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SYSTEMS-LEVEL QUALITY IMPROVEMENT

Operating Rooms Scheduling for Elective Surgeries in a Hospital Affected by War-Related Incidents

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Abstract

Hospital scheduling presents huge challenges for the healthcare industry. Various studies have been conducted in many different countries with focus on both elective and non-elective surgeries. There are important variables and factors that need to be taken into considerations. Different methods and approaches have also been used to examine hospital scheduling. Notwithstanding the continuous changes in modern healthcare services and, in particular, hospital operations, consistent reviews and further studies are still required. The importance of hospital scheduling, particularly, has become more critical as the trade-off between limited resources and overwhelming demand is becoming more evident. This situation is even more pressing in a volatile country where shootings and bombings in public areas happened. Hospital scheduling for elective surgeries in volatile country such as Iraq is therefore often interrupted by non-elective surgeries due to war-related incidents. Hence, this paper intends to address this issue by proposing a hospital scheduling model with focus on neuro-surgery department. The aim of the model is to maximize utilization of operating room while concurrently minimizing idle time of surgery. The study focused on neurosurgery department in Al-Shahid Ghazi Al-Hariri hospital in Baghdad, Iraq. In doing so, a Mixed-integer linear programming (MILP) model is formulated where interruptions of non-elective surgery are incorporated into the main elective surgery based model. Computational experiment is then carried out to test the model. The result indicates that the model is feasible and can be solved in reasonable times. Nonetheless, its feasibility is further tested as the problems size and the computation times is getting bigger and longer. Application of heuristic methods is the way forward to ensure better practicality of the proposed model. In the end, the potential benefit of this study and the proposed model is discussed.

Keywords Operating room scheduling · Mixed integer linear programming · Elective surgery

Introduction

Scheduling is one of the most important functions in service and manufacturing operations [1]. It is responsible for the allocation of available production resources over time to meet a set of performance criteria [1]. Nowadays, the managements of firms and services are rediscovering the importance of scheduling, and are interested in how scheduling can minimize the sum of a weighted number of tardy jobs, the total weighted completion time, total costs, and the waiting time for patients, while maximizing the number of patients [2–6]. The objective of the paper is to find ways to utilize operating room for elective surgery in neuro-surgery department in which non-elective surgery due to war-related incidents were also considered. In a nutshell, the study intends to examine the potential impact of war-related incidents in a volatile country like Iraq towards utilization of elective surgeries. The case is Al-Shahid Ghazi Al-Hariri Hospital in Baghdad, Iraq. In this paper we proposed a Mixed Integer Linear programming model (MILP) where the aims are to maximize utilization of operating rooms so as to minimize potential idle time. The remaining part of this paper is organized as follows. In *Section II* literature review related to operating room

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scheduling is presented. *Section III* depicts the problem description followed by *Section IV* on the proposed model formulation. *Sections V* AND *VI* focuses on the computational experiments and *Section VII* concludes the study.

Literature review

It has become imperative for operating rooms to provide good services. Hospitals seek to reduce costs (fixed and overtime) as much as possible while maintaining a high level of quality and patient satisfaction. Scheduling operating rooms is one of the primary factors to be considered for hospitals to achieve their goals [7, 8] (Cardoen, Demeulemeester, & Beliën, 2010;Zhao & Li, 2013). According to Denton, Viapiano and Vogl 2007 [9], the value of revenues and costs of operating rooms is more than 40%. This high percentage has made hospitals and researchers focus on the scheduling of operating rooms. Some articles related to operation room scheduling aim at reducing patient waiting time [10–15]. Some researchers have focused on the total time required to complete operations [12, 16, 17] while others have studied the limitations of resources in operation rooms. They have used algorithms and models to solve this problem in order to ensure timely provision of staff, surgeons, equipment and beds [12, 18]. Other objectives of research articles include finding and developing a two level meta-heuristic to solve problems pertaining to weekend bed scheduling, operation room planning and patient scheduling for maximising patient benefit through minimised waiting time, and for maximising hospital benefit through diminished production costs [13].

