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Research article

Factors influencing adoption model of continuous glucose monitoring devices for internet of things healthcare

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ABSTRACT

Continuous Glucose Monitoring Systems (CGMs) device is the most developed technology, which has reshaped manual diabetes management with smart features having sensor, transmitter and monitor. However, the number of users for CGMs device is still very low compared to existing manual systems although this device provides a smart landmark in blood glucose monitoring for diabetes management. Consequently, the aspire of the assessment is to explore the factors that influence users' intention to adopt CGMs device on the Internet of Things (IoT) based healthcare. This paper provides an adoption model for CGMs device by integrating some factors from different theories in existing studies of wearable healthcare devices. The proposed adoption model also examines current factors as a guideline for the users to adopt the CGMs device. We have collected data from 97 actual CGMs device users. Partial least square and structural equation modelling were involved for measurement and structural model assessment of this study. The experiential study specifies that interpersonal influence and trustworthiness are the strong predictors of attitude toward a wearable device, which shows significant relationships to use for CGMs device's adoption. Personal innovativeness shows no significant relationship with attitude toward a wearable device. Besides, self-efficacy has no direct influence on a person's health interest where heath interest directly influences users' intention to use CGMs device. Moreover, perceived value is not found to be significant for measuring intention to use CGMs devices. The results from this research provide suggestions for the developers to ensure users' intention to adopt CGMs device.

1. Introduction

Internet of Things (IoT) is a network of linked objects through the Internet for collecting and exchanging data [1]. IoT is the next phase of the Internet where machines talk to machines autonomously. Along with the improvement of sensors and announcement technologies, IoT has shaped its potential in support of users to incessantly examine a variety of physical circumstances by the use of healthcare wearable devices [2]. Consistent with a study by [3], healthcare wearable devices stated

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as "a device which is self-directed, non-aggressive, and also carries out health tasks specifically for instance monitoring or supporting over an extended time" [4].

It is also interesting that IoT is one of the most fast-growing terms in sensor-based communication including some smart areas like smart city, smart car, smart home, smart agriculture, smart healthcare. Among all of those, smart healthcare is now in an upward position as because it is related to the health status of a person, which facilitates patients and medical specialists with easy and convenient technologies for monitoring and reporting continually health status [3,5].

Formerly, finger prick was the common method for blood glucose monitoring, but after the 20th century, Continuous Glucose Monitoring Systems (CGMs) devices have become popular to monitor blood glucose easily [5]. The realization of the IoT healthcare system can even ensure remote treatment for patient monitoring as well as disease detection, which is a trendy feature [6]. In 1999, CGMs devices first started self-blood glucose monitoring for type 1 and type 2 diabetes patients. Type 1 diabetes can occur at any age mostly in children and adult where the patients need oral medicine or insulin to keep their blood glucose under control. Type 2 diabetes patients can be found mostly in older ages people who need regular support for their insulin measurement in a regular basis which is stated as continuous monitoring of blood glucose [6].

Though CGMs device surrounds with smart features, yet fewer amounts of people are using it compare to the traditional system [5]. Formerly, people had some issues of using CGMs in 1999 about the accuracy of the sensor, but now this device has come forward using special techniques relating with new-fangled trends of Information Technology (IT) [5]. CGMs devices represents the specific notification given by the device through professionals which is quite trustworthy but not limited to warning error or handling events [23]. One study by [7], mentioned about United Kingdom prospective diabetes group assumption, which claimed that CGMs could reduce long-term complications of the diabetes patients for their regular blood glucose monitoring from 75% to 40%.

According to [8], wearable devices have great highlights with intellectual landscapes for global IT companies. The realization of the IoT healthcare system can even ensure remote treatment for patient monitoring as well as disease detection, which is a trendy feature [6]. Those wearable healthcare devices are used for disease management like heart monitoring, blood glucose monitoring and asthma [3]. However, the factors that influence wearable CGMs device adoption have not been identified since this device invented [8]. CGMs devices reveal patient's burden of using finger prick diabetes management. [9]. In [9], the authors have also stated that the usage of CGM devices by Type 1 diabetes patients standing within the range of 8% to 17%. Though it is predicted that the IoT healthcare market size will spread $2 trillion by 2025 [10], yet the percentage of CGMs device uses is still in the initial stage [9].

