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HEALTHCARE SYSTEM USING A MEDICAL SERVICE ROBOT BASED ON INTERNET OF THINGS

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ABSTRACT

The coronavirus (COVID-19) epidemic in Egypt exposed the medical community to a high risk of death. Because cases erupted later in Egypt than in many other countries, the Egyptian medical community was warned of the injuries caused by contact between medical staff and infected patients, which led to the breakdowns of health systems. To protect against these injuries, this study proposes a medical service robot (MSR1) that fights the spread of COVID-19 by sterilizing its paths. Moreover, the robot provides health and medical services to patients in their rooms, avoiding direct contact between patients and medical staff. The MSR1 robot was designed and realized using electronic device components and sensors. Its video frontal camera is installed with a chat application that allows easy communication with patients. The proposed MSR1 architecture was examined remotely by our colleague patients using Internet-of-Things (IoT) technologies. The evaluation confirmed the reliability of MSR1 and its fast response to issued commands.

Keywords: Arduino, covid-19, C++, flutter, robotics, healthcare, IoT.

1. INTRODUCTION

Internet-of-Things (IoT) is a network that connects the internet to physical devices such as vehicles and homes. IoT permits remote sensing and monitoring of objects through existing networks [1]. Clearly, this technology offers large benefits to professionals in the community, health, and related fields [2]. During the novel coronavirus (COVID-19) outbreak, medical staff faced a high risk of infection [3]. To prevent spread of the coronavirus infection among the medical community, we designed a medical service robot (MSR1) that provides medical services to COVID-19-infected patients in isolation wards.

The robot provides patients with food and medicine and sterilizes their rooms and the hospital passages. To prevent direct contact between the patients and medical staff, the robot is remotely controlled through electronic and electrical sensors and is installed with a video chat application for easy, contactless communication with patients. The main contributions of the MSR1 robot control system are summarized as follows:

- The system is remotely controlled with a joystick over a distance range of 1000 meters in open spaces and 500 meters in closed spaces.
- The android application in the robot enables doctors to communicate with patients through video calls, which limits the direct contact between the medical staff and infected patients.
- The robot has a sterilization system that sterilizes the paths taken by the robot.
- By sensing its environment, the robot circumvents obstacles in its path and avoids falling downstairs.

The rest of this paper contains the related work in Section 2 that briefly illustrates the current work in robot healthcare system based IoT by which we highlighted two robots in Istanbul and Mansoura University. The proposed architecture of MSR robot is illustrated in detail in Section 3. While the design, implementation, testing, and operation stages are demonstrated in Section 4. The results and discussion of different MSR scenarios are investigated in Section 5. Finally in Section 6 the conclusion and future work related to this work.

2. RELATED WORK

Robotics has replaced or supplemented humans in many fields, especially customer service and certain nursing tasks, because it avoids direct connection between two humans. Moreover, Wan *et al*. [1] demonstrated in case studies that robots lower the perceived risk of COVID-19 infection using a bootstrapping approach. They analyzed the changes of customer visits during the pandemic in an Amazon Mechanical Turk and Tencent Questionnaire. More precisely, Robots can link their physical components to the internet. Such technology, called IoT enables the early identification of the objects and patients using these devices. Robots can help health staff by handling patient management and reducing work stress [2].

Yang *et al*. [3] reported that robotics can assist COVID-19 arrest by delivering medications, disinfection, and food, measuring vital signs, and assisting border controls. Furthermore, the robot can track non-contact ultraviolet surface disinfection, measure the patients' temperatures, and assist nasopharyngeal and oropharyngeal swabbing to detect COVID-19 positive cases [4]. Murphy *et al*. [5] surveyed 203 examples of robot use in COVID-19 applications and classified these applications into six five groups: public safety, clinical care, education, supply chain automation, and non-hospital care. Tavakoli *et al*. [6] outlined the variety of healthcare delivery services

ARPN Journal of Engineering and Applied Sciences

performed by healthcare robot interactions (HRIs) and compared the task uncertainties in the HRI modality and human roles. They also investigated the COVID-19-related services provided by HRI.