Researchers have established the relationship between efficient scheduling in operation rooms and maximising utilisation [7, 19–22]. Some of the other articles and researchers have explained operation room scheduling by dividing patients into two categories namely, elective [9, 15, 17, 23–28]. and non-elective [29–33]. Some articles have studied and discussed the relationship between scheduling and capacity planning by matching the demand of operation rooms to the availability of resources [34–36]. Articles have also suggested increasing the number of surgeries in hospitals by reducing the idle time between one operation and another for surgeons [37]. Xiang, Yin, and Lim, [38] used the ACO approach to solve scheduling problems using FJSSP. They aimed to increase the efficiency of operating rooms, maximising the number of completed operations per day and allocation of adequate resources (nurses and surgeons) to the operation rooms. They used five surgery tests to resolve the following problems: improvement of patient flow, optimisation of operation room management and increasing the level of exploitation of the available resources at the hospital. Castro and Marques [28] focused on elective surgery. They proposed a GDP model based on IP planning models and MILP scheduling model to improve the overall time for surgery and to increase the number of surgeries.

Silva, de Souza, Saldanha, and Burke [39] proposed two Integer programming-based heuristics (Relax, fix heuristic and Liner programming based heuristic) to solve a daily scheduling problem at a hospital in Brazil. This model aimed at improving the utilisation of operating rooms. They generated 22 algorithms (Eighteen algorithms) by using relax-fix heuristic model to increase the occupation of operation rooms and to increase their utilisation (four algorithms). A liner programming based heuristic model was used to schedule surgeons but they were never assigned two operations at the same time. Dios, Molina-Pariente, Fernandez-Viagas, Andrade-Pineda, and Framinan [40] focused on DSS for operation room scheduling in the Virgen Del Rocio, Spain using the MILP model. The research problem centred surgery scheduling problems and how these could be solved by the manager by applying DSS. This article aimed at improving the quality of service at the hospital by reducing patient's waiting time through medical priority. Bouguerra, Sauvey, and Sauer [41] used a mathematical model to increase operating room utilisation and minimising idle time. They used the LIP model to solve the problems of distribution of surgeons and patients to operating rooms and determination of medical priority of patients who needed operating room services. Saadouli, Jerbi, Dammak, Masmoudi and Bouaziz [42] focused on the assignment of surgeries to an operating room. They used the MILP model to minimise the make-span, waiting time, overtime, and maximise utilisation. They used a DESM model to analyse the scheduling. Schmid and Doerner [43] based their study on operating and examination room scheduling in a medium-sized hospital in Austria. By using LNP, the researchers proposed a new model called CHM to achieve their research objectives of reducing total costs and idle time. Veen-Berkx, Elkhuizen, Kuijper and Kazemier [44] used Q-ECTS and experimental data to realise their research objectives of increasing utilisation, reducing total overtime and number of operating rooms used after 4 PM, and reducing surgery cancellations. Regrettably, the results from this study were quite different than the simulation results from previous studies owing to the empirical nature of data. Saremi et al. [12] studied operating room problems such as the lack of human and material resources and the limited availability of appropriate specialised surgeons for a patient. Their research objectives were reducing waiting time, make-span for patients and minimising surgery cancellations. The researchers used three simulation methods: STS, IPETS and BPETS, and achieved their objectives. BPETS minimised the make-span better when the actual completion time was compared to the simulated schedule. IPETS reduced the waiting time. STS reduced the frequency of operation cancellations.

Li, Rafaliya, Baki and Chaouch [45] focused on four objectives i.e. decreasing the expected number of patients awaiting processing, maximising the utilisation of operating rooms, decreasing the prospective of patients in recovery rooms and estimating their average number. They used the ILP model, two goal programming Lexicographic GP and Weighted GP to solve their research problems of elective surgeries. The research was successful in achieving its set goals. Marques, Captivo and Vaz Pato [46] selected elective surgeries at the central and university hospital in Lisbon. Their article aimed at increasing the utilisation of surgical rooms and minimising the waiting time for patients. To achieve these goals, the researchers determined the following objectives: maximising the use of operating rooms and rescheduling urgent surgeries by including them in the subsequent week's scheduling. The researchers proposed an ILP approach to meet their objectives. [47] used two MILP methods to solve their article problems of finding the best scheduling of operating rooms to reduce over time and waiting time of the patients at the SFAX hospital in Tunis. This research proposed a model for elective surgery scheduling. The results from the study showed a 28% improvement in completed surgeries in first MILP and 32% in the second MILP. Jeang and Chiang [48] studied the quality and economics of operating room scheduling. They focused on three constraints in their study: Are there operating rooms available? Are there doctors available when needed? What is the number of operations that can be undertaken by the hospital in the planned duration? The researchers aimed at reducing the overtime and idle time for operating rooms and increasing their utilisation. To achieve the research goals, they proposed a mathematical programming method based on NLIP. This model helped the hospital reduce costs without affecting the quality of service.

