REVIEW ARTICLE

Features and application of wearable biosensors in medical care

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One of the new technologies in the field of health is wearable biosensor, which provides vital signs monitoring of patients, athletes, premature infants, children, psychiatric patients, people who need long-term care, elderly, and people in impassable regions far from health and medical services. The aim of this study was to explain features and applications of wearable biosensors in medical services. This was a narrative review study that done in 2015. Search conducted with the help of libraries, books, conference proceedings, through databases of Science Direct, PubMed, Proquest, Springer, and SID (Scientific Information Database). In our searches, we employed the following keywords and their combinations; vital sign monitoring, medical smart shirt, smart clothing, wearable biosensors, physiological monitoring system, remote detection systems, remote control health, and bio-monitoring system. The preliminary search resulted in 54 articles, which published between 2002 and 2015. After a careful analysis of the content of each paper, 41 sources selected based on their relevancy. Although the use of wearable in healthcare is still in an infant stage, it could have a magic effect on healthcare. Smart wearable in the technology industry for 2015 is one that is looking to be a big and profitable market. Wearable biosensors capable of continuous vital signs monitoring and feedback to the user will be significantly effective in timely prevention, diagnosis, treatment, and control of diseases.

Key words: Medical smart shirt, monitoring, physiological, vital signs, wearable biosensors

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INTRODUCTION

Today, the industry of medical care and control has undergone significant changes owing to a wide range of facilities and services; these changes include more emphasis on prevention, recognition of primary risks, proper education of users, new ways of health care, and people's authority in control of their personal health. These changes have evolved following the emergence of factors such as increases in the population of the elderly, various chronic diseases, and the field of their treatment.[1] No one likes to see a doctor (particularly the inhabitants of impassable areas); people who visit clinics have to spend some time in waiting rooms and the doctors must often spend the whole day listening to the complaints of patients regarding their health; they examine the patients quickly and sometimes do not recognize some problems. Moreover, physicians' fees and the need for the continuous care of the elderly and people with chronic diseases should not be forgotten. Considering significant advances in science and technology such as basic developments emerging in the fields of micro/nanotechnology, wireless communication, information technology, and biomedical sciences during the past 10-15 years, a transformation has occurred in this area, and the models designed and built of a wide range of biosensors as well as recently wearable biosensors are a clear indication of this truth.[1] In fact, one of the ways to improve the quality of care in the health care industry is through application of new technologies.[2] These biosensors provide vital signs monitoring of patients, athletes, premature infants, children, psychiatric patients, people who need long-term care, and people in impassable regions far from health and medical services, and they are significantly effective in

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the prevention, timely diagnosis, control, and treatment of diseases. One of the applications of these telemedicine technologies is to provide health care services to inmates and consequently reduce prisoners' transfer to health centers.[3] In recent decades, with developments in computer and information technology, applications of technology have contributed to the excessive development of many wireless and telemedicine applications.[4]

The wearable technology market is expected to rise from $20 billion in 2015 to close to $70 billion in 2025, led by the health care sector. Growth and development in the sector is being driven by the likes of Apple, Accenture, Adidas, Fujitsu, Nike, Philips, Reebok, and Samsung. Advanced informatics is expected to make a huge impact, as new healthcare and informatics devices could be a billion-dollar opportunity. A new wearable device for infants created by a Cambridge-California social enterprise could be the key to preventing fatal or crippling ailments such as diarrhea, malnutrition, malaria, human immunodeficiency virus infection and acquired immune deficiency syndrome (HIV/AIDS), and others. The use of wearables in health care is still in a stage of infancy, but research from TrustMarque points toward 81% of respondents wanting more use of connected devices in patient care. The benefits of wearables in health care are well-documented but include remote monitoring to allow patients to go home earlier to improve their comfort and reduce the burden on manual hospital checks.[5] Smart wearables in the technology industry for 2015 are poised to form a large and profitable market. The technology that these new devices are employing is innovative, to say the least. Smart technology is certainly something that will be the key to the optimal operation of our future society, especially when it comes to health care. The aim of this study was to explain the features and applications of wearable biosensors in the medical sciences.