Khan *et al*. [7] compared the performances of different medical robots with different specifications. They investigated the most common robot used in the healthcare field, which performs services such as cleaning, nursing, food service, and waste removal. Lewis *et al*. [8] presented a comparative study of robotics routines in pediatric care. Freeman *et al*. [9] declared that robots can be easily employed at the Intensive Care Unit level and can decrease the waste of personal protective equipment worn by health workers after COVID-19 exposures. Paulius and Sun [10] reviewed the most common knowledge representations of robotic operations in practical tasks. Kim *et al*. [11] presented a cruising stereotactic electroencephalogram robot for adult patients with epilepsy who are resistant to medical treatment. Below we describe the results of experiments performed in Istanbul and Mansoura University as follows.

2.1 Tetrobo Robot

This robot is remotely controlled by a mobile application, thus limiting direct contact between the medical staff and infected patients. The robot provides the patients with food and medicine. It is used in the Medicine College of Istanbul University [15].

2.2 Mansoura University Robot

This robot provides patients with food and medicine in their rooms. The robot is remotely controlled over distance ranges of 200 and 1000 meters in closed and open spaces, respectively. It captures images with a normal camera and sends them to the controller in the control room [16].

The MSR1 robot has a range of application abilities; for instance, it can sterilize the roads along which it passes, permit contactless doctors-patient interaction through video calls in a chat room, and perform obstacle and stair-falling avoidance by observing the environment through a set of sensors.

3. PROPOSED MSR1 ROBOT ARCHITECTURE

Figure-1 shows the input-process-output of MSR1. The input contains the patient IDs and names, the patients' faces captured by the camera sensor, the patients' inputs from the chatting room (voice messages recorded by a microphone), the stored x-ray images of COVID-19-positive patients, and the materials available for sterilization. The processing stage simultaneously executes the programming of each enrolled feature. The output response of the MSR1 robot is based on IoT and the assigned mobile application. The components and characteristics of the MSR1 robot are summarized in Table-1. The essential components include a power bank, nozzles, a tablet, and wires.

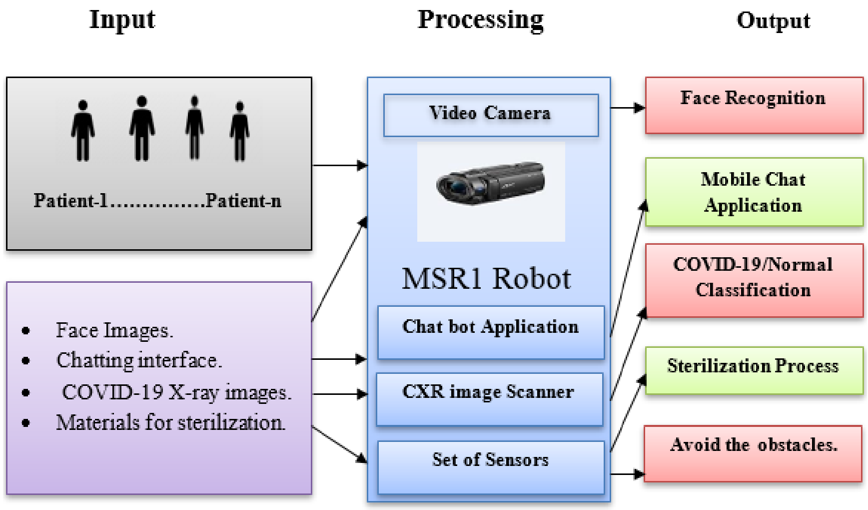

Figure-1. Input-process-output of the proposed MSR1 robot.

4. DESIGN, IMPLEMENTATION, TESTING AND OPERATION STAGES

4.1 Design and Implementation Stage

In this paper, the structure/operation of the proposed MSR1 architecture was divided into three categories. The first stage was the design stage, in which the components of the electronic devices were connected. The power supply was 12 V, and the interconnected circuits were grounded as shown in Figure-2. Figure-3 shows the connecting wires between the Arduino, nRF24L01 module, and driver motor. In the implementation stage, the MSR1 robot was constructed from natural wood and metal pillars (see Figures 4 and 5). The initial form of the MSR1 robot is presented in Figure-6.

