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Research article

Study of the economic consequences and phthalate emission caused by centralized and decentralized patterns of infectious waste management

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ABSTRACT

The development of health services of hospitals in developing countries has led to a significant increase in the production of infectious waste, which has important economic and environmental consequences. Therefore, reducing pollutant leakage caused by disinfection and reducing infectious waste management costs are important in achieving sustainable development goals in hospital management. In this study, the centralized and decentralized patterns of infectious waste management were studied in three hospitals in Behbahan, Iran. Economic analysis was done based on the financial model. Phthalate emission from disinfection equipment was measured for investigating the level of exposure to the pollutant in the studied patterns. The results showed that the cost of waste transportation for studied hospitals in the centralized patterns increased by 12.1 %. However, reductions in disinfection and transfer costs up to 32.4 % were available by increasing the segregation ratio of infectious waste. The average emission of phthalates from disinfection equipment in the studied hospitals was 0.260 ng/kg. But emission of phthalate types was not the same, so that the emission of BEHP, IBP, and DBP was 35.97, 4.90, and 1.55 μg/m^3, respectively. Considering the hospital waste reduction plan and increasing the segregation ratio to reduce the costs of the hospital led to economic justification of the centralized pattern of infectious waste management as a safe option.

1. Introduction

Producing a significant volume of municipal solid waste in different vary sources due to economic growth in recent decades is one

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of the challenges of urban management [1,2]. This is one of the challenges of developing countries because the technology and knowledge of waste management are still insufficient in these countries [3]. For example, considering health criteria as one of the indexes of development has led developing countries to focus on providing health services to citizens [4]. In addition, economic growth in recent decades has led to migration to cities and urbanization. In this situation, providing the basic needs of large populations, including health needs, has led to an increase in health care centers, including hospitals, in developing countries [5]. Therefore, the production of hospital waste has increased significantly in the recent decades, especially in developing countries [6].

Hospital waste is caused by medical, diagnostic, and general services provided in hospitals [7]. Therefore, the composition of hospital waste includes general waste, infectious waste, sharp waste, chemical and pharmaceutical waste, and pathological waste [8]. However, the volume of solid waste produced in hospitals depends on several factors, including the number of visits, the quality of services, and the existence of a waste management plan [9]. Improper management of hospital waste can lead to health consequences for hospital staff and clients, as well as environmental consequences affecting public health [10]. Therefore, monitoring the composition and quantity of hospital waste and developing efficient solutions for its management is one of the most necessary measures related to the sustainable development goals, especially in developing countries [6,11]. For this purpose, it is important to consider the characteristics of each component of hospital waste. Meanwhile, infectious waste has a special importance in the management of hospital wastes due to the potential of pathogen transmission and the need for disinfection [12].

A significant proportion of hospital waste management costs are related to the disinfection of infectious waste [13]. Also, the emission of different pollutants according to the type of disinfection tool causes significant environmental consequences related to infectious waste [9,13]. Iran is a developing country that has experienced a significant increase of hospital waste production in the past decades [14]. Therefore, choosing an infectious waste management pattern has an important impact on the economy of hospitals and the emission of pollutants from disinfection tools leads to health risks for employees and clients. The aim of this study is to compare two centralized and decentralized patterns of infectious waste management in hospital costs and phthalate concentration in indoor air. This information can be used as a decision-making tool in choosing the best scenario leading to risk and cost reduction. The necessity of this study included the development of basic data to reduce hospital management costs and also to reduce health risks in the indoor environment. Also, the innovation of this study included the simultaneous investigation of economic and environmental consequences in infectious waste management decision making.

2. Method

2.1. Hospitals

This study was conducted in the main hospitals of the Behbahan, Iran, includes three hospitals. This city has a population of 140,000 people and is located in the southwest of Iran in Khuzestan province. The studied hospitals including Shahidzadeh Hospital, Farideh Hospital, and Valiasr Hospital had 124, 125, and 108 beds, respectively. The pattern of waste management in Behbahan hospitals was in accordance with the common pattern in Iran. Segregation of infectious waste in the hospital is one of the defined principles of medical waste management in Iran [6] which was observed in the studied hospitals. According to local laws, infectious waste must be disinfected by the its producer [15]. Based on this, disinfection equipment including autoclave was used in the studied hospitals. Also, based on locally defined principles, sharp waste was stored separately in special containers called "safety box".