MATERIALS AND METHODS

This study was a narrative review done in 2015. The use of wearables in health care is still in its infancy. Thus, the researchers collected all sources based on their relevance, and a search was conducted with the help of libraries, books, conference proceedings, and databases of Science Direct, PubMed, Proquest, Springer, and Scientific Information Database (SID). In our searches, we employed the following keywords and their combinations: vital sign monitoring, medical smart shirt, smart clothing, wearable biosensors, physiological monitoring system, remote detection systems, remote control health, and bio-monitoring system. The preliminary search resulted in 54 articles, which were published between 2002 and 2015. After a careful analysis of the content of each paper, a total of 41 sources were selected based on their relevance. Then, published information, that is, the contents of each article typically were summarized and synthesized.

RESULTS

Wearable technology may provide an integral part of the solution for providing health care to a growing world population that will be strained by a ballooning aging population. By providing a means to conduct telemedicine — the monitoring, recording, and transmission of physiological signals from outside of the hospital — wearable technology solutions could ease the burden on healthcare personnel and use hospital space for more emergent or responsive care. In addition, employing wearable technology in professions where workers are exposed to dangers or hazards could help save their lives and protect health care personnel.[6]

As wearable technologies are the cornerstone of health informatics,[7] in this study a number of wearable biosensors and their applications have been introduced. These biosensors are available in various forms such as hats, shirts, rings, belts, bracelets, shoes, socks, glasses, contact lenses, necklaces, and watches.

Biosensors

A biosensor is composed of three main parts:

1. Bioreactors systems.
2. Transducer.
3. Output system.

Biosensors are designed to react only with a particular substance and the result of this reaction comes in the form of messages that can be analyzed by a microprocessor.[8] These biosensors can be considered as receptors or stimuli; communication systems based on sensors can display, stimulate, treat, or substitute human biophysics performance.

Telemedicine sensors

Telemedicine sensors are chips 2 × 2 millimeters made of silicon. These chips consist of a thermal sensor and a narrow strip lithium battery and require a little power to start up the circuit, process electronic signals, and send them. The antenna embedded on the chip sends the data by radio signals to the monitor when it receives the command to send data.[9] The applications can be include measurement of blood pressure, heart rate, body temperature, and blood oxygen level. The purpose of introducing this sensor is to develop a range of chips to display and monitor body activities and transfer the results to target medical centers. By placing the chip of a telemedicine sensor on the fingertip, it is possible to

record and send several vital parameters. They can be noninvasively attached to different parts of the body and the results reported.[10]

"Tele-sensor operation = Identification + recording + sending (transferring)"[11]

Telemedicine sensors were first applied to monitor and send soldiers' vital signs from war zones to a remote control register center. They have been noninvasively attached to different parts of body like a sticky substance. Additionally, they are capable of sending physiological data to a small monitor on another soldier's hat through wireless transmission. In this case, if data show physical injury conditions in one of five predetermined levels, the monitor will sound the aid alarm and assistance will be provided in the shortest time. Moreover, this monitor is capable of sending and receiving signals of Global Positioning System (GPS) for quick access to the incident location.[11]

One of the main challenges the world faces is the increase in the aging population in developed countries. In the next 20 years, this population will increase by 20%. Hence, the need to provide high-quality care and health care services becomes increasingly important.[12]

In this regard, Steele *et al*. (2009) in a research study titled "Elderly people's perception and acceptance of wireless sensor networks to assist healthcare" suggested that elderly people were not interested in the use of wireless systems and that if they wanted to learn, they would forget very soon and even then they were afraid of working with this technology. Therefore, simple systems with which working is easy and which are acceptable from a social perspective should be applied for this group.[9] One of the technologies that address these conditions is a medical smart shirt. These shirts have potentially helped to develop elderly personal independence; however, nurses cannot be replaced by them.[13]

Sardini and Serpelloni (2010) in a work of research titled "Instrumented Wearable Belt for Wireless Health Monitoring," referred to the belts which were equipped to two skin electrodes, temperature sensors, accelerometer sensor, respiratory sensors, the ability to measure other vital signs, electrocardiogram, and even the ability to provide these valuable information based on people's activities (running, walking, resting, falling). These belts can be used to measure physiological parameters for telediagnostics and particularly for management of care in elderly people's houses.[14]

