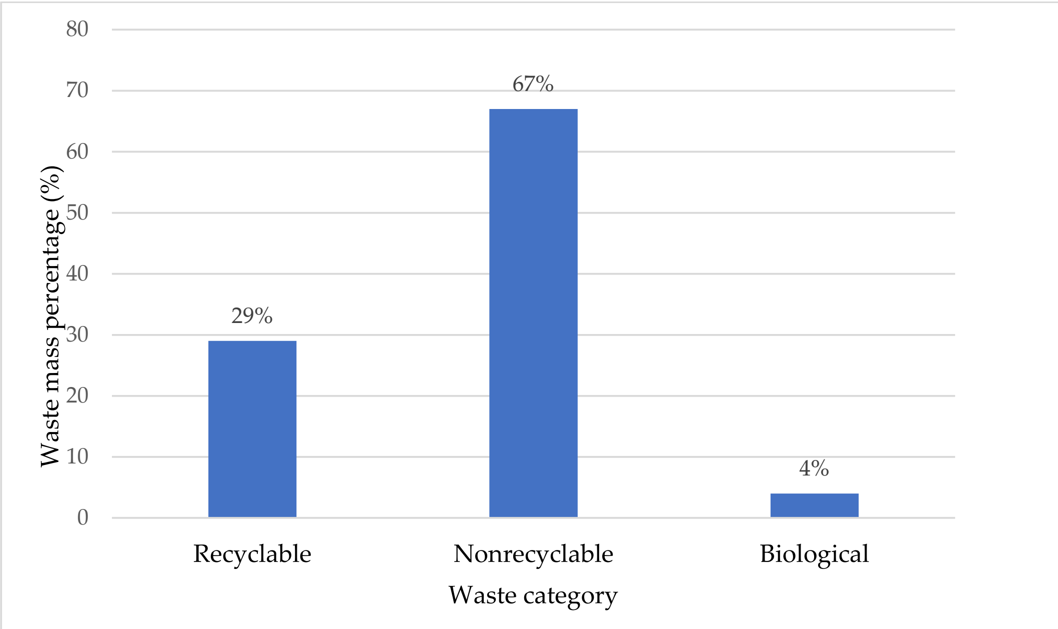

Figure 2. Waste mass percentages collected from all types of interventions.

During the preoperative period, 130.3 kg of waste was produced and more waste during the intraoperative period with a total of 303.8 kg of waste. In the preoperative period, approximately 78% of the waste was recyclable, and in the intraoperative period only 11% of the waste was recyclable (Figure 3).

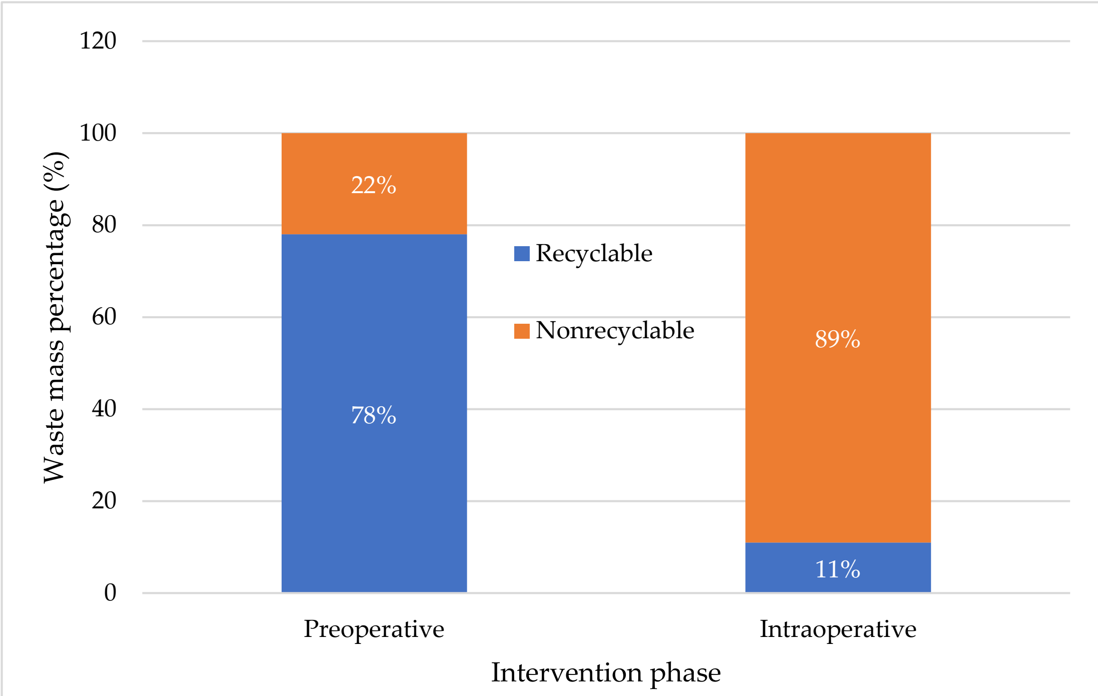

Figure 3. Recyclable and nonrecyclable waste mass percentages collected in the phases of all types of interventions.

