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Research

s^2Cloud: a novel cloud-based precision health system for smart and secure IoT big data harnessing

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Abstract
This study aims to demonstrate a novel cloud big data system, s^2Cloud, to enabled both smart and secure transmission and management of patient big data from Internet of Things (IoT), especially in the new common of long covid. More specifically, s^2Cloud allows doctors to manage patient records effectively through the interactive web server. It further enables real-time, long-term, and continuous streaming and management of biomechanical dynamics from IoT phones/wearables. The big data can be visualized in both real-time and historical modes. Besides, s^2Cloud achieves big data security through secure sign up and log in, as well as data transmission protection. It also allows doctor-patient interactions through instantaneous chat. s^2Cloud has been evaluated on the real-world application, in which human IoT biomechanical dynamics are streamed, managed, stored, and visualized to demonstrate the effectiveness. Overall, the proposed system, empowered by smart and secure design innovations, has demonstrated the feasibility and potential for IoT big data-driven precision health.

Keywords Big data system · Cloud big data · Medical decision support · Precision health

1 Introduction

The world is now defined by mass production and consumption of data. The amount of data generated by the world continues to increase exponentially each year and shows no signs of stopping. It is predicted that the annual size of the global datasphere will increase to 175 ZB in 2025 [1–4]. We rely more heavily on this data to make decisions and to make our world smart [5–10]. Due to these increases, new challenges arise to manage the massive amount of data, which is known as "big data". As a result, systems from different industries must now adapt to deal with these challenges. Internet of Things (IoT) are playing an important role to generating this big data. While new challenges appear, however, technologies to manage this IoT data-driven world have been developed and are continually improving. Big data consists of multiple characteristics like volume, velocity, and variety. These characteristics imply that multi-type large amounts of data are quickly generated. It is pressing to develop an innovative and effective system to manage big data.

We take a special interest in the IoT big data-driven precision health area [11–19], and research how to tackle these challenges through innovative design as shown in Fig. 1. In this study, we investigate how to enable smart and secure IoT big data management on the cloud, thereby advancing big data healthcare, long covid management, and broadly precision health.

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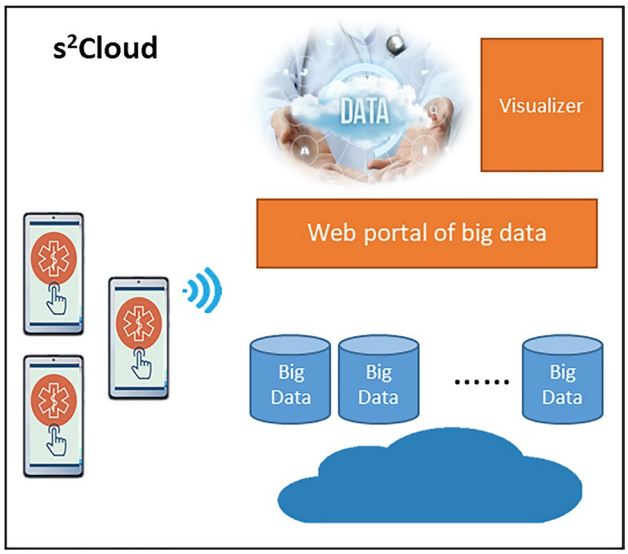

Fig. 1 The big picture of smart and secure big data-driven rehabilitation system—s^{2}Cloud, for precision health big data applications. The system is proposed to be able to continuously stream, manage, leverage, and storage the big data, for data-driven medical decision support and other innovations

There are some previously reported studies for healthcare data capturing and management. Some studies have mainly focused on the data capturing using wearable sensors [20–22], and have not developed the cloud system for big data management. However, demonstrating and storing big data in the cloud is highly important for medical decision support [23–26]. Further, continuously establishing the big data on the cloud by streaming and managing the long-term dynamics from edge devices is still a challenge [27, 28], and previously works usually capture and store short-term data [29–31]. Besides, some other studies usually have not fully implemented the big data management features [32–35], such as secure doctor and patient management, interactive chatting, and visualization functions. Therefore, it is still lacking an effective system that can effectively, securely, and in a smart way, to manage the big data. Especially, during the long covid, the continuous data streaming and management is even more important for medical insights extraction.

To enable effective, smart, and secure IoT big data-driven precision health and long covid management, we propose an innovative system, called s^{2}Cloud. s^{2}Cloud achieves big data security through secure sign up and log in for the doctors, as well as IoT data transmission protection. The system allows the doctors to manage both patients and their records effectively. The doctors can add and edit the patient and record information through the interactive website. Furthermore, the system supports both real-time and historical modes for IoT big data management. Therefore, the patient measurement information can, not only be visualized and demonstrated in real-time, but also be retrieved for further analysis. The smart website also allows doctors and patients to interact with each other effectively through instantaneous chat. s^{2}Cloud, implemented on Amazon Web Service (AWS) [36], can help enhance healthcare systems to better monitor patients and give doctors critical insights into their patients' health.

Our major contributions include:

(1) Differentiated from the traditional electronic health record system, s^{2}Cloud enables real-time, long-term, and continuous IoT big data streaming and management for precision health and long covid management;
(2) The real-time interactive doctor-cloud interface allows the doctors to easily access the data, and communicate with the patients via chatting;
(3) The secure IoT big data management system has doctor sign up and log in functions, as well as data transmission protection;
(4) The system allows the doctors to conveniently manage both patient information and patient records;
(5) The system supports both real-time and historical demonstration of the IoT big data, which is essential for critical pattern demonstration.

The s^{2}Cloud has been evaluated on the real-world application, in which the IoT human biomechanical dynamics are streamed, managed, storage, and visualized to demonstrate the effectiveness of the proposed novel system. Biomechanical data is essential for many applications, such as disability monitoring, rehabilitation monitoring, and neural disease monitoring. As known, covid is related to most of above health concerns, and this system is expected to greatly benefit long covid management and understanding.

This study is significantly extended from our previously work [37, 38], which reported a pilot version of the s^{2}Cloud system. In this study, we have enhanced the cloud health system to support more advanced big data management and visualization including both real-time and historical modes. And we have further enhanced the patient information system to support multiple useful functions including effective patient creation, record management, and seamless interactive communication functions. Overall, the proposed s^{2}Cloud system, empowered by smart and secure design innovations and dramatically enhanced by the new functions and features, has demonstrated the feasibility and potential for healthcare big data-driven precision health and long covid management. This study will further broadly benefit and advance other smart home and world big data applications.

2 Approaches

2.1 System overview

The proposed system can provide a smart and secure big data system for doctors to access to their patients' health data, better manage and understand the data, and communicate with the patients. The system diagram is shown in Fig. 2. In order to keep the data safe, verification of user credentials was done by AWS Cognito. Login credentials are required for every doctor to access their data. This is done to ensure no unauthorized user has access to critical data. Doctors can use the Patient Management page to add patients to their patient list. Doctors can create health records to help organize, track, and improve their patients' health. Health records and their associated analysis are viewable via the Records page. This page lists out all the health records associated with each patient. The Dashboard page will allow doctors to view the patient data. Real-time visualization can be used to view the real-time data coming from the patient's phone. In addition, historical visualization of past patient data can be viewed on the Dashboard page as well. The doctor can view past data from a specific patient. Another page that is available is the Chat page. The Chat page allows the doctor to directly send messages to their patients. This gives doctors direct access to their patients conveniently and vice versa. The website also has a Settings page. This page is for doctors to view and update their information. Doctors can change their information they would like as well as sign out of the website.

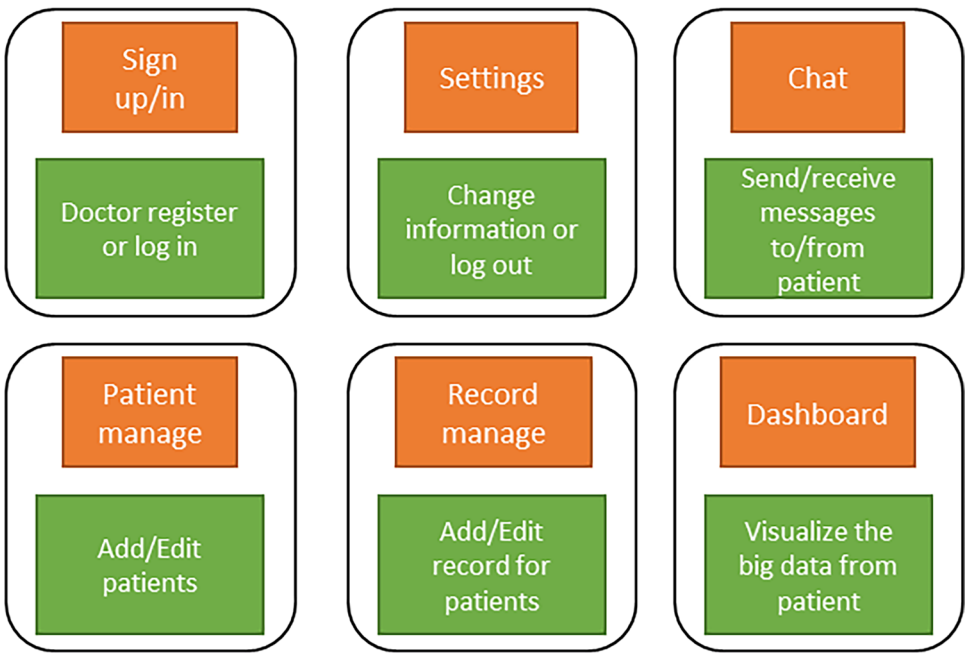

Fig. 2 System diagram of the proposed s^{2}Cloud system, for smart and secure IoT big data-driven precision health and long covid management, which includes key features such as sign, settings, chat, patient management, record management, and dashboard

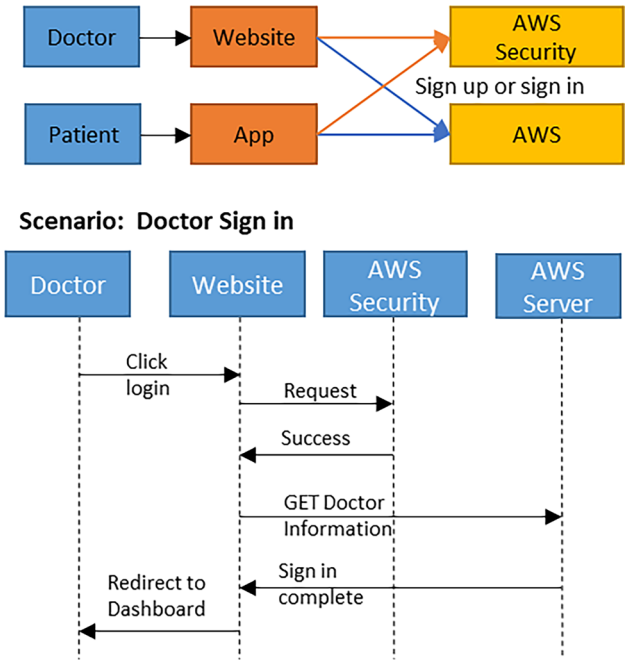

Fig. 3 Doctor sign up or sign in flow and protocols, towards secure big data management in the S^{2}Cloud system

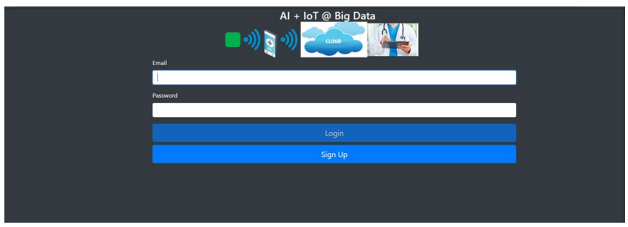

Fig. 4 Sign up or log in page of the s^{2}Cloud system

2.2 IoT big data security

Security is a critical component of healthcare data applications [39–43]. Here we have proposed a mobile-cloud collaboration mechanism to provide secure data access. We have introduced AWS Cognito to verify user credentials, through robust user authentication and authorization, for both cloud website and mobile APP users.

Additionally, each doctor that signs up with the website has their credentials securely saved in AWS Cognito. The processes of signing up and signing in is shown in Fig. 3. Signing up involves filling out doctor information (e.g. name, email, hospital, etc.). Once this data is filled out, a request is sent to AWS Cognito where the account is created with the credentials the doctor entered. Then a verification code is sent to the doctor's email. The doctor must enter in the verification code to the website so that their email is verified.

The login and signup screens are also shown in Fig. 4. Upon signing in via the website, a sign-in request is made to AWS Cognito. If this request returns that the doctor credentials are valid, an additional request to retrieve that valid doctor's information is made.

2.3 Interactive chat

Effective doctor-patient communication is also critical. That is why the website is enabled with a chat feature that allows the doctor to directly communicate with their patients. Doctors can use the chat feature to quickly notify

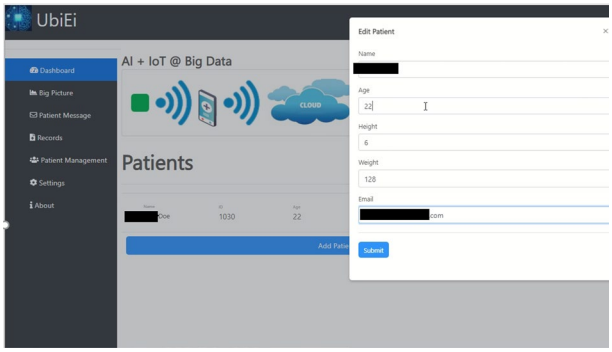

Fig. 5 Patient management function of the S[2]Cloud system, which allows the patient information input and editing to facilitate managing informative patient records

their patients of new information regarding their health. Likewise, patients can instantly receive replies from their doctor about questions they have regarding their health.

2.4 Patient management

Every doctor may have multiple patients that are under their care. The Patient Management page gives a list of all of the current patients that they are helping and their associated data (e.g. patient id, height, weight, etc.). In this page, doctors have the ability to add available patients under their care by pressing the 'add patient' button. This button will open up an 'add patient' window that will allow the doctor to select a patient that does not have a doctor. On this page, the doctor can edit any of their patient's information like their height, weight, etc. as shown in Fig. 5. Finally, doctors also have the ability to remove patients from under their care. The function has been implemented as the SQL database.

2.5 Record management

Doctors are associated with many patients. To keep track of a patient's health, doctors can create health records. These health records are used to help monitor patients so that doctors can maintain and improve patient health. Patient records can be viewed using the Records page. A record contains the following information: disease type, record description, start and end times of the record, the analysis type performed, and the sensors to be used to capture data for the record. Electronic health records help doctors stay organized and let them quickly retrieve the data they need to know about their patient.

2.6 IoT big data visualization

After a doctor retrieves the data from the cloud, the data is visualized using a time-series graph for the input data. The graphs created contain several functionalities that allow doctors to closely view the data such as zoom in. One complicated task associated with visualization is viewing large amounts of data at once. The data has been stored on the S3 bucket. Since a large amount of data is in cloud storage, retrieval and visualization can be difficult. Some reasons for this include timeouts when retrieving the data and large responses. To address these problems, data is retrieved in set intervals only. This method is used so that requests to retrieve data do not timeout and that the response size is not too large. Since not all of the data is viewable at once, the doctor is given buttons (backward, forward, play, stop) that allow them to scroll through the data.

If the doctor scrolls past the end of the dataset they have stored in their browser, then a request is made to retrieve more data. Each time a request is made, the data is appended to the data the doctor currently has already in their browser. These graph features allow the doctor to closely analyze all of a patient's data without being hindered by the size of the data.

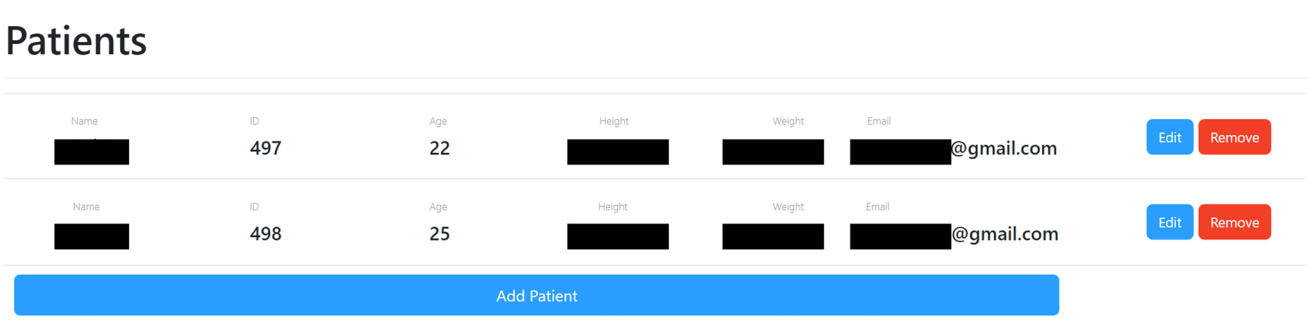

Fig. 6 The patient recording function in the cloud big data system, which stores and manages the patient information including the patient number, ID, age, and some measurements like height and weight. The patient information can be edited easily, and/or removed if needed

Fig. 7 The interactive function of the cloud system through patient-doctor chat, to facilitate the active communications

3 Results

In this section, we give the function demonstration of the cloud big data system.

3.1 Experimental setup

We have tested the developed functions on s^{2}Cloud to demonstrate the effectiveness of the proposed big data management system. To test the different parts of the system, test accounts have been created for the doctors and the patients using the respective signup pages. Afterwards, different pages with various functions have been tested, like adding the patient, adding the patient record, sending the data to our cloud system, and visualizing the data.

The system proposed and developed is unique, in which human IoT biomechanical dynamics are streamed, managed, stored, and visualized to demonstrate the effectiveness.

3.2 Patient record

The patient recording function in the cloud big data system is visualized in Fig. 6, which stores and manages the patient information including the patient number, ID, age, and some measurements like height and weight. The patient can be edited easily, and/or removed if needed.

3.3 Chat

Messages were exchanged between the test doctor and test patient to demonstrate the functionality, as shown in Fig. 7. Since doctors have multiple patients, they must first select the patient they wish to converse with in the list on the left side of the page. The chat will be rendered on the right side along with a message box and submit button.

Doctors and patients communicate with each other by typing messages into a message box and sending them. Sent messages are saved to the cloud and are readily available for viewing. Each message has sender, date, and content information associated with it. When messages are rendered, this information is displayed in real-time with a negligible latency. To help make conversations more readable, on the website, doctor messages are colored blue

and patient messages are colored red. The chat feature enables doctors and patients to have a direct connection with each other.

3.4 IoT big data storage and visualization

Visualizing the big data stored on the cloud is critical for big data management. The doctor can either visualize real-time data or historical data. On the Dashboard page, there are two buttons that help the doctor to select the exact patient data they want to view. When the patient data is retrieved, a graph will show the time-series data from the sensor. For the real-time case, a test patient account was setup and was used to send test data. When data is sent from the patient, it is saved to the cloud storage in real- time.

A doctor account was used to visualize the real-time data sent from the patient. Before real-time data can be viewed, the patient must be actively sending data. The cloud system is used to keep track of whether patients are active or not. So, if a patient is not active then the doctor will not be able to view real-time data. If the patient is active, then a real-time visualization request can be sent. The system is setup so that only authenticated users with Cognito can view the data. Once this occurs, the system determines the necessary information to view real-time data. As Fig. 8, the graph visualizes the data within a certain window length. If data exceeds this window, then the graph is shifted so that the new data can be viewed.

For the historical case, existing patient data in the cloud storage was used to visualize. The doctor can view data from a specific patient. To view data, the doctor makes selections using the historical visualization form on the Dashboard.

3.5 Discussion

The website consists of different pages that enable the doctor to fully manage and monitor their patients. The pages are setup such that the design of the page is simple and clear, and the functionality is easy to use. Doctors navigate the website using the main side navigation bar on the left side of the page. This navigation bar is available on all pages. Upon clicking on a different tab within the navigation bar, the corresponding page is loaded. Each page is identified with a unique URL. The components within each page consist mainly of buttons, lists, dropdowns, and forms.

For the security testing, doctors were signed up with AWS Cognito. When a doctor attempts to sign up, they must fill out the necessary information. When the form is fully filled out, it is sent to AWS Cognito where then the doctor's credentials are saved. After this, an email containing a verification code is then sent to the doctor's email. The doctor must enter in the code to the verification code popup window to verify their email. After the doctor's email is verified, the doctor's information is then saved to the cloud and given a unique identifier. Once this is complete, the doctor is redirected to the main dashboard page. When a doctor attempts to sign in, they must fill in the email and password fields. After the doctor presses the login button, the credentials are sent to AWS Cognito for verification. If the credentials match an existing account, a success is returned. If a success is returned, the doctor's information is then fetched from the cloud.

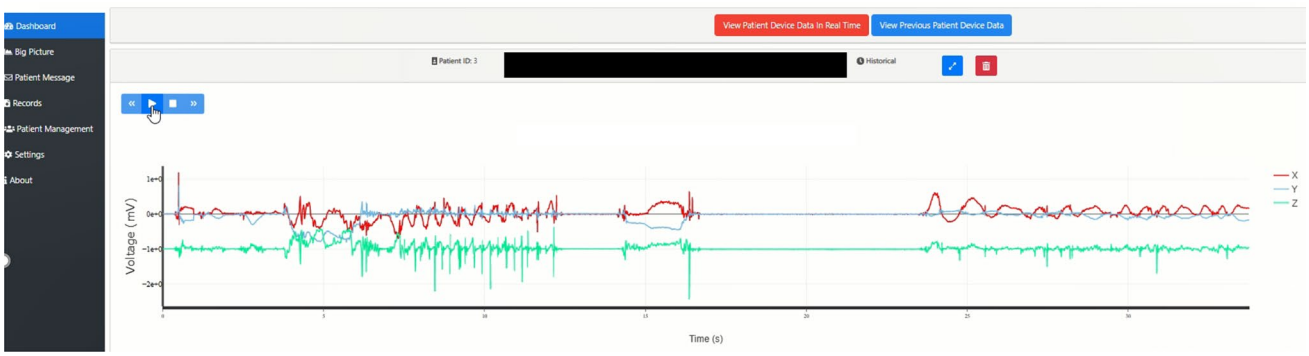

Fig. 8 Visualization of big data on the web portal supported by the developed S^{2}Cloud system, in which the human motion big data-based precision health applications are demonstrated. More specifically, the accelerometer data sent from the smart phone is captured and stored on the S^{2}Cloud system, and the data can also be visualized either in the real-time or the historical mode, towards big data-driven applications such as long covid management, lifestyle management, fall detection of aging population, and other human motion dynamics-related practices

Finally, the doctor is redirected to the main dashboard page. Only preexisting doctor accounts could sign in and that their information was fetched from the cloud.

Detailed patient information like ID, age, height, weight, and email can be added to the system, with the SQL-based database. The doctor can click the 'add patient' button to add more patients, or click the edit or remove button to change the patient information or delete the patient information. With his patient management page, the doctor can easily go through and/or update the patient information if needed.

Also, now we have leveraged the Cognito of AWS to add the security steps, and have not yet set up the attack models for the testing. It will be future interesting steps to further test the security of the system.

Further, the user traffic testing and network condition testing are also interesting in the future efforts to evaluate and enhance the proposed system.

4 Conclusion

In this study, we have proposed and developed an innovative smart and secure IoT management system for big data-driven rehabilitation, s^2Cloud, and demonstrated its potential on the real-world healthcare big data application, especially precision health for long covid. We have developed the interactive cloud-cloud interface, allowing the doctors to conveniently access the big data, and communicate with the patients. Differentiated from the traditional electronic health record system, s^2Cloud enables real-time, long-term, and continuous streaming and management of biomedical dynamics that are measured by smart phones or wearable sensors. The system further supports both real-time and historical demonstration of the big data. Besides, both patient information and patient-specific record information can be effectively created and managed. With the security in mind, we have also developed functions for doctor sign up and log in, as well as data transmission protection. Real-world experiments have been conducted to demonstrate its effectiveness on human biomechanical dynamics-based precision medicine big data applications. Overall, the proposed s^2Cloud system, empowered by smart and secure design innovations, is expected to advance not only the IoT big data-driven rehabilitation and covid management, but also many other promising areas.

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Author contributions JS worked on the coding, testing, and manuscript; QZ worked on the concept, methods, and manuscript.

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Data availability The data is available upon request and approval.

Declarations

Ethics approval and consent to participate Not applicable.

Competing interests The authors have no competing interests as defined by Springer, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

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