4.2 Testing Stage

In this stage, the proposed MSR1 architecture was tested for its ability to perform its main objectives: sterilizing the paths along which it passes, permitting contactless doctor-patient interactions through video calls in the chatting room, and avoiding obstacles and stair

ARPN Journal of Engineering and Applied Sciences

falling. Figure-7 displays the sterilizing process of the MSR1 robot over the specified area, which is determined and adjusted by the user. Obstacle avoidance and stair recognition are realized by ultrasonic sensors attached on the front and back of the MSR1 robot. When the robot senses a descending or ascending stair, it tracks back to the patients' rooms. Figure-8 shows the ultrasonic sensors installed at the sides of MSR1 for obstacle avoidance.

Table-1. Main component devices in the MSR1 healthcare robot.

Component	Image	Specifications
1. DC Motors		Geared Motor 183 r/min, 50 kg.cm, 12 V.
2. Drives DC Motor Driver		DC Motor Driver Single Channel with Double BTS7960 43A H-bridge High-power Module.
3. Arduino Uno		The Arduino Uno is an open-source microcontroller board based on the Microchip ATmega328P. The board is equipped with sets of digital and analog input/output (I/O) pins.
4. Arduino Mega		Arduino Mega is a microcontroller board based on ATmega2560. It has 54 digital input/output pins.
5. Joystick		Joystick Shield Module is a Uno Compatible Shield that allows the user to turn an Arduino Uno or compatible into a game console or robotic controller. Its voltage range is 3.3-5.0 V. Gamepad Joystick Shield Module Game Rocker Button Controller Expansion Board for Arduino Simulated Keyboard Mouse Module.
6. nRF24L01		This 2.4-GHz NRF24L01 Module with a PA LNA SMA Antenna uses a 2.4- GHz transceiver from Nordic Semiconductors. The nRF24L01+PA+LNA transceiver IC operates in the 2.4 GHz band and has many new features.
7. Ultrasonic Sensor		Ultrasonic sensors measure distance using ultrasonic waves. The sensor head emits an ultrasonic wave and receives the reflected wave from the target. Ultrasonic Sensors measure the distance to the target by measuring the time between the emission and reception.
8. Pump		DC 12V 40W High-pressure Diaphragm Water Self-Priming Pump 4 L/Min

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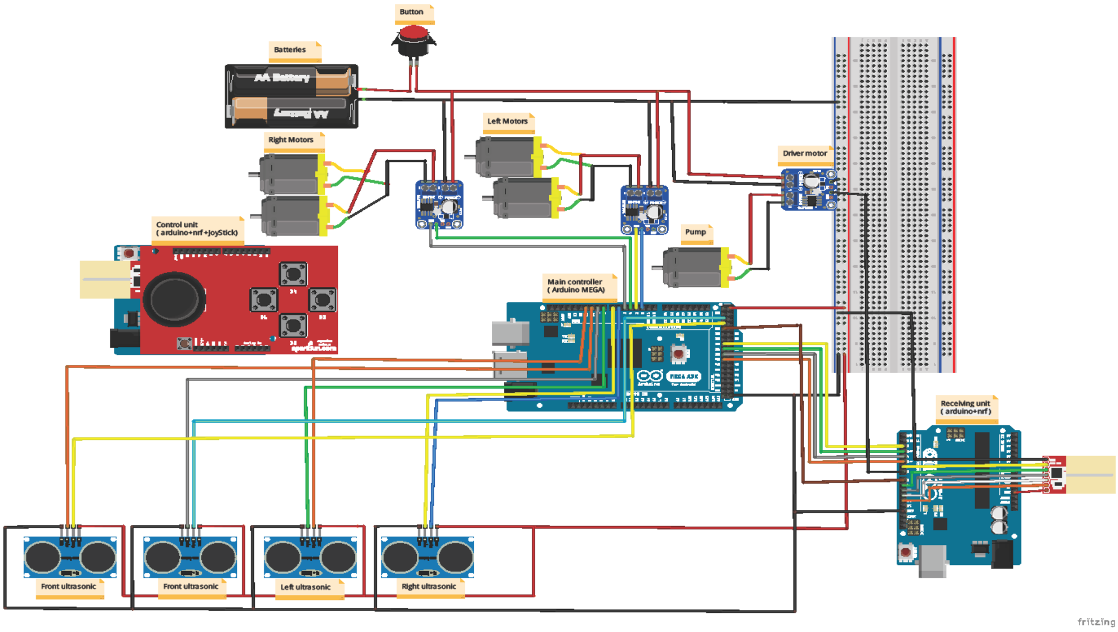
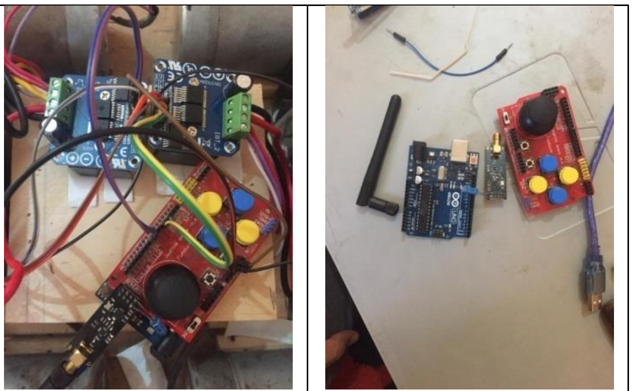