The average percentage of recyclable waste/case was 25.5%. Trauma surgery produced the largest amount of recyclable waste per case in the preoperative phase (3244.1 g/case) (Figure 4). Arthroplasty surgery produced the most recyclable waste in the intraoperative phase (991.8 g/case).

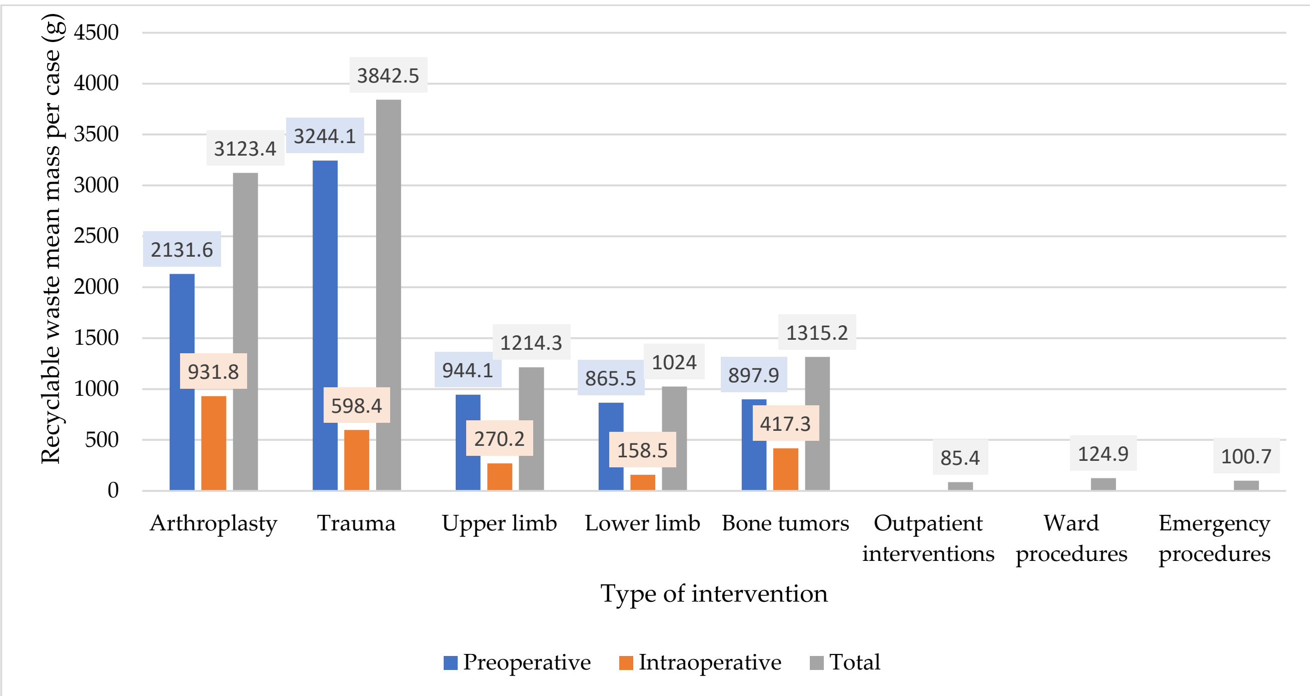

Figure 4. Recyclable waste mean mass per case according to the type of intervention.

The highest percentage of recyclable waste was also for the arthroplasty intervention, in the preoperative phase 88.2% and in the intraoperative phase 16.4% (Figure 5).