Adding with [9], maximum of the users of CGMs devices are from developed countries like Germany, U.S.A, U.K, Saudi Arabia, Sweden and so on. Wherein developing countries, people still have lack of proper knowledge about the use of these smart devices, for instance blood glucose monitoring devices, i-Heart devices, smart fitness tracker [11]. In general, a survey found that many people show interest in wearable healthcare devices, but a few of them adopt those devices [3]. As CGMs devices exist in disease management and in-depth with wearable smart healthcare technology [3], so it is worthwhile to examine factors that influence user's adoption intention to use CGMs device in smart healthcare [3,11].

Therefore, this study investigates the theories and model of adoption for the existing smart technologies. Hence, developers can take proper decision to make CGMs devices more approachable whereas users can be benefited in understanding the factors that influence CGMs device adoption to others.

To the best our knowledge, no research provides proper adoption model with interpersonal influence, self-efficacy, personal innovativeness, attitude toward a wearable device, health interest, perceived value and trustworthiness unruffled for CGMs device use.

Furthermore, this study focuses on diabetes management through wearable healthcare devices examining the technology acceptance model, self-efficacy theory, theory of reasoned action and theory of planned behavior. People who want to adopt this CGMs device first time; they can get feedback from the proposed model where the data is collected from the actual users of these devices.

The reminder is organized as follows. Section 2 provides the literature review on recent advances of CGMs devices, overview of the proposed adoption model, formation of the CGMs device and its functionality including the advantages of using it. Section 3 gives description of theoretical model development including hypotheses. Along with this, Section 4 discusses about the definition of each construct and conceptual model as well. Research methodology is fully explained including instrument development and questionnaire design in Section 5. In Section 6, Results are demonstrated with measurement and structural model assessment. Section 7 gives the justification including discussion of the findings from proposed model. Finally, Section 8 and 9 includes the theoretical and practical implications where Section 10 concludes the paper with limitations and future works.

2. Literature review

The health technologies have recently witnessed a massive attention by the governments and authorities in different countries across the globe, which has formed the new emerged e-health ecosystem. For instance, this has reflected on the increasing number of smart technologies for blood glucose measuring, which is now available in finger-prick technology and CGMs. In CGMs devices, the users need to get trained, so they have a proper idea on how these devices are working and supporting for the diabetes management. Patients must be counselled with the usefulness and also limitations of CGMs

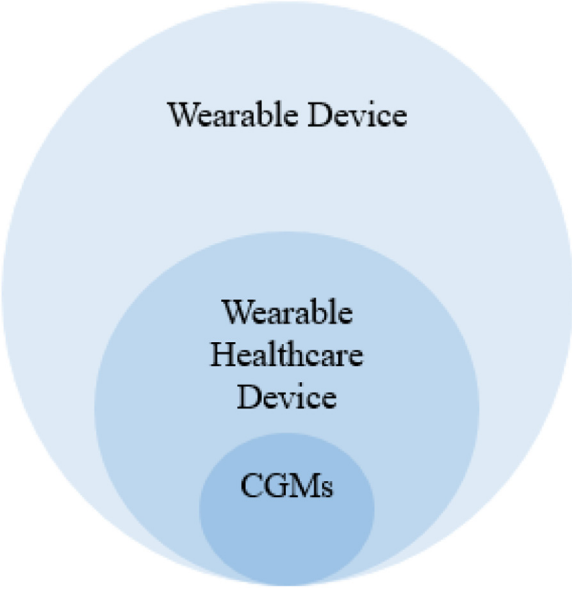

Fig. 1. Insights on wearable device.

devices as well [5]. With the time passed away after the beginning of CGMs device, it has also crossed all the possible limitations to make the self-diabetes management system more popularly adopted and user friendly [5].

It is noticeable that previous studies included some factors for fitness tracker devices and for CGMs device but from traveler's perspective. In [3], the use of CGMs device and barriers were mentioned along with their examining factors for smart healthcare wearable devices adoption.