Figure-2. Circuit diagram of the proposed MSR1 robot.



(a) (b)

Figure-3. The nRF24L01 module and Arduino: (A) interconnected cables, and (B) Arduino with the joystick control and driver motor.

(a) (b)

Figure-5. Implementation and design of the rack-holding pillars of the MSR1 robot: (A) left side view, and (B) right side view.

(a) (b)

Figure-4. Implementation and design of the outer MSR1 robot: (A) left side, and (B) right side of the MSR1 base.

(a) (b)

Figure-6. Initial outer form of the MSR1 robot: (A) left side view, and (B) right side view.

Figure-7. Sterilization system of MSR 1.

Figure-8. Side-installed ultrasonic sensors of MSR1.

4.3 Operation Stage

The third and final stage of the MSR1 robot is the operation stage, in which the operations of the proposed robot are tested and performed. Figure-9 shows the MSR1 robot after assembling and equipping all parts. The video call mobile application uses a graphical user interface (GUI) and an android operating system connected through a local area network (LAN) that requires no explicit internet as shown in Figure-10. Through the video call function on the GUI, this application handles the direct connections between the patients and the room of the monitoring doctor, who directly tracks the patients' cases and meets the patients' requirements. The user controls the movements of the MSR1 robot using the joystick shield, as shown in Figure-11. The control operations on the joystick shield are listed in Table-2.

Figure-9. Finally assembled MSR1.

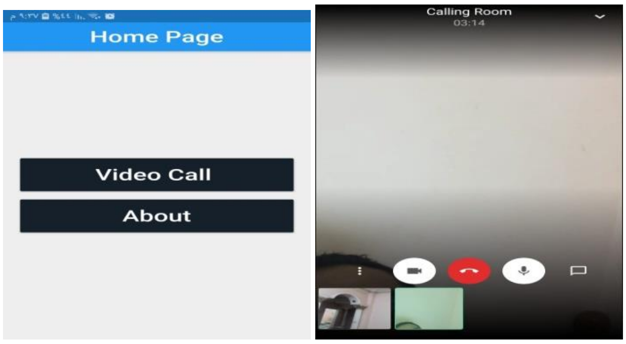


Figure-10. MSR1 Android application.

5. RESULTS AND DISCUSSIONS

We tested the MSR1 health care services of the MSR1 robot in three scenarios. In the first scenario, we determined the response time of performing movement tasks between the patients' rooms. Table-3 lists the arrival times (in seconds) of the robot's movements over various distances (in meters) to the patients' rooms in the absence and presence of obstacles.

In the second scenario, we determined the response times of capturing images and performing LAN-based video calls between the patients and the monitoring doctor's room. The MSR1 robot allows video calling between the doctors in the control room and all patients inside their rooms as investigated in Figure-12. The patients' faces are captured and stored in the database to authenticate their enrolment to the MSR1 robot. The time required to image an enrolled patient was 0.5 seconds and the video calls between patients and doctors were quickly and directly communicated through the LAN, without requiring the internet.

In the third scenario, we determined the surrounding area that can be sterilized by the MSR1 robot. MSR1 required only 0.25 seconds sterilizing the surrounding area by automatically calling the pumping function, which pumped the sterilization fluid located in the glass aquarium. The MSR1 sterilization area was 3.5 m2 for every one-meter movement to the patients' rooms. The COVID-19 cases were classified in the patients' chest X-ray (CXR) images using the Chest X-ray Covid Network (CXRVN) presented by Elzeki *et al*. [12]. The CVXRN was trained on the dataset presented by Shams *et al*. [14], which contains three class labels: normal, Covid-19, and pneumonia patients that can be augmented using generative adversarial networks as presented by Shams *et al*. [13].

Table-4 compares the services provided by the MSR1 robot and other recently proposed robots [7, 12]. The proposed MSR1 robot showed promising ability in multitask operations: nursing, pharmacy, lab, food services, video calls, sterilization, and classification of CXR images.

Technological advances can potentially refine manufacturing from industrial production to customized products. To appraise the potential of the proposed MSR1 robot in the next manufacturing market, we conducted a strength, weakness, opportunity, and threads (SWOT) analysis of MSR1. The outcome of the SWOT analysis is displayed in Figure-13.

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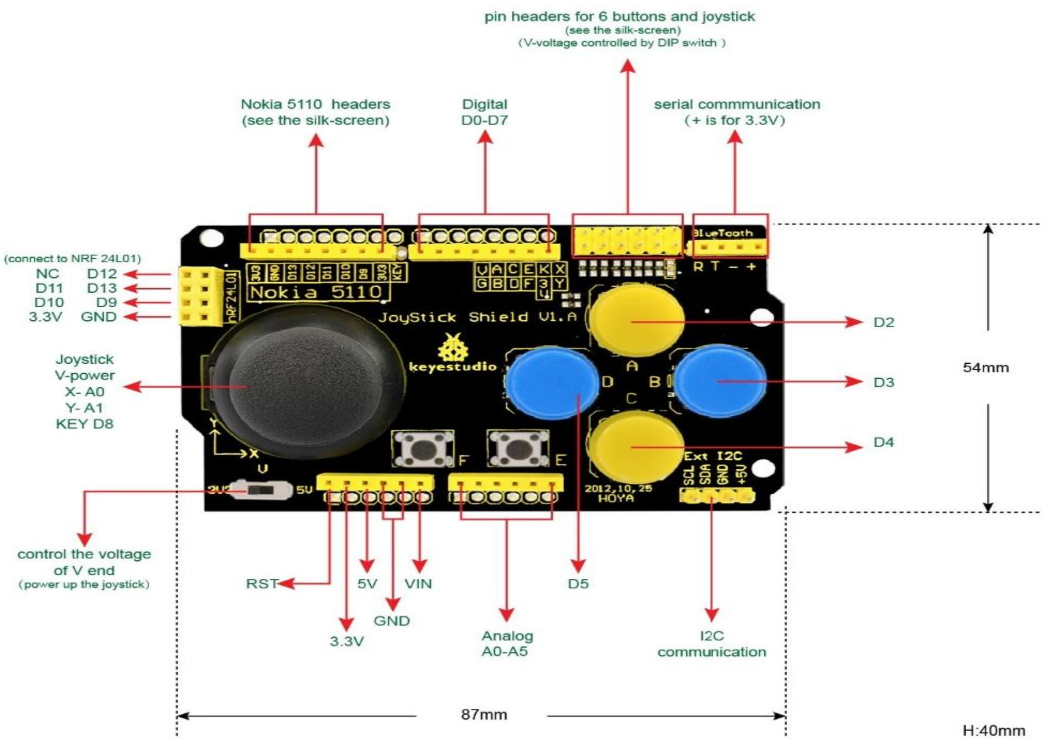

Figure-11. MSR1 joystick shield.

Table-2. MSR1 operation controls on the MSR1 joystick shield.

Button	Operation
X-Right	Forward ultrasonic on
X-Left	Forward ultrasonic off
Y-Top	Pump on
Y-Down	Pump off
E-Button	Side ultrasonic on
F-Button	Side ultrasonic off
A-Button	Robot move forward
C-Button	Robot move backward
B-Button	Robot move right
D-Button	Robot move left

Table-3. Times of moving the MSR1 robot toward the patients' rooms.

Distance to the patients' rooms (m)	Elapsed time (s) without obstacles and stairs	Elapsed time (s) in the presence of obstacles and stairs
1	3.77	4.00
10	32.64	33.21
50	170.25	175.65
100	355.85	362.11
150	510.20	523.24

Figure-12. An MSR1 video call between patients and the doctor in the control room, conducted through the LAN-based android mobile application.

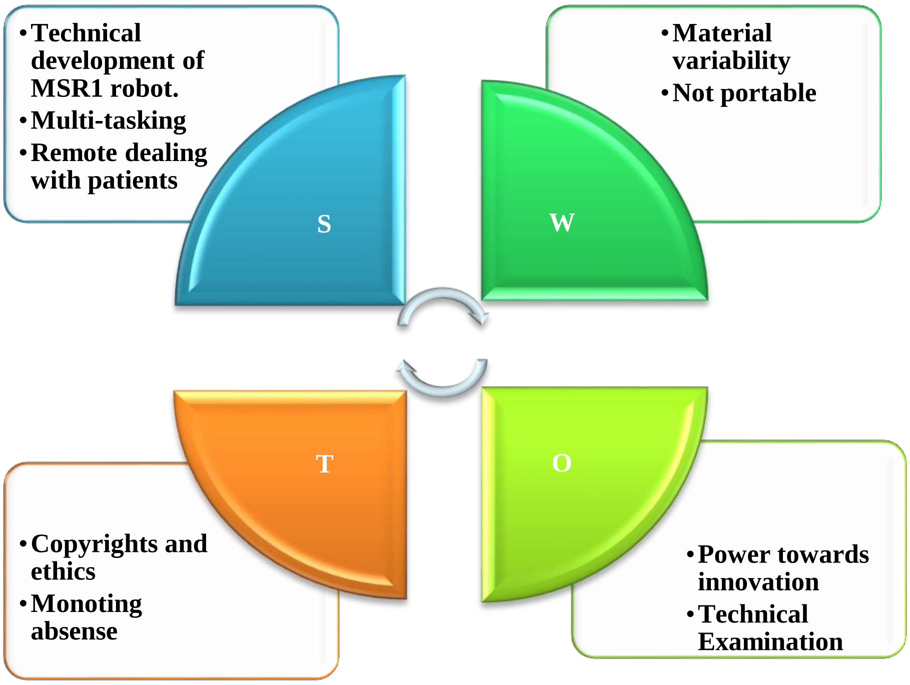

Figure-13. SWOT analysis of the proposed MSR1 robot.

Table-4. Comparative study of the services presented by the proposed MSR1 and recent healthcare robots.

Robot	TUG	RP-VITA	Moxi	Relay	Ambubot	Drone Robot	Dinsow	Mansoura Robot	MSR1
Country of origin	**Aethon(USA)**	**iRobot(USA)**	**DiligentRobots (USA)**	**Swisslog (Switzerland)**	**Thailand**	**TU Delft (Netherlands)**	**CT Asia Robotics (Thailand)**	**Mansoura university (Egypt)**	**Kafrelsheikh University (Egypt)**
Nursing	√	√	√		√	√	√	√	√
Pharmacy	√		√	√	√	√		√	√
Lab	√			√					√
Food Service	√			√				√	√
Waste Removal	√			√					√
Video Call									√
sterilization system									√

6. CONCLUSIONS AND FUTURE WORK

We presented our multitask robot called the medical service robot (MSR1). This robot enables doctors to remotely monitor and track patients' cases using IoT technology. The MSR1 robot services include nursing, pharmacy, lab, food services, waste removal, sterilization, and classification of CXR images. We tested the MSR1 robot in three different scenarios: determination of the time required to move the MSR1 robot between the patients' rooms in the presence and absence of obstacles and stairs, the enrolment of all patients in the mobile android application that communicates with patients through video calls, and sterilization over a specified area using the automatic pumping system. In the last scenario, the proposed MSR1 robot sterilized 3.5 m2 for each one-meter movement. In the future, we plan to use an automatic face recognition system for enrolling large numbers of patients in a real hospital. Remote monitoring can reduce the number of threads and charge the MSR1 robot in an automatic manner.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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