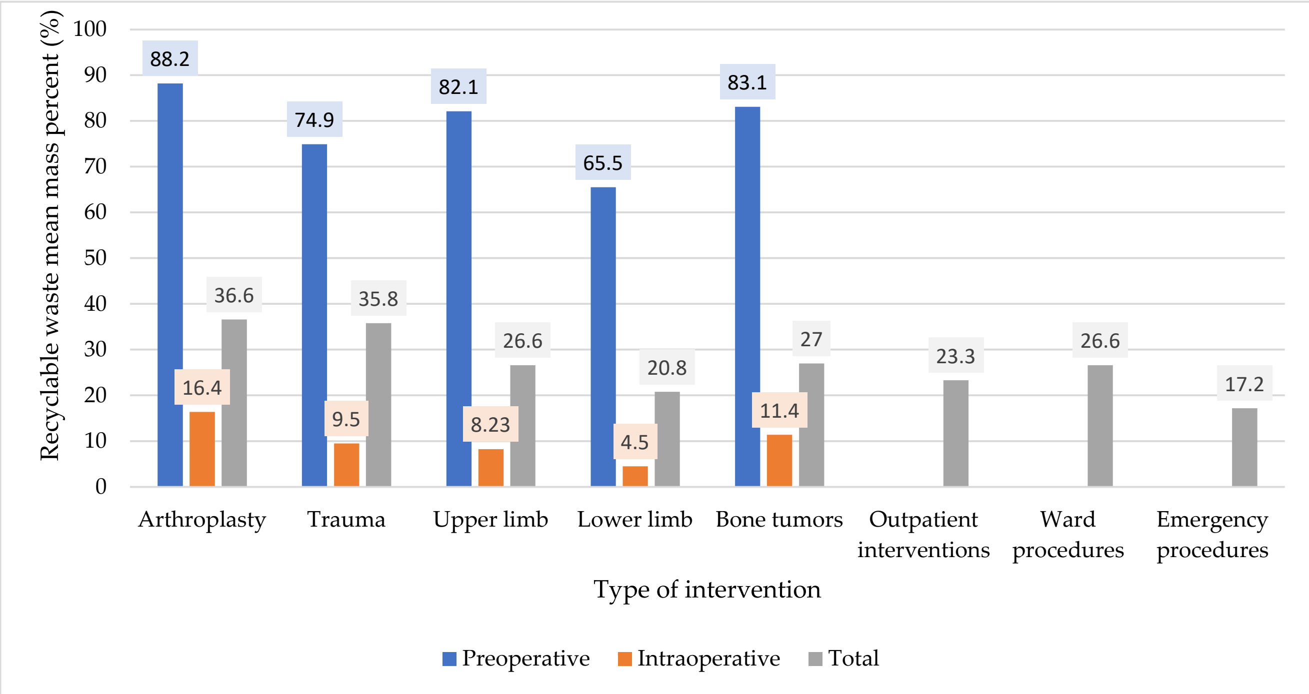

Figure 5. Recyclable waste mass percentages according to the type of intervention.

Trauma surgery produced the largest amount of nonrecyclable waste per case (6824.6 g/case), most of which was produced in the intraoperative phase (5738.3 g). This was followed by arthroplasty surgery with 5343.2 g/case of nonrecyclable waste (Figure 6).