One of the first types of digital clothing designed by the researchers at the Georgia Institute of Technology, USA for military purposes approximately two decades ago was capable of measuring vital signs, heart rate, and breathing rate using optical fibers and sensors in the fabric. This smart clothing item was also able to show the location of a bullet in the body of a wounded soldier. In this clothing, an optical signal was sent from one side to the other; if the light did not reach the other side, it meant that the soldier was wounded. In this case the light returned and showed the bullet and perforation of clothing.[15]

Reinzo (2005) in a research study titled "A Textile-based Wearable System for Vital Signs Monitoring Applicability in Cardiac Patients" has referred to magic smart vests made of conductive fabric, which can measure heart and breathing rate during working and resting time and then send the information to the processing center. In this way, health checkup is also provided after hospital discharge.[16]

Perego *et al*. (2012) in an article entitled "Sport Monitoring with Smart Wearable System" recommended biosensors application in continuous monitoring of athletes' health.[17]

Mehr News Agency (2011) quoted Roso, the director of research and development of Tesan Center, that patients' referral to health care centers leads to waste of time and cost for each country's health system as well as for patients. Research results of Tesan Company indicated that remote monitoring such as using smart biosensors, decreased patients' referral to care centers by up to 30%.[18]

In this regard, the news agency announced that researchers of eight European countries, in a research project titled "Chrinius," designed a smart shirt for patients with chronic obstructive pulmonary disease (COPD). These shirts have sensors connected to smartphones to transfer patients' health information to the doctor and immediately analyze patients' data using smart software.[18]

Gibbs and Asada (2005) in an article entitled "Wearable Conductive Fiber Sensors for Multi-axis Human Joint Angle Measurements",[19] and also Tognetti (2005) in an article titled "Wearable Kinesthetic System for Classification of Upper Limb Gesture in Post-stroke Rehabilitation" referred to high performance of wearable sensors in physical medicine and rehabilitation.[20]

Moreover, in Gilan province, Iran, researchers succeeded in designing and manufacturing smart clothing using metallic nanoparticles able to receive the vital signs of the body. In this clothing, sensors and processors were embedded by which vital signs such as heart rate and blood temperature can be received and the required information can be sent to the doctor in emergency and

critical conditions.[21]

Pandian *et al*. (2006) in their article titled "Smart Vest: Wearable Multi-Parameter Remote Physiological Monitoring System" referred to the shirts being washable and having low weight as well as easy movement, which makes them suitable for occupations such as firefighters, soldiers, divers, miners, and astronauts.[22]

Gyselinckx *et al*. (2007) in a research study entitled "Potentials and Challenges of Body Area Networks of Cardiac Monitoring" expressed that biosensors can send system data to the ambulance in emergency warning, for example, when a person who lives alone suffers stroke or heart failure, the data are transmitted to the ambulance and decreases the time to check the patient.[23]

Leea and Chungb (2009) in an article titled "Wireless Sensor Network-Based Wearable Smart Shirt for Ubiquitous Health and Activity Monitoring" suggested that smart shirts provided a very diverse framework for incorporation of assays, monitoring, and data processing devices. Smart shirts can be used in applications such as the battlefield, public security, health monitoring, and sports and fitness,. The research refers to the presence of accelerometers in smart shirts and recording electrocardiograph signals while using a treadmill at different speeds.[24]

Jam News Scientific Services quoted the Islamic Republic News Agency (IRNA) that Om-signal T-shirts are among the smartest shirts in the world. These shirts have sensors that are sewn into the fabric and regularly check users' body health status. The shirts show heart rate, breathing, breathing capacity, movement, movement intensity, heart rate variability, and calories burnt. Data are stored on a small black box and sent to a program so that users can observe their body operation. According to researchers, not only can these shirts can be used for bodybuilding exercises but they can also be worn during the day in offices; these shirts even announce the extent to which people are stressed. They have been designed in such a way that they can be worn alone or with other clothes.[25]

In recent years, studies have shown that smart clothing technology can be used in operating rooms for monitoring patients.[26]

Dittmar *et al*. (2005) in a research study titled "Wearable Medical Devices Using Textile and Flexible Technology for Ambulatory Monitoring," cited that sensors applied in clothes should be thin, flexible, and compatible with the textile or made using textile technology or new fibers with specific features such as mechanical, electrical, and optical features.[27]

Introduction of a number of wearable biosensors and their applications

Helmets for treatment of depression

Danish researchers have designed a helmet that helps to reactivate parts involved in depression and rapid recovery of patients by transmission of weak electrical pulses to the brain. Scientific Services of Iranian Students' News Agency (ISNA) reported that performance of this helmet differed from the controversial method of electroconvulsive therapy (ECT), as in this method very weak electrical pulses are transmitted to the parts of the brain to which depression is related. Electrical pulses activate the capillaries by imitating the body's treatment mechanism to form new blood vessels. In this method, patients do not feel electrical pulses, whereas in ECT, electrical pulses are so severe that they may lead to the loss of patients' memory in some cases. Professor Steen Dissing from Copenhagen University states that electrical pulses affect capillaries in the brain and depression symptoms disappear in most patients after 7 days and they achieve better scores on the depression test. A clinical test of this helmet was performed on 65 patients with depression in Denmark and New Zealand; for 34 patients, half an hour per day and for others, one hour per day of treatment was prescribed using this helmet. In 65% of patients, depression symptoms disappeared after 1 week; depression improvement in patients who had received a half an hour treatment was reported 73% and in the second group 67%. The only side effect of this helmet is mild nausea, which is resolved after completion of the treatment. The results of this study help in the development of new treatment methods for disorders such as posttraumatic stress disorder (PTSD).[28]

Prevention of bedsores by smart clothing

Scientists have designed clothing that can assess the level of blood flow, oxygen, and nutrients required for different parts of the body. This clothing is equipped with a set of electrodes that apply mild shocks to specific parts of body when needed in order to increase the blood flow to that part; as a result, the risk of bedsore will greatly reduce.[29]

Smart clothing for premature babies

Annually, 15 million babies are born premature in the world. More than one million of this population die or suffer physical and psychological complications due to the loss of body water. Polish researchers have succeeded in designing smart clothing to be worn by premature babies. This clothing is composed of two layers: one layer is ordinary fabric and the other is a membrane that prevents excessive sweating in the baby.[30]

Smart socks

Researchers have revealed smart socks that allow parents to check their infants' health using a mobile application.

These smart socks are called Owlet and can send the child's heart rate, oxygen level, skin temperature, sleep quality, and sleep position to parents' smartphones. According to manufacturers, this technology can check child's daily health and can help to identify sudden infant death syndrome. Manufacturers are collecting online funds for this device, which costs £159, and they hope to market it in 2015. This system also sends data to the company anonymously so that the manufacturers can create a database to help in identifying the problems and send an early warning to parents.[31]

Smart socks have been equipped with sensors that can control walking and the manner by which the feet are placed on the ground in different conditions, walking, running, or sitting. Wearing smart socks plays a major role in people's balance while walking, and it can particularly be used as a tool to help the elderly who have difficulty walking. These socks can be used as a training tool to help children who are learning to walk. Wearing these socks can prevent possible injuries during walking. According to experts, smart socks are an appropriate wearing tool for rehabilitation and improvement of people's walking. In addition, athletes can use them to modify exercise. Data recorded in sensors are transmitted wirelessly to the user's computer or cellphone, after which it can be analyzed through a proprietary program; the alarm will be set for the person if necessary.[30]

Smart clothing to monitor children's health status

Parents who have recently had a baby can use smart clothing to monitor their baby's physical status permanently. The clothing is equipped with different sensors, Wi-Fi transmitter/receiver, and of course a Bluetooth; it can permanently monitor breathing, body temperature, physical state of body, and infant's activity level (awake, naughty, or in quiet sleep). The Only Memo application should be installed on the smartphone [Android or iPhone Operating System (IOS)]. This is one of the appropriate applications for wearable technologies, as every year some children under 7 years of age die suddenly due to infant death syndrome and cessation of breathing during sleep. Such equipment can reduce the incidence of these conditions and inform parents about their children's health as soon as something unnatural occurs.[32]

Smart shoes

Researchers at the University of Utah have designed smart insoles equipped with internal sensors, which can help in correcting motion abnormalities and reforming people's walking patterns. Stacy Bamberg, researcher at the Engineering Department of Utah University, emphasizes that the smart insole system called Rapid Rehab significantly corrects motion abnormalities of people with a foot fracture, replaced hip joint, or artificial leg. With the aid of a special gel insole and with sensors for pressure, accelerometer, and internal gyroscope, the system provides simultaneous reports of people's walking patterns. Data provided by smart insole are visible on the users' smartphones wirelessly and with the help of a software program; physiotherapists or users can correct motion abnormalities using this data as well as simultaneous audio and video instructions. This technology can be used as one of the effective methods of rehabilitation for people with bone fracture or temporary paralysis of legs.[33]

Measuring stress with a t-shirt

Canadian researchers have designed a new t-shirt, which is equipped with a sensor and can measure stress levels during the day based on analysis of motion, breathing, and heart activity, while it can also monitor sleep. Hexo-skin t-shirts and their companion devices are currently produced in Canada; data are sent wirelessly to a smartphone and then to an online account through phone. This device measures the levels of activity and stress during the day. Additionally, it gives coaches the ability to plan and schedule athletes' training programs.[34]

Digital clothing that examines mental conditions

Tiny sensors in this clothing can measure heart rate, body temperature, and even skin conductance (which is one of the most important physiological indices for determining people's mental state). Then data are sent to a database through mobile phone, where an appropriate response is sent considering the current situation and people's general interest. There is a screen equipped with light-emitting diode (LED) lamps in the clothing, which can display hopeful statements when people grieve or panic. Moreover, the speakers located in the hat can play appropriate music and send promising messages or even some family jokes.[29]

Heart health by smart vest

One of the most used types of digital clothing is a vest named "magic," which was made by Italian researchers. This vest has been made of a conductive fabric that can measure people's heart rate as well as breathing rate and send the data to a processing center. In this way, it is possible check people's health after hospital discharge.[29] This vest was used by a group of hikers who intended to climb Mount Everest. The hikers' physical situation at work and in sleep was sent to a medical center. Comfortable wearing of the vest, its adaptability to different body sizes, and being washable are the main characteristics of this smart clothing. With progress in micro- and nanotechnology in all fields, particularly in the health care field, and also the growing demand for new applications and textile industry trends,[35] it can be stated that in

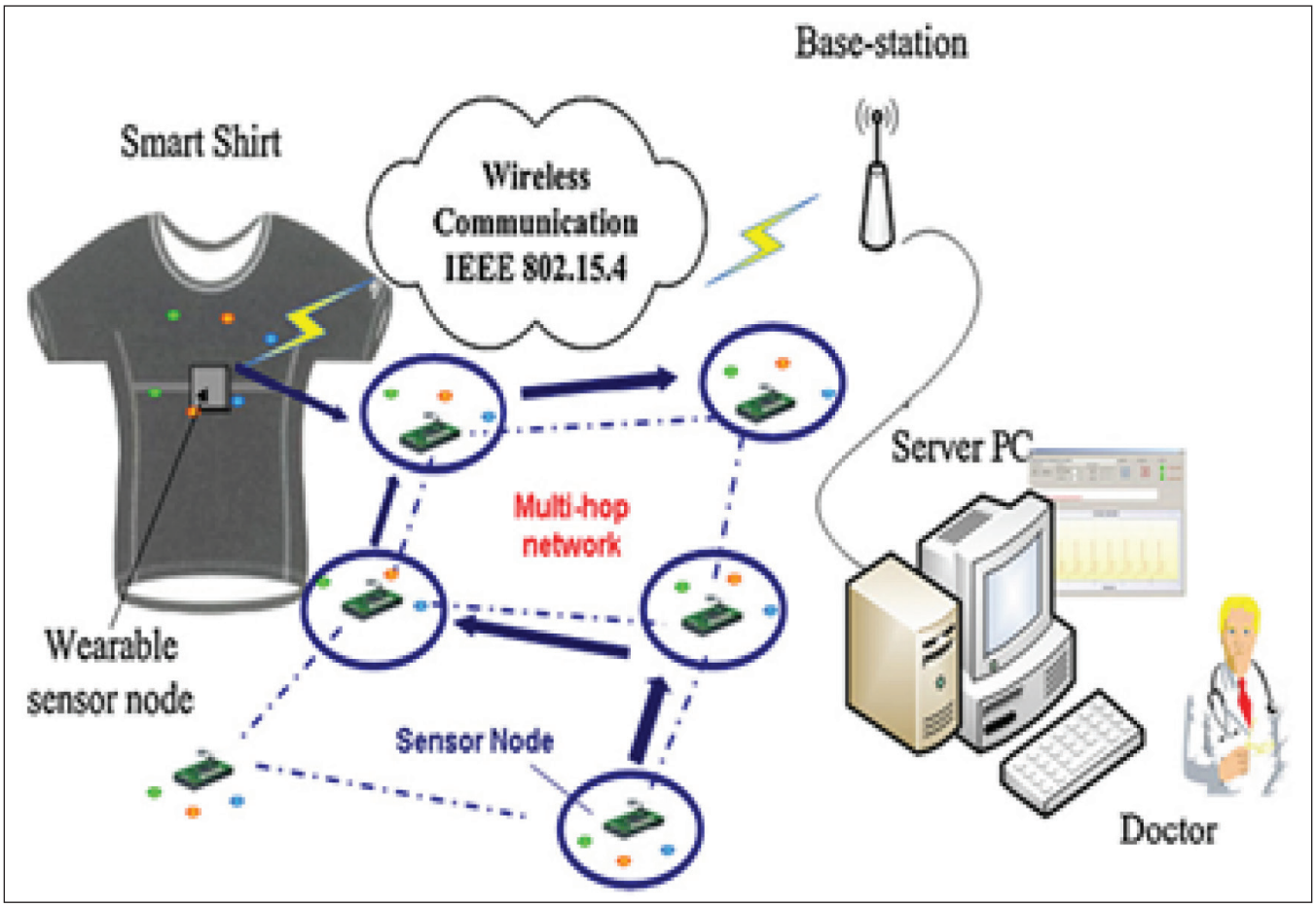

Figure 1: System architecture with smart shirt[37]

the future we will have significant developments in the production of wearable sensors.

Meinande and Honkala (2004) in their article titled "Potential Applications of Smart Clothing Solutions in Health Care and Personal Protection" stated that rapid development in the field of sensor and telecommunication technology has created a new opportunity in the field of textiles and clothing.[34] Figure 1 shows an outline of system architecture in smart shirts.[36]

Chana *et al*. in an article (2012) titled "Smart Wearable Systems: Current Status and Future Challenges" noted that one of the key solutions to maintain health is integrated architecture of smart house services with wearable systems.[38]

Decreasing the volume of digital tools on one hand and significant expansion of public access to some technologies such as mobile phones on the other hand has accelerated the design of smart clothing. A wide range of noninvasive measurement tools is expected to be introduced in the near future 1.[37] The health care industry must be accompanied by technology, and in fact it must have the ability to accept the technology. In this regard, knowledge and training in new health technologies should be improved in health care service providers.[39-41]

CONCLUSION

Using textile will launch a unique application in contact with skin. Instances of textiles with the ability to process and record medical data and display biological signals through placing carbon nanotubes in the warp and weft of the fibers, which in practice play the role of biosensors, have been tested in medical, firefighting, sports, and military industry settings and similar cases where the results have been emphasized. Perhaps smart clothing was considered a luxury before, but some applications of the clothing, particularly in the health field, have converted it to the first choice in some practical areas. It is probable that in the not-too-distant future, the use of smart clothing will be widespread as smartphones. Soon, wearable biosensors will find routine clinical applications. Recently many companies have turned to the production and development of these wearable products and undoubtedly it can be said that the future of the digital world is linked to wearable tools.

Recommendations

- Develop and conduct more research projects and studies in wearable biosensors field.
- Support financially the designers and manufacturers of this technology.
- Subsidize expenses and costs.

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Conflicts of interest

There are no conflicts of interest.

AUTHOR'S CONTRIBUTION

SA contributed to conducting the research project, preparing and editing the manuscript, and approving the final version of the manuscript. FT contributed to collecting data, preparing and editing the manuscript, and approving the final version of the manuscript.

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