However, authors did not find much research for CGMs device adoption model, where most of the research discussed about the functionality of CGMs, history of CGMs and also the adoption barrier of CGMs device. Hence, there is a lack of proper adoption model of CGMs devices. Because of this, it is difficult for diabetes patients to get proper suggestions from the developer to ensure their demand criteria.

In [3], the study has introduced an adoption model for wearable fitness tracker, where authors have identified that personal innovativeness and attitude towards a wearable device, as well as health interest have a significant impact on intention to use a wearable fitness tracker. In contrast, interpersonal influence, self-efficacy and perceived expensiveness have no significant influence on wearable fitness tracker adoption.

Another study successfully showed user's acceptance through Technology Acceptance Model (TAM) integrating perceived value, risk and benefit for wearable devices [12]. The authors also stated about financial risk and social image but missed to consider other factors that taking into the account of CGMs devices uses.

For the traveler, in [13], CGMs device is considered a priority for measuring their blood glucose more than a manual system. Authors demonstrated the applicability of TAM for the use of CGMs when travelers perform travel planning. They also found out significant roles of the factors that influence on traveler's CGMs device adoption. Perceived ease of use and perceived trustworthiness showed significant influence for attitude toward a CGMs device adoption.

On the other hand, the use of wireless technology in i-Heart is proposed successfully to play a restraining role for success factors. The authors in [14] have conducted a beneficial study to the coronary heart disease patients and also to the service providers for utilizing new healthcare systems through wearable devices. The results of that study have figured out a significant relationship of usability, communicability, time response, data processing for measuring intention to use of i-Heart [14].

CGMs devices might have some errors about hypoglycemia when the blood glucose level is $<$ 2.8 mmol/L [15]. The accuracy of hypoglycemia is also not proper, like self-blood finger stick glucose monitoring (SBGM) [15]. Some of the researchers have also mentioned about repeated use of CGMs, which may cause optimize basal through sensor replacement after 7 to 14 days uses [16]. In another way, CGMs devices provide higher accuracy if calibrated with plasma glucose level before insulin infusion [17]. Including with these, researchers also identified some barriers of using CGMs where they mentioned about the attitudes of users influenced by the suggestions of experienced people [11]. Fig. 1. shows the CGMs concept through the insights of wearable device.

As the CGMs devices are used to monitor the glucose level of diabetes patients so, the users need more clarification about the device and how it performs with the sensor-based system. In existing studies, authors clearly mentioned about the factors, which can be followed for the adoption of smart healthcare devices including asthma, heart disease and also diabetes [3]. For the travelers, adoption model for CGMs device already included some factors where trustworthiness attitude toward a wearable device showed significant influence on the intention to use CGMs device at the time of traveling [13].

Cost of CGMs device showed barrier of adoption but sufficient number of users have reported their satisfaction and showed great potential towards CGM devices, as they have experienced promising accuracy [11]. In existing studies, it is always suggested towards investigating the adoption influencing factors to identify the exact influencing constructs. These factors will help the users significantly to use smart healthcare devices, especially the sensor-based devices [3,11,13].

The people who are not experiencing CGMs device now, they are also in question whether to use this device or not as there is no proper adoption model for this device. Users can also get proper suggestions from the close contacts and their using experience of these devices to make their decisions for health status monitoring [3,11,28,41].

2.1. Overview of wearable devices

Regular communications are driven through the emerging innovations of continuous technological development in this era [12]. As a result, the smartest inventions in the area of new technology are wearable devices, smartphones and tablets [12]. Following new technology, healthcare wearable devices are now an attractive trend for disease management and monitoring. A study stated that, 31% people nowadays tend to have the trendy device to monitor their health status, physical activity with easy and cloud-based monitoring as technology is now more advanced with smart features [18]. In the following, definition of wearable device and healthcare wearable device are described to provide proper idea of this paper.

2.1.1. Definition of wearable device

Wearable technology is a term which is considered as a device that worn in or out of the body [19]. Another study has described wearable devices like a cloth that is also attached in/out of the body area for monitoring and measuring purposes [12]. When a device is embedded with human bodywork with machines through collecting, transmitting and storing data, then it is considered as smart wearable devices [20].