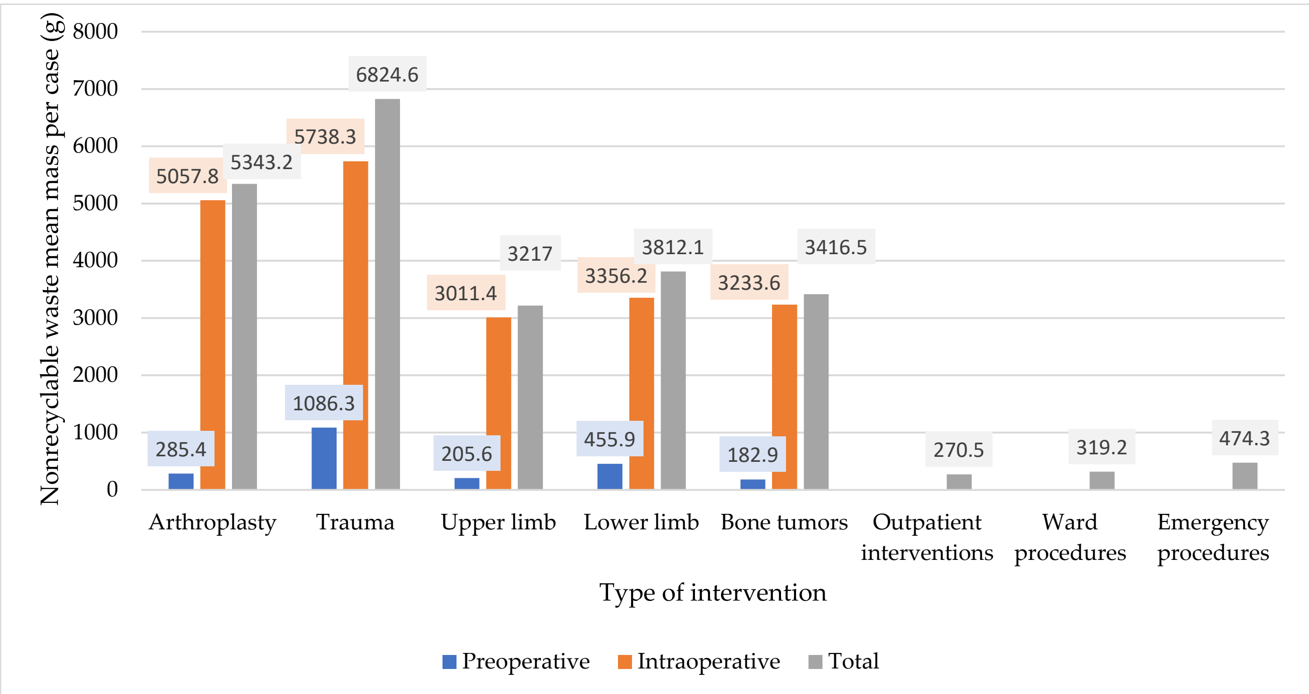

Figure 6. Nonrecyclable waste mean mass per case according to the type of interventions.

The largest amounts of biological waste per case were recorded in trauma operations 516.2 g/case and arthroplasty 423.4 g/case, which were higher compared to the amounts collected from the other types of orthopedic medical interventions (Table 1).

Medical waste is eliminated by incineration or treatment at specialized companies on a contract basis. Incineration consists of burning waste in incinerators by developing high temperatures. This category includes sharp cutting waste, infectious waste, chemical and medicinal waste, and anatomical–pathological waste. Waste treatment takes place through physical, thermal, or chemical processes. The hospital uses technologies based on thermal decontamination processes at low temperature (+105 °C–+177 °C) through hot air disinfection, steam disinfection and microwave disinfection. Chemical treatment processes use disinfecting solutions such as sodium hypochlorite, peracetic acid, or inorganic chemicals. An improvement measure consists of the use of technologies based on irradiation by exposing medical waste to the action of electronic particles, Cobalt-60 rays, or UV rays.

4. Discussion

The objective of our research was to identify the types and related amounts of waste and recyclable materials produced in orthopedics–traumatology. According to RQ1, we defined in the study four representative categories of waste and what items make them up in orthopedics. They have the potential to improve the waste management system by identifying the interventions from which the largest amounts of waste and the greatest recycling potential come [13].

In the literature, successful implementations of similar measures are exemplified in other medical fields like intravitreal injections [27] or surgical fields, such as general surgery [14], phacoemulsification surgery [28], surgical procedures including operations of the back, heart, abdomen, hip and knee, and hernias [29]. The first finding was related to the real nature of the two categories of waste according to the recycling potential. In the preoperative stage, the waste was composed of recyclable (packaging, non-blood intravenous tubing, empty bottles, non-blood diapers and bags, paper, flowers) and nonrecyclable (split medications and disinfectants, broken thermometers and blood pressure gauges; dressings, bandages, gauze, gloves and masks contaminated with blood or body fluids, food scraps) waste. The intraoperative waste consisted of recyclable (uncontaminated medical clothing and medical personal protective equipment, packaging) and nonrecyclable (gloves, masks, gauze and medical equipment contaminated with blood and body fluids, gowns, organs and tissues, disinfectant products, anesthetic gases) waste. Then, we found that surgical medical services generate much larger amounts of waste compared to nonsurgical ones. The average amounts of recyclable waste per case generated by arthroplasty, trauma, upper limb, lower limb, and bone tumors surgical interventions are on average 2103.9 g/case, and those generated by nonsurgical outpatient interventions, ward procedures, and emergency procedures are on average 103.7 g/case. In the case of nonrecyclable waste generated by surgical interventions, per case the average amounts of waste 4522.6 g/case are also substantially higher than the average amounts 354.7 g/case generated by nonsurgical interventions.

Our study showed that trauma surgery produced the highest amounts of recyclable, nonrecyclable, and biological waste per case compared to the other types of medical interventions.