Marques, Captivo, and Pato, [49] worked to find solutions to the three problems of scheduling operating rooms so as to ensure the allocation of surgery to each room at a specific time, ensure the presence of a surgeon in an operating room at a particular time and not exceeding the upper limit of hours for surgeons in operating rooms. To solve these problems, the researchers proposed two ILP models and accomplished their research goals through increased susceptibility operating rooms and by running the rooms to their maximum capacities. This methodology was practical and had great applications as a DSS to schedule and plan operating rooms efficiently. Riise, Mannino and Burke [50] generated a new model to solve surgery-scheduling problems. They used an ACI algorithm to realise their research goals of reduction of total time of work and total costs. They focused on Norwegian hospitals and their daily, weekly scheduling and planning.

Problem description

This article focuses on Al-Shahid Ghazi Al-Hariri a biggest public hospital in Baghdad related with Ministry of health in Iraq. The hospital has 10 surgical departments with 24 operating rooms and 90 surgeons and serviced around 15,000 surgeries yearly. Each surgical department have a specific set of operating room. Each set of operating room have a unique and specially type of equipment. This article focusses on neurosurgery department because it is deal with cases come from conflict and because of the high number of injures (head and spin). This department have 3 operating rooms, 10 surgeons and served around 130 cases per month. The hospital work 5 day per week and 8 h per day. In this study the model is built according to following assumptions:

- Focusing on elective surgery only (with probability of potential interruptions of non-elective surgery).
- Surgeon cannot move to other room or other patient before finish his work.
- Rooms, staffs and patients must be ready on time and date of scheduling.
- Sterilization and cleaning were calculated within the duration of surgery.
- First operation starts at 8:00 am.
- Assigned at least one operation for each operating room per day.
- No overtime accepted.

In this article, works to assigned one patient to one operating room with at least one surgeon at the beginning time of workday to avoid any lack of surgeons and waiting and idle time of patients and make a space for cases coming from conflict.

Model formulation

This section elaborates model formulation for this study. The study develops a Mixed-integer Linear Programming model (MILP) in which the scheduling goal is to maximize utilization of operating rooms. Probability of non-elective surgery or incoming patients that require immediate surgery is also incorporated into the model. The probability represents scenario in al Shahid Ghazi al-Hariri hospital in Baghdad for which scheduling for elective surgeries were occasionally interrupted by incoming war-related incidents victims that require immediate treatments. Follows are details of the model:

Index set

Ds: Duration of surgeries; This will be measured in minutes to avoid any losses in time and eliminate idle time and waiting time.

SCs: Surgeon assigned to surgery *s*: The focus will be on surgeons working in the neurological department.

AScdt: gives the availability of surgeons' c in the day d at period t: it will explain which surgeon available in neurological department will be scheduled the day d at period t.

$$AScdt = \begin{cases} 1\ if\quad surgeon\ c\ is\quad available\quad the\ day\ d\ at\ the\quad begining\quad of\quad the\quad period\ t \\ 0\ otherwise \end{cases}$$

Input parameters

S: set of surgeries {1...ns}: It is defined by surgeons and approved by neurosurgery department according to patients waiting list. The surgeries must be scheduled to operating room.
C: set of surgeons {1….nc}: The set of surgeons available for operating scheduling.
R: set of rooms {1….nr}: The set of room available for operating
D: set of days {1…nd}: The set of day available for scheduling**.**
T: set of periods {1…nt}: Time available for scheduling.
$\mathbf{T_{cd}^{MaxD}}$**:** Operating time limits for each surgeon.
Ns: number of elective surgeries to schedule:
Nc: number of surgeons.
Nr: number of rooms.
Nd: number of days.
Nt: number of unit period.