It is clear from extant definition by existing studies that CGMs device is a wearable device as it is embedded with the body, transmits data by the transmitter, collecting data via sensors and showing results by small built-in monitor. Add to this CGMs device works with continuous Internet accessing for disease management of diabetes patients, which can be connected to the network of IoT with user's mobile data or Wi-Fi [52,53].

2.1.2. Wearable healthcare devices

Wearable medical devices are autonomous, which is worn in the body for a longer time to monitor the health status of patients. These devices can provide medical feedback through transmitting data. Usually, these devices are very small and light to be fitted for unskilled patients also. In recent years, the development of technology is proving real-time data, alert systems and also wireless communications [22]. In the market, various categories of wearable healthcare devices are available, which is classified with their different functioning. Three types of wearable healthcare devices named as 1) disease prediction, 2) disease management, and 3) activity monitoring are existing. Disease management deals with chronic diseases such as diabetes, heart disease and asthma. Activity monitors calculate calorie burning, weight loss measurement, heart rate. Disease prediction is used for undiagnosed disease [3]. This will help in facilitating and enabling a resilience and predictive healthcare system especially for elderly people that enquire especial care [54].

The present study focuses on disease management for CGMs device, which deals with diabetes patients and examines factors that influence the user's intention to use a wearable CGMs device for diabetes management. The reasons for this choice were to identify the main factors for what the users intend to use this device to monitor their blood glucose rather than cheaper manual finger prick systems.

2.2. Formation of CGMs devices

In regular diabetes management system, CGMs device has become an icon for its incredible features. CGMs device contains three different components named sensor, transmitter and monitor [23].

The primary source of energy for the body's cell is glucose. This glucose is the concentration of blood sugar in the blood. Ordinary blood glucose level is considered for mature people, which is approximately 3.5 g to 7.5 g. Normally this glucose level rises during the period of the very first morning phase and also after taking the meal. Due to this, CGMs devices can help diabetes patients to monitor their blood glucose 24/7 for better and healthy life [9, 24].

After wearing the sensor on the body, users can get help from the device with the alarms given through the monitor [9]. CGMs devices give alarms when the blood glucose level is low (hypoglycemia) and high (hyperglycemia) as well [23]. The task of the sensor is to measure the blood glucose that users can attach on upper arms, abdomen and lumbar region with replacing after 7 to 14 days [9,24]. This sensor is made with small metallic filament, which is inserted on the screen through the hypodermic layer of fat tissue [9]. The other component of CGMs which is the transmitter, it is not attached to the body, but work with wireless connections for transmitting data to receiver [9].

Finally, the receiver can be mobile, smartphone and personal laptop having a monitor itself to show the results of blood glucose level [9]. In the following, CGMs devices functionality and benefits are discussed in depth.

2.2.1. Functionality of CGMs

From 1999, CGMs device introduced itself for self-monitoring diabetes management. Nowadays, different companies are offering CGMs device with smart and easy features where these devices are helpful for all diabetes patients [5]. Medtronic Minimed CGM, Dexcom's STS, freestyle navigator, Dexcom G4 Platinum continuous glucose monitoring system, freestyle libre pro flash glucose and Medtronic Minimed's ipro2 system are available in the market for smart glucose monitoring [5,24].

CGMs devices take some time to set up the whole process. First, the receiver needs to be ready while attaching the sensor on the body along with the transmitter. The sensor takes upon 2 h to get the reading of blood glucose level. In [5], authors recommended to attach the transmitter with no more than 20 m' distance from the receiver so that it can capture more readings continually [5]. As a result, these devices are able to give a review evaluating the results performed by the sensor.

2.2.2. Benefits of using CGMs

In manual system, type 1-diabetes patients need to check their blood glucose four times a day with a finger prick. In contrast, CGMs device provides automatic blood glucose level in the body in each 5 min. In addition, CGMs devices work with sensor and the patients need to give blood once the sensor is attached to the body. So, comparing to the manual system, one CGMs device could provide better functioning as it gives alarms in every 5 min [5]. CGMs device is good to identify blood glucose for type 1 and type 2 diabetes patients for improving patient's health status [25]. In similarity, some researchers have suggested CGMs device as safe method and well tolerated for the diabetes patients in regular blood glucose monitoring which insures data accuracy as well [25]. CGMs device is considered as IoT devices and it can provide infrastructure for wide adoption as this device transforms medical practices for disease prevention remotely [52]. In addition, this device can perform seamless data transforming with the medical specialist which is fully secured and trusted widely.