2.2. Data collection

Data on the quantity and composition of medical waste in the studied hospitals were collected using the results of the analysis of hospital waste that was done periodically and was officially recorded. For this purpose, physical analysis including weight measurement of produced waste was performed. In this method, the produced waste in the hospitals was weighed daily, and after separating the different components, including common waste, infectious waste, sharp waste, etc., the weight ratio of each component was measured. The weight analysis of hospital waste led to the identification of the proportion of each component in four main classifications including common waste, infectious waste, sharp waste, and chemical and pharmaceutical waste. Hierarchy of medical waste management in the studied hospitals was evaluated by field survey and interviews with relevant waste management staff in each hospital. Waste management costs were estimated based on reported financial data. The current situation and the change of situation based on the available options were evaluated by assuming multiple scenarios. Finally, the difference in cost and pollutant leakage caused by the change in the weight ratio of waste in the routes of each scenario was calculated by an economic model that is described below.

2.3. Scenarios

The studied scenarios were defined based on variable conditions in the current situation. Medical waste reduction by using strategies such as reducing the use of disposable equipment and considering the volume of packaging in purchasing was one of these conditions. Improving the segregation ratio of infectious waste with the aim of reducing the loading of waste in disinfection equipment was also one of the considered conditions. The use of on-site disinfection equipment or ex-situ was also one of the conditions. Based on the considered conditions, the scenarios listed in Table 1 were studied.

2.4. Cost analysis model

The cost of hospital waste management in the studied scenarios was estimated using a financial model based on the costs of the hierarchy of waste management. As shown in Fig. 1, this financial model was defined for the four main chains of the waste management hierarchy, including storage, collection, transportation, and disinfection [16]. This method was defined based on previous experiences in the evaluation of solid waste management costs in material flow analysis [17,18]. Therefore, the quantity of waste in each of the defined routes in the studied scenarios was the basis for calculating hospital waste management costs.

2.5. Pollutant analysis

Sampling was done for 8 h in the operating period of the autoclave at a height of 1.7 m from the ground in the disinfection room. Sampling was done in each of the studied hospitals for six months with a one-month interval. Sampling and analysis of phthalates was done according to NIOSH method 5020. A 37 mm mixed cellulose ester (MCE) membrane filter was used for sample collection. Air flow rate in the sampling device was set to 2 L/min. The filters were placed in 2 mL of a mixture of hexane:dichloromethane (50:50) and the phthalates were extracted with an ultrasonic bath for 30 min. Finally, filtered samples were analyzed in GC-MS by injection 1 ml of the solution. The analysis was repeated three times for each sample.

3. Results and discussion

3.1. Waste quantity

The results of weight analysis of medical waste in the studied hospitals are shown in Table 2. Common wastes had the highest weight ratio in the studied hospitals, so that on average constituted 55.19 % of the composition of hospital wastes. Also, the proportion of infectious waste in the studied hospitals was significant. On average, 38.9 % of the composition of medical waste in the three studied hospitals was infectious waste. This significant ratio of infectious waste in studied hospitals has also been reported in other Iranian hospitals (6), which is due to the model of waste management in hospitals and the wide definition of infectious waste in Iran. For example, in the studied hospitals, in accordance with the pattern of the entire Iran, the wastes caused by serum injection, including serum bottles, were considered as infectious wastes, and the radioactive wastes, which constituted a small percentage of the total wastes, were managed as chemical wastes. In all the studied hospitals, the lowest weight ratio of medical waste was related to sharp waste, which constituted less than 1.5 % of the waste composition. However, the composition of medical waste in the studied hospitals had slight differences, which can be caused by the diversity of the hospital wards and also the difference in the quality of waste management, especially in the segregation ratio [9,19]. Therefore, the ratio of waste production to each bed can be a better measure to compare the status of waste production in the studied hospitals. The results showed that waste production in the studied hospitals was in the range of 3.2–3.7 kg/bed. The quantity of waste in the studied hospitals was in the reported range of waste production in Iranian hospitals [9]. The production of solid waste in Iranian hospitals is reported in the range of 2.2–4.5 kg/bed, and 3.5 kg/bed on average [6]. However, factors affecting the number of patients and provided services in the hospital, change the production of medical waste [20]. For example, the experience of the Covid-19 pandemic showed that the occurrence of an epidemic in society and other factors that lead to more visits to health care centers will cause an increase in the production of medical waste [21–23]. In addition, the structure of the health care system in Iran has been defined by determining each hospital to refer patients suffering from various complications from smaller cities and villages, which had a direct impact on the number of visitors in the studied hospitals [6].