Decision variable

$$Xsdrt = \begin{cases} 1\ if\quad surgery\ s\ is\quad start\ on\ day\ d\ in\quad the\quad room\ r\ at\ the\quad begining\quad time\ t \\ 0\ otherwise \end{cases}$$

$$Ycdr = \begin{cases} 1\ if\quad surgeon\ c\ is\quad assigned\ on\ the\ day\ d\ at\ the\quad room\ r \\ 0\ otherwise \end{cases}$$

Objective function

The objective is to maximize the utilization rate of operating room by maximizing the operating room occupation and minimizing the idle time between surgeries while taking into account probability of receiving incoming patients (non-elective) affected by war-related incidents. The model is formulated as follows:

$$MAX = a\begin{bmatrix} operating\quad room \\ occupation \end{bmatrix} + \beta\begin{bmatrix} SURGERY\quad IDLE \\ TIME \end{bmatrix} * \begin{matrix} Probability\quad of\quad received \\ patients\quad come\quad from\ war \end{matrix}$$
$$MAX\ Z = a\sum_{s\in S}\cdot\sum_{d\in D}\cdot\sum_{r\in R}\cdot\sum_{\tau\in T}\cdot[Xsdrt\ Ds] + \beta\sum_{s\in S}\cdot\sum_{d\in D}\cdot\sum_{d\in D}\begin{bmatrix} (nd-d+1) \\ (nt-t+1)xsdrt \end{bmatrix} *prob/ \quad (1)$$

The objective function has three parts. According to Marques, Captivo, and Vaz Pato [46] the first part concerns the maximization of the occupancy of operating room. The second part of the function allows operations to be planned at the earliest (in terms of periods and also in terms of days) [41]. While the third part demonstrates the probability of receiving cases came from war-related incidents and requiring immediate surgical intervention. First and second part of objective function are weighted with $\alpha > \beta$ in order to reflect the significant importance of operating room occupation with compared with surgery idle time.

Constraints

The constraints are as follows:

1. To avoid any overlapping between surgeries.

$$\sum_{s\in S}\cdot\sum_{d\in D}\cdot\sum_{r\in R}\cdot\sum_{t'=t-Ds+1_{t'\in Tc}}^{t}\cdot\left[xsdrt' \leq 1, \forall s\in S, d\in D, r\in R, t\in T\right] \quad (2)$$

2. To ensure surgeon is assigned to only one operating room and can only leave to a second room or second surgery after completion of the first operation. The number Y must be equal to or smaller than 1

$$\sum_{c\in C}.Ycdt \leq 1, \forall D\in d, \forall T\in t \quad (3)$$

3. To ensure that each surgeon operates on according to his availability. The number X during duration of surgery must be equal to or smaller than sum of availability of surgeons that are assigned to surgery S.

$$[Xsdrt\ Ds] \leq \sum_{t'=1}^{Min(t+Ds-1,nt)} AS\ SCsdt' \quad (4)$$

4. To ensure that each operating room r in the period t can accept only one patient intervention through the availability of operating room. The number X must be equal to or smaller than 1.

$$\sum_{s\in S_{d\in D}}.Xsdrt \leq 1, \forall r\in R, \forall t\in T \quad (5)$$

Table 1 Problem size

No.	Number of day (nd)	Number of surgeon (nc)	Number of surgery (ns)	Number of room (Nr)	Number of time (T)	Variables
1	1	10	50	3	8	1200
2	2	10	70	3	8	3360
3	3	10	90	3	8	6480
4	4	10	120	3	8	11,520
5	5	10	150	3	8	18,000

5. The time available for surgery is the same as the actual working time for surgeons (extra work is not allowed). In this constraint want to ensure that the daily operating time is limit for each surgeon.

$$\sum_{S \in s} DsXsdrt \leq TcdMaxD \forall d \in D, c \in D \qquad (6)$$

6. To find links between decision variables (surgeries and surgeons).

$$\sum_{s \in S} Xsdrt \leq ySCsdt \forall d \in D, r \in R, t \in T \qquad (7)$$