3. Theoretical model and hypotheses formulation

In existing studies, many authors introduced different models and theories for healthcare wearable devices adoption, especially which are technology related. In this study we have examined some models and theories such as: TAM [21,26–30]; Theory of Reasoned Action (TRA) [27,30–32]; Theory of Planned Behavior (TPB) [3,31,33]; Self-efficacy Theory (SE Theory) [3,34,35].

For developing CGMs device adoption model, primary factors are considered in this study, such as: interpersonal influence, self-efficacy, personal innovativeness, attitude toward a wearable device, health interest, perceived value and trustworthiness. From this critical literature review, this study addressed a total of seven constructs to measure the 'intention to use' of CGMs device in smart healthcare for diabetes patients where TPB, TRA, SE Theory and TAM were adopted. All these theories and model are combined in this study for the development of CGMs device adoption model.

3.1. Interpersonal influence

As mentioned by [3], interpersonal influence is defined as the influence of others. It is referred as an individual's intention to perform the attitudes of behavior for the technology-related device. Users get some benefits if they get a recommendation from others like close friends, contacts and the persons they valued most. Prior research has asserted that interpersonal influence is an important predictor of new technology adoption that significantly influences the attitude toward a wearable device [3,36–38]. People tend to adopt new technology devices when they see others using it regularly [3]. Hence, it is hypothesized that interpersonal influence (INF) significantly affects attitude toward a wearable device (ATW). Therefore, this study posits the following hypotheses:

H1: INF will positively affect ATW of wearable CGMs device adoption.

3.2. Personal innovativeness

In [3], authors discussed how personal innovativeness influences user's CGMs device adoption intention. In there, authors also mentioned about healthcare IT-related devices where personal innovativeness is considered as an important factor for healthcare wearable devices adoption [3]. In the literature, personal innovativeness is also considered as a significant predictor that may affect the adoption of new technology devices [37]. Another study [37] also explored, how the lack of the individuals' skills effects on less adoption of new technology. Furthermore, the direct influence of personal innovativeness (PI) on attitude toward a wearable device (ATW) has been investigated [3,39]. Thus, it is hypothesized that:

H2: PI will positively affect ATW of CGMs device adoption.

3.3. Trustworthiness

In [13], authors stated that trustworthiness (TW) could also be an important factor for wearable healthcare device adoption along with other factors like attitude, motivation and usability. As trust is achieved from the performance of a device and its accuracy for the transformation of data, so the accuracy of a e-health device can influence user's adoption intention highly [38]. One study did not find any significant relationship between privacy concern and adoption intention for the wearable IoT devices [30]. Individual trust significantly influences the adoption of new technology devices [38]. Moreover, it is argued that trust is a positive predictor for the consumer's attitude toward new technology [39]. Furthermore, trustworthiness has the potential to influence the user's intention and attitude toward a new system of IT [36]. Trust is also identified as the most significant factor in doctor-patient communication said by the authors [40]. Based on the discussion, the following hypothesis is proposed:

H3: TW on CGMs will positively affect ATW for intention to use CGMs.

3.4. Self efficacy

Self-efficacy (SE) is referred to an individual's self-belief to a new system or device or function [3]. In [3], authors also indicated that SE has a significant influence for health-interest to measure the intention of using a health-related device. Other study found a direct relationship of SE on the intention to use a new system [41], whereas SE can also influence the user's health-interest for the adoption intention of a device [3]. Moreover, it is has found that SE insignificantly affects intention to use (IU) of a new system which is health-related [3], which leads to an individual's health-interest and adoption intention [3,42]. In [42], authors also identified a significant influence of SE on health-interest (HI) to use a new health-related device like arthritis self-management. Therefore, this study proposes the following hypotheses:

H4: SE will significantly affect the HI of CGMs device adoption.