3.2. Waste composition

The results of estimating the quantity and composition of medical waste in the studied scenarios are shown in Fig. 2. The results showed that by applying the principles of the green hospital and increasing the segregation ratio, the reduction of hospital waste in the

Table 1
Details of studied scenarios.

Conditions	Reduction	C1	Waste reduction up to 10 %
		C2	Waste reduction up to 15 %
		C3	Waste reduction up to 25 %
	Segregation	C4	leads to a reduction in the ratio of infectious waste up to 5 %
		C5	leads to a reduction in the ratio of infectious waste up to 10 %
		C6	leads to a reduction in the ratio of infectious waste up to 15 %
	Disinfection	C7	On-site
		C8	Ex-situ
Scenarios	Centralized	S1	C7, C1, C4
		S2	C7, C2, C5
		S3	C7, C3, C6
	Decentralized	S4	C8, C1, C4
		S5	C8, C2, C5
		S6	C8, C3, C6

$$SC = Cn\left(\frac{Oc + Mc}{Py}\right)$$

SC is storage cost, Cn is number of containers, Oc is operating cost, Mc is maintenance cost, and Py is years of project.

$$CC = Lc\left(\frac{Cn}{Ls}\right) + Pc$$

CC is collection cost, Lc is cost for each labor, Pc is personal protective equipment cost, Ls is standard of labor number for collection.

$$TC = Trc\left(\frac{Wv}{Tv}\right) + Fc\left(\frac{distance}{Trn}\right) + Trn\left(\frac{Oc+Mc}{Py}\right)$$

TC is transportation cost, Trc is truck cost, Wv is waste volume, Tv is truck volume, Fc is fuel cost, Trn is truck number.

$$DC = Ecc\left(\frac{Wv}{Ev \times Oc}\right) + En\,(Oc + Mc) + Egc$$

DC is disinfection cost, Ecc equipment capital cost for each device, En is equipment number, Ev is equipment volume, Egc is energy cost

Fig. 1. Details of cost estimation model.

Table 2
Results of waste analysis in studied hospitals (kg/day).

		Common waste	Infectious waste	chemical and pharmaceutical waste	Sharp waste
Shahidzadeh	H1	238.7 ± 7.3	184.5 ± 4.2	19.1 ± 1.5	6.75 ± 1.2
Farideh	H2	272.9 ± 6.4	174.2 ± 5.1	17.8 ± 1.7	5.65 ± 1.1
Valiasr	H3	188.9 ± 5.7	134.9 ± 3.2	15.9 ± 1.6	6.23 ± 1.4

studied city was available up to 115.61 tons/year. Accordingly, the composition of hospital waste will change as shown in Fig. 3. Reducing infectious waste as one of the goals of segregation will reduce the cost of waste in the next stages of the hospital waste management [16]. Also, due to the impact of infectious waste quantity on pollutant emission during disinfection [24], these scenarios provided less health and environmental risk compared to the current situation. Therefore, S3 and S6, which supported the highest reduction of medical waste and the minimum weight ratio of infectious waste in the composition of hospital waste, were recognized as favorable options compared to other scenarios. Predicting the next consequences by defining available scenarios is considered as a decision-making tool in solid waste management [17,25]. As the comparison of the change of quantity and composition in the

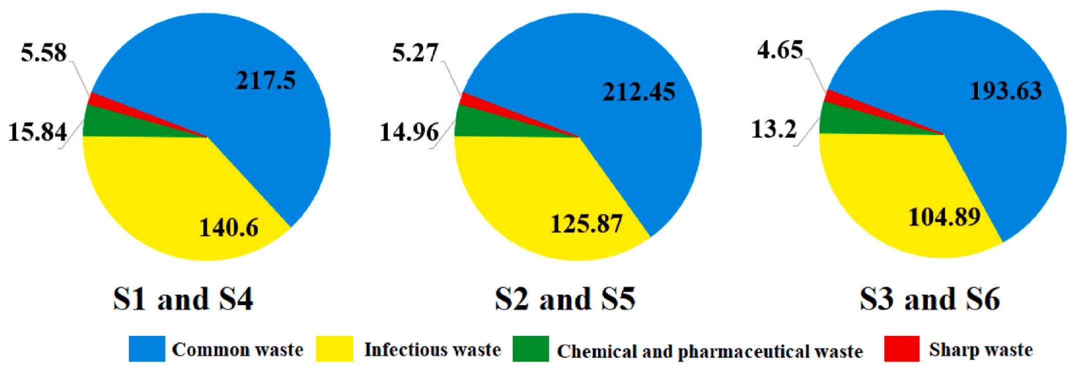

Fig. 2. Average of medical waste composition in studied hospitals (kg/day).

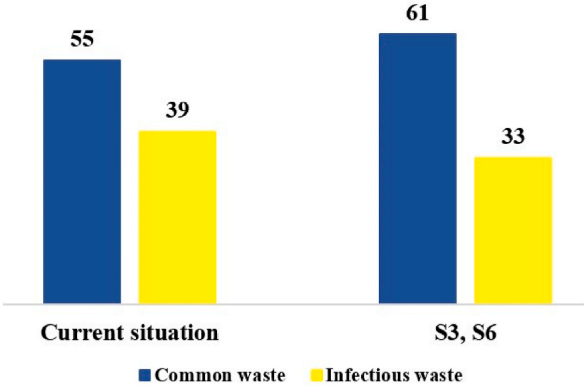

Fig. 3. Changes in the proportion of infectious waste in the best scenarios compared to the current situation (%).

scenarios defined in this study showed, choosing the best option according to the economic and technological characteristics can be effective in achieving the goals of waste management [18,26]. For example, a study of different battery waste management scenarios in Iran showed that more use of rechargeable batteries and the development of recycling can reduce the cost of battery waste management by 200,000 USD per year [18]. It has also been reported that increasing the ratio of source separation of plastic waste in the available scenarios reduces the social consequences caused by solid waste in developing countries, including waste-pickering [17].

3.3. Waste management costs

The results of the cost analysis of medical waste management in the studied hospitals are shown in Table 3. Based on this, the proportion of disinfection in waste management costs was significant in a way that included 61.4 % and 65.9 % of the total costs in centralized and decentralized patterns, respectively. Also, the disinfection pattern had a direct effect on transportation costs, so that Ex-situ disinfection required an increase in transportation costs up to 6 times. Based on this, the cost of waste transportation in the studied hospitals in S1, S2, and S3 was estimated to be much higher than other scenarios. However, the impact of indirect costs such as operating and maintenance costs of disinfection tools can be considered. Economically, in all the studied hospitals, the sixth scenario was the best option, although due to the different of waste quantity in the hospitals, different costs were calculated in this scenario. In general, the difference in waste management costs in the studied scenarios was significant. For example, in the H1 cost of waste management in the third scenario was estimated to be 21.84 % higher than the sixth scenario. But, in the H1 the calculated cost in the sixth scenario was 22.45 % less than the fourth scenario. Considering the important impact of economic aspects on the efficiency of waste management in developing countries [27], it is necessary to choose the options that support the lowest cost. However, a positive financial balance in waste management requires the use of material recycling or energy recovery [18,28] which can be considered as a

Table 3
Cost analysis of medical waste management (USD/year).

		Centralized (C8)					Decentralized (C7)				
		Storage	Collection	Transport	Disinfection	Total	Storage	Collection	Transport	Disinfection	Total
H1		82.1	739.1	404.1	2020.2	3245.5	82.1	739.1	0	1683.3	2508.2
H2		85.7	773.4	381.4	1907.4	3148.1	85.7	773.4	0	1589.5	2452.4
H3		63.1	568.3	295.2	1477.1	2403.8	63.1	568.3	0	1230.7	1865.8
S1	H1	73.9	665.2	345.4	1727.3	2811.9					
	H2	77.3	696.2	326.1	1630.9	2730.7					
	H3	56.8	511.4	252.5	1262.9	2083.8					
S2	H1	69.8	628.2	309.1	1545.5	2552.6					
	H2	73.1	657.5	291.8	1459.2	2481.7					
	H3	53.6	483.1	226	1130	1892.7					
S3	H1	61.5	554.3	257.5	1287.9	2161.4					
	H2	64.4	580.2	243.2	1216	2103.9					
	H3	47.3	426.2	188.3	941.6	1603.6					
S4	H1						73.9	665.2	0	1439.4	2178.5
	H2						77.3	696.2	0	1359.1	2132.7
	H3						56.8	511.4	0	1052.4	1620.7
S5	H1						69.8	628.2	0	1287.9	1985.9
	H2						73.1	657.5	0	1216.1	1946.6
	H3						53.6	483.1	0	941.6	1478.4
S6	H1						61.5	554.3	0	1073.2	1689.2
	H2						64.4	580.2	0	1013.3	1658
	H3						47.3	426.2	0	784.7	1258.3

complement in the chains of waste management. According to the local laws in this study, the recycling of medical waste was prohibited, which made it impossible to recover the costs of waste management. But energy recovery from medical waste was available due to high calorific value. However, the emission of pollutants such as dioxin and furan in the use of waste incinerators [29,30] is a serious concern and a limitation of this option. In general, only considering the direct costs of medical waste management cannot be desirable because each of the proposed options can have an impact on the pollutant cycle and indirect costs [24]. For this reason, life cycle analysis is a tool to estimate the quantity and fate of pollutants in different options [31], which has been experienced by material flow analysis technique for solid wastes [17,18]. Therefore, the emission of phthalates from disinfection equipment was considered in the different studied scenarios to complete the decision-making tool.

3.4. Pollutant emission

The results of the analysis of phthalate emissions from the autoclaves of the studied hospitals are shown in Table 4. The results showed that the release of phthalates in H1, H2, and H3 was 47.05, 46.57, and 34.94 μg/m^3, respectively. On average, in the studied hospitals, the concentration of phthalates in disinfection room was 42.85 μg/m^3. Considering the volume of loaded waste in the studied autoclaves, the concentration of phthalates was 0.260 μg/kg. However, the concentration of the types of phthalates analyzed was not the same, so that BEHP, IBP, and DBP was constituted 83.9 %, 11.4 %, and 3.6 % of the total phthalates, respectively. Therefore, as shown in Fig. 4, the emission of phthalates in the studied scenarios was different according to the change in the volume of infectious waste, so in S4 phthalates emission was higher than S6 by 3.80 mg/year. However, in the first to third scenarios, due to the centralized pattern, the exposure of hospital staff and clients to these pollutants was controlled.

Different types of phthalates, including di-iso-decyl phthalate (DiDP), diethylhexyl phthalate (DEHP), and dibutyl phthalate (DBP) are widely used in the production of plastics and medical equipment [32]. Therefore, the emission of these pollutants from the autoclave can be caused by the effect of heat and pressure applied during the disinfection of infectious waste, because an important part of medical waste is consisted of plastics [33]. The wide use of phthalates has ultimately made exposure to these pollutants inevitable [33], but exposure control, especially in an indoor environment, including in hospitals can reduce health consequences of these pollutants [24]. Phthalate is an important pollutant for human health because it has a short biological half-life and rapid bio-metabolism in the human body [34]. Therefore, reducing the exposure to this pollutant, especially the occupational exposure of medical waste management staff, should be defined as a priority in hospital management. Prioritizing the reduction of exposure to various pollutants, including phthalates, in the management of infectious waste will lead to the control of health consequences. Health effects vary depending on the type of phthalate and the concentration of exposure. For example, toxicity to organs such as kidney, liver, and thyroid gland tissue was reported in the face of some types of phthalates [35]. Also, exposure to some phthalates can lead to severe irritation of the skin and mucous membranes of the nasal and oral cavities [36]. Some studies reported the negative impact of exposure to phthalates on fertility in both men and women [37]. Therefore, considering to the difference in the emission of phthalates in different infectious waste management options will affect the health of hospital employees and clients.

4. Conclusion

Infectious waste management was studied in three hospitals in Behbahan, Iran. The emission of phthalates as a consequence of disinfection and also the costs of medical waste management were compared in different scenarios. The results showed that an average of 3.54 kg/day of medical waste was produced in the studied hospitals. On average, 38.9 % of hospital waste was infectious waste. On average, the disinfection of each kilogram of infectious waste in the studied hospitals led to the emission of phthalates by 26 μg/m^3. Also, the costs of medical waste management in the studied hospitals were estimated at 2403–3245 USD/year. The decentralized pattern reduced the waste management costs by 22.5 % compared to the centralized pattern. However, in the studied scenarios, the minimum exposure to phthalates was in the decentralized pattern. Estimating the economic and health consequences of waste management scenarios is necessary to reduce the costs of waste management in hospitals and to reduce the exposure of employees and patients to pollutants related to solid waste in choosing the available options. Therefore, the following can be suggested.

1. Complete segregation of infectious waste to reduce waste management costs and reduce pollutant emissions from disinfection equipment
2. Development of waste reduction programs in the hospital
3. Attention to the goals of the Green Hospital related to waste management
4. Choosing the centralized pattern in the management of infectious waste
5. Health risk assessment related to disinfection equipment for hospital staff and clients

CRediT authorship contribution statement

Nematollah Jaafarzadeh: Writing – review & editing, Writing – original draft, Methodology, Investigation. **Neda Reshadatian:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Iman Parseh:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Mojtaba Haghighat:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Touran Feyzi Kamareh:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Mohamad Sabaghan:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Hossein Malekzadeh:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Rozhan Feizi:** Writing – review & editing, Writing – original draft,

Table 4
The concentration of phthalate emissions in the studied hospitals (μg/m³).

	H1	H2	H3
DBP	2.03 ± 0.21	1.46 ± 0.11	1.18 ± 0.09
DEP	0.19 ± 0.03	0.06 ± 0.01	0.0
IBP	7.19 ± 0.44	3.51 ± 0.12	4.02 ± 0.61
BEHP	37.25 ± 2.23	41.12 ± 2.98	29.54 ± 2.56
DMP	0.21 ± 0.01	0.12 ± 0.01	0.14 ± 0.01
DOP	0.0	0.19 ± 0.02	0.06 ± 0.01
BBP	0.18 ± 0.01	0.11 ± 0.01	0.0
Total	47.05	46.57	34.94

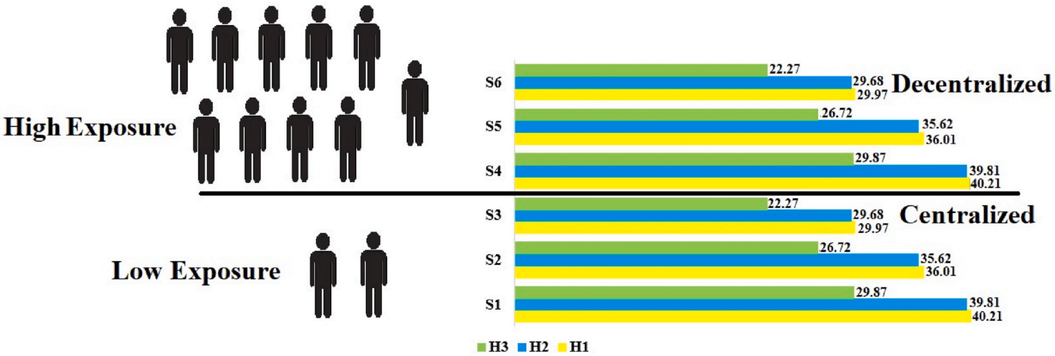

Fig. 4. The concentration of phthalate emissions in the studied scenarios (μg/m³).

Supervision, Methodology, Investigation. **Sahand Jorfi:** Writing – review & editing, Writing – original draft, Methodology, Investigation.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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