According to RQ2 and RQ3, we found the highest percentage of waste recycling per case, 36.6% in the arthroplasty operation [13]. This is followed by trauma surgery with a recycling percentage of 35.8%. Considering the findings of our study and the average number of interventions performed annually in Romania [30], we estimate that at the national level 405 thousand kilograms of waste is produced annually in orthopedic surgical interventions. Our research shows an average recycling rate of 25.5%. With these data, we estimate that at the national level over 101 thousand kilograms of waste from orthopedic surgeries can be recycled each year.

In our study we found a disproportion between the percentages of material recycling from the preoperative period (which have values for surgical interventions between 88.2−65.5%) and the intraoperative period (with values between 16.4−4.5%). This constant disproportion among the types of surgical interventions investigated is also found in the global assessment, which indicates that 78% of the waste produced in the preoperative period is recyclable, and a lower 11% in the intraoperative period. Consequently, we appreciate that orthopedics–traumatology generates significant amounts of waste, which is mostly recyclable [31]. Starting from this finding and corresponding to RQ4, the ecological sustainability measures can be formulated. All measures must be oriented towards the maximum use of the identified recycling potential.

Currently, each orthopedic hospital collects different combinations of recyclable materials. A standardized collection system for recyclable waste would create scale and efficiency. With a standardized system, orthopedic hospitals can collect larger volumes of post-consumer recycled content. This would allow the processing of more and different types of materials that would be kept out of landfills. For this, a minimum framework of best practices should be created, including minimum recycling rates at hospital level, and technological capabilities in material recovery systems to provide hospital managers and healthcare staff with guidance on what orthopedic recycling should look like. In time, such programs can be certified. The establishment of collection criteria can be based on the types of materials identified in this research as recyclable and the development of standardized methods of use and reuse of each recyclable item. An alternative solution is the development of standardized care diagrams that allow using only materials that are necessary in each intervention, simultaneously with the assessment of the degree of waste reduction. The development and implementation of these ecological practices and policies has practical implications for practitioners and the potential to orient hospitals, staff, and patients towards sustainability.

The challenges of this study come from the fact that waste recycling is a multidisciplinary issue that must be considered at different decision levels simultaneously. When designing the recycling system, a holistic view and consideration of the characteristics of different types of waste is necessary. Another challenge comes from the collection of biological waste, but also sharp objects, for which a special treatment regime is necessary. Factors that could have a potential influence on the results are the selection of cases that were included in the study. Depending on their severity, they can generate variable amounts of waste.

There are some limitations in the study we conducted. It is possible that by randomly selecting the cases of medical interventions we can only obtain approximate values of the amounts of waste generated. Another limitation of the study comes from the fact that it was conducted at a single hospital that procures certain medical supplies from a limited number of suppliers and, due to this fact, it constitutes a pilot study. Findings may vary in other hospitals using other providers. Also, in other hospitals, other medical procedures may be applied, such as those intended for pediatric surgery, which we did not have the opportunity to explore. As a result of the identified limitations, we propose to continue the study by including in the research other hospitals that have several orthopedic medical procedures in their portfolio and that have different suppliers of medical materials. In this way, a national study can be conducted over different periods of time where it could be that the results are more varied and therefore the conclusions might not be the same. This would allow the tracking of trends and the formulation of policies whereby hospitals and medical staff are oriented towards ecological sustainability.

5. Conclusions

Orthopedics produces appreciable amounts of waste, mainly in surgical interventions. Traumatic fracture surgery, followed by arthroplasty, generates the largest amounts of waste. Arthroplasty, followed by trauma surgery, has the greatest potential for waste recycling. During surgical interventions, the greatest potential for recycling is found in the waste from the preoperative period, which can be recycled up to three-quarters. Of the total waste collected in orthopedics, a quarter is recyclable. Effective recycling programs for waste in this category can reduce the ecological footprint.

The main findings challenge of the pilot study consisted of selecting the studied medical intervention cases from a hospital that is supplied with a limited range of medical materials. This led to obtaining approximate results of the generated waste quantities. The way forward for the research is to include in the study a larger number of hospitals at the regional or national level.

Author Contributions: Conceptualization and methodology; supervision; and project administration F.M. and L.M.; investigation, validation, and resources; data curation; and writing—original draft preparation F.M.; formal analysis; visualization; and writing—review and editing L.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data used in this study can be requested from the corresponding author.

Acknowledgments: We gratefully acknowledge the Department of Orthopedics–Traumatology and the County Emergency Clinical Hospital of Targu Mures for facilitating this research.

Conflicts of Interest: The authors declare no conflicts of interest.

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