3.5. Attitude toward a wearable device

In [18], authors stated that clarification and prediction for the adoption intention of a device or service are fully influenced by the attitude toward a wearable device (ATW). In a study, researchers found a significant relationship of ATW on health-related behavior and intention to adopt a new device or system [3]. According to planned behavior theory (TPB) [31], attitude significantly influences adoption intention of new IT systems. Attitude also reflects a person's behavior to adopt a health-related device [18]. Another study by [13], proclaimed significant evidence between ATW and intention to use (IU) of a new system or device. Thus, this study posits the following hypotheses:

H5: ATW will positively affect the IU of CGMs device adoption.

3.6. Health interest

Health-interest (HI) is defined as a person's interest in health to keep himself/herself fit. [3]. If a person is willing to monitor his/her daily health status, then their health interest is identified [21]. A study [43] claimed, when a person is more conscious about his/her health condition, then he/she intends to use the new health-related technology. A person's health behavior affects health-interest for the adoption intention of a healthcare device [43]. Moreover, it has been found a significant relationship of HI on the intention to use (IU) for wearable healthcare device [3]. Therefore, this study hypothesizes the following:

H6: HI will significantly affect the IU of wearable CGMs device adoption.

3.7. Perceived value

Four terms are initiated with perceived value (PV) such as 1) lower price, 2) users demand on a product, 3) quality of a product and 4) what the users get in terms of piecing 12]. Many studies related to IT-related device adoption found that PV has a significant effect on the intention to use (IU). PV is also referred as the benefit of users in terms of their purchasing [12]. A study [3] indicated healthcare devices as products so, when consumers intend to use a product, they will consider the value of the products as well as benefits. In this study, PV has considered a significant factor for wearable CGMs device adoption examined from previous studies [12,44]. Thus, the following hypotheses is proposed:

H7: PV will positively affect the IU of wearable CGMs device adoption.

4. Conceptual model and definition of constructs

In this section, researchers examined adoption model and some theories from different studies. Here, adoption model for CGMs device is developed with seven constructs where five factors names as interpersonal influence [3,36], self-efficacy [3,41,42], personal innovativeness [3,37], trustworthiness [13,38,39], and perceived value [12] are independent variables. In contrast, attitude toward a wearable device [3,13,18], health interest [3,43], and intention to use are dependent variables.

In the literature review, all factors are described with their source where most of the authors conducted on fitness tracker activities. But as CGMs device is a health-related device so, it is important to clarify the possible adoption factors which can help the users to adopt this device and the developers as well [21]. Based on the existing pieces of literature, the researchers here combined TPB, SE-theory, TRA and TAM for developing proper adoption model of CGMs. Furthermore, health interest [3] and trustworthiness [13] factors are added in the proposed model to explain the concern of users for new healthcare technology. The proposed model of this study is based on existing literature which is stated (Fig. 2).

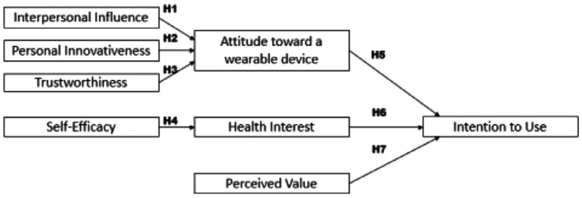

Fig. 2. CGMs Adoption – proposed model.

Table 1
Definition of constructs.

Constructs	Definition	Source
Interpersonal Influence (INF)	INF is defined as an individual's decision making to confirm the positive expectations of others.	[3,36]
Personal Innovativeness (PI)	PI is defined as an individual's decision which he/she takes independently to make comparison with others.	[3,37]
Trustworthiness (TW)	TW is defined as the degree of confidence or beliefs of a person where he/she considers the validity and reliability of service.	[13,38,39]
Attitude Toward a Wearable Device (ATW)	ATW is defined as a degree of evaluative effect that an individual is associated with the target of using a system.	[3,13,18]
Self-Efficacy (SE)	SE is defined as a person's self-belief of using a new system or service.	[3,41,42]
Health Interest (HI)	HI is defined as a person's interest in improving his/her health condition.	[3,21,43]
Perceived Value (PV)	PV is defined as a combination of sacrificing and desiring attributes.	[12]
Intention to Use (IU)	IU is defined as a person's general mind of using a new service.	[3,13]

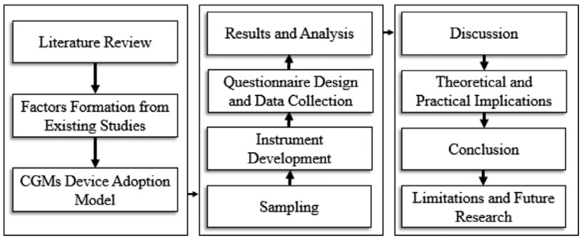

Fig. 3. Research methodology.