7. To ensure that the variables are in the domain and they are binary variables

$$(Xsdrt) \in \{1, 0\}, \forall s \in S, d \in D, r \in R, t \in t \qquad (8)$$

$$Ycdr \in \{1, 0\}, \forall c \in C, d \in D, r \in R, \qquad (9)$$

Computational experiments using randomly generated data

In order to evaluate the performance and limitations of the proposed model, we randomly generated 50–150 cases in each of the problem sizes tested. The sizes generated are divided in five working day. This is in line with the planning horizon in terms of number of days (*nd*) and the number of surgeries to be planned (*ns*). The number of surgeons (*nc*) are fixed. We consider, for the experiments presented, the case of (3) operating rooms available simultaneously for 8 h period per day. The number of surgeons (*nc*) is 10. The availability of surgeons is generated randomly. First, we generate the number of days each surgeon must be present within the operating room. In addition, we require that each surgeon must be in attendance for at least one day during the planning interval. Secondly, we generate number of surgeries for their working days and the number of period to work per-day. Table 1 depicts problem size, number of variables and randomly generated data.

The experiment was executed on a PC with Intel (R) core (TM) i3-2328M, CPU 2.20 GHz and 2.00GB RAM and solved using Microsoft Visual Basic. Net 2012. Table 2 shows summary of the computational results:

I. Computational experiments using real data from Al-Shahid Ghazi Al-Hariri Hospital

This section will be testing the model with data was collected from Al-Shahid Ghazi Al-Hariri hospital in Baghdad with 5 of work days per week and 20 days per month, number

Table 2 Computational result with random data

No.	Number of day (nd)	Number of surgeon (nc)	Number of surgery (ns)	Utilization	Time
1	1	10	60	0.74	453
2	2	10	80	0.75	952
3	3	10	100	0.79	1172
4	4	10	150	0.84	2036
5	5	10	200	0.90	1753
6	6	10	250	0.97	2235
7	7	10	300	0.98	2989
8	8	10	400	0.97	3389

Note: Time was calculated in seconds

Table 3 Computational result with real data

No.	Number of day (nd)	Number of surgeon (nc)	Number of surgery (ns)	Utilization		
				R1	R2	R3
1	1	10	6	0.98	0.98	1.06
2	2	10	6	1.00	0.95	0.90
3	3	10	6	0.79	0.97	0.87
4	4	10	6	0.75	0.78	0.71
5	5	10	6	0.64	0.63	0.62

of weekly workhours, number of operating rooms available and number of surgeons present in the Neurosurgery department in problem description. Table 3 shows the utilization of operating room for week number one as follow:

Chart 1 shows the behavior of utilization rate for operating affected by war-related incidents (Fig. 1).

From the table and chart above, we can see that the utilization rate increased up to 100% in all three rooms in the first day of the week and in second day for room one and two. In these cases, the hospital will face problem related with spending extra money for extra time of surgeons and assistants, but because Al-Hariri Hospital is a government hospital and the resources is limited so the management of hospital need to find another solution to avoid any extra expenses by railing on surgeons in night shift. Table 3 show the utilization of operating rooms in neurosurgery for the three rooms when it is interrupted by non-elective surgeries for war-related incidents. In Tables 4 and 5 below show the total utilization for each day in one month by finding the average utilization for three rooms. The table express clearly how the hospital can increased the utilization by relying on internal resources (surgeons, nurses …etc) to receive incoming war-related incidents.

Table 4 depicts the utilization in operating room for week (2–4). From the table we can see that on the first day of the week full utilization had been achieved for all rooms while room 1 had achieved similar feat in the following day. The high utilization in this day came from the minimization of the waiting time for patients, minmize the idle time for surgeons and maximizing the occupation of operating room through high response to all patient under scheduling plus the cases war-