In sum, user's perceptions of interpersonal influence, personal innovativeness and trustworthiness are postulated to affect their attitude and intention to use CGMs device for blood glucose monitoring (Fig. 2). User's self-efficacy relates to health-interest to measure the variable intention to use whereas intention to use variable is directly influenced by attitude, health-interest and perceived value of a person (Fig. 2). The definition domain establishes the problem statement and scope of the study [13]. Content analysis is used to identify the domain of this study. Definition is provided for each of the construct to identify the domain of the content, which will be further analyzed in this research (Table. 1).

5. Research methodology

This study represents a quantitative approach of research methodology that aims to identify the factors in wearable CGMs device adoption for blood glucose monitoring of diabetes management. Concerning the CGMs device adoption model, data needs to be collected from the users who are using the device at present and also the people who have experience of using CGMs devices before. Therefore, this study contacted several developers of CGMs to get the relevant users. As a result, this study collected data from Germany and Sweden. A survey questionnaire was delivered to the respondents through online via the link of Google form. This survey took more than 3 months to be completed and finally, 97 data were accepted from 114 of total data collected. The questionnaire was designed into two sections, named as 1) Demographic, and 2) Assessment questions. The assessment part of the questionnaire was in five-point Likert-scale, where Strongly Disagree (1) to Strongly Agree (5) as indicated. Smart-PLS 3.0 and SEM were used for the assessment of measurement model and structural model. In following, proper workflow of research methodology for conducting this study is demonstrated (Fig. 3).

From the literature review, preliminary studies were examined for adapting theories and constructs as well. In this study, 7 constructs are finalized to measure the latent variable intention to use. In Fig. 2, a conceptual model is developed with a total seven hypotheses.

5.1. Sampling

Sampling is a procedure for gathering specific information from many population size into small size population. Appropriate sample size will determine the output of final data collection [45].

In this study, purposive sampling strategy is used where authors can do the judgment of choosing participants. As it is difficult to find out the exact number of users who are using CGMs devices, so it needs to have more observations of sample size suggested. Though SmartPLS considers small size data from 100 to 200, yet the pointing arrow to latent variable needs to measure for actual size of the sample. In the conceptual model (Fig 2.), a total of 7 rows are pointing to the latent variable IU. A study by [45], stated that if maximum 7 rows are pointing to a latent variable, then minimum sample size should be 80. In this study, 3 rows are directly pointed to measure IU. The sample of 59 is also considered as accepted sample size [45]. In G-power statistics 3.1.9.4 version, shows the sample size 79 for 7 independent variables pointing to the dependent variable of the IU.

For this research, the above approaches are chosen to find the minimum sample size that is suitable for the proposed model. Thus, 97 data were collected from actual users who have been using CGMs devices for a longer period.

5.2. Instrument development

Developing and constructing items are necessary for instrument development before questionnaire survey [46]. After defining each construct, this study identified the items from existing studies to get the proper instrument for expert validation [47]. Five experts were consulted after the face validation process to evaluate the instrument for data collection where face validation refers the reviewing of the questionnaire by the expert of same research field. Here, authors evaluated instruments by 5 experts in information systems research domain as well as quantitative research specialist. For 8 constructs, 33 items were selected for the expert validation process in this study. To achieve the most valid instrument, content validity index (CVI) and content validity ratio (CVR) methods were also applied, and 31 items were finalized for questionnaire development. Here, CVI and CVR method were adopted from existing literature [47]. These two methods were applied to accept or reject an item to build a construct in this quantitative research. CVI and CVR are used to measure the acceptance level of the selected items marked through the expert panelists. After applying CVI for all the items selected by Lawshe formula in Excel file, here authors used CVR to get the most accurate items for the final questionnaire development in this study. Lawshe method