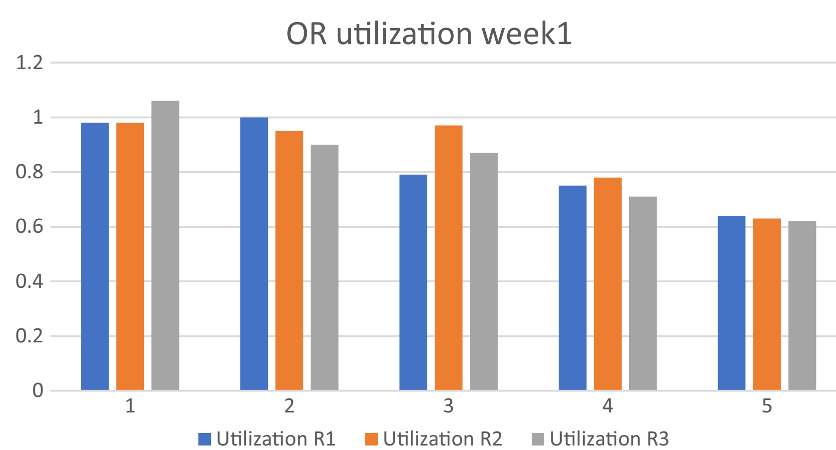

Fig. 1 Utilization rate war-related incidents of week 1

Table 4 Utilization for week 2–4

NO.	Number of day (nd)	Number of surgeon (nc)	Number of surgery (ns)	Week2			Week3			Week4		
				R1	*R2*	*R3*	*R1*	*R2*	*R3*	*R1*	*R2*	*R3*
1	1	10	6	1.11	1.05	1.07	1.1	1.07	1.08	1.12	1.07	1.14
2	2	10	6	1.04	0.93	0.94	0.98	0.99	0.96	0.96	0.93	0.96
3	3	10	6	0.87	0.86	0.85	0.84	0.85	0.87	0.82	0.85	0.86
4	4	10	6	0.64	0.69	0.78	0.79	0.72	0.72	0.69	0.76	0.72
5	5	10	6	0.64	0.68	0.59	0.68	0.61	0.59	0.59	0.59	0.64

Table 5 Summary computational with real data for weeks with time

No.	Number of day (nd)	Number of surgeon (nc)	Number of surgery (ns)	Week1	ETs	Week2	ETs	Week3	ETs	Week4	ETs
1	1	10	6	1.07	170	1.07	189	1.08	204	1.10	117
	2	10	6	0.99	255	0.97	310	0.97	289	0.97	197
3	3	10	6	0.89	833	0.86	780	0.85	447	0.84	564
4	4	10	6	0.75	328	0.70	455	0.74	376	0.72	383
5	5	10	6	0.61	447	0.63	430	0.62	623	0.61	204
Total time					2033		2164		1939		1465

related incidents. Although the high results have been recorded in room (3) in week (4) on the first day of scheduling with (1.14), while the lowest utilization rate of operating room recorded in the fifth day in weeks (2,3,4) at rooms (3,3,1,2) sequentially. Back to Table 5 the result shows the utilization of operating room for one month in which we can see that the utilization in the first day was at 100% rate. The highest utilization was on the first day in week (4) it was (1.10) while the lowest utilization was on the fifth day in week (4) it was (0.61). The lowest utilization rate came from the high waiting time of patients. From the tables above, we want to confirm that our model work to maximize the occupation of operating room and minimize the idle time between surgeries and received another case came from conflict and enter it with elective surgery.

Conclusion

This research intends to find ways of utilizing operating room availability of Al-Shahid Ghazi Al-Hariri hospital by using a mathematical programming method. The focus was on non-elective surgery of the Neurosurgery department with probability of interruptions of non-elective surgery due to war-related incidents.

A MILP model was developed to address the issue. The model aims to maximize utilization rate of operating room so as to minimizing the idle time between surgeries. The workability of the model was then tested. The computational experiments showed that the model is workable and feasible. Nevertheless, the time taken to solve larger problem size was longer. Hence, the usage of heuristics method is the way forward and require further investigations. Future research is needed to determine the near best solutions for scheduling in operating room using heuristics methods to make the model faster and more practical. Overall, the proposed model has managed to demonstrate its potential usability and capability. It may also be beneficial to hospital administrators or regulatory bodies particularly in volatile country where hospitals are dealing with victims from war-related incidents, and where scheduling for elective surgery often interrupted by non-elective surgery.

Author's Contribution Hussein Hasan Ali: Responsible for writing the side related of the literature review and developing the mathematical model and formatting the problem description. In the other hand, responsible for testing the model and comparing results.

Dr. Hendrik Lamsali: Responsible for review and modify the article.

Dr. Siti Norezam Othman**:** Responsible for review and modify the article.

Compliance with Ethical Standards

Conflict of Interest authors declare that they have no conflict of interest.

Ethical Approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed Consent Informed consent was not required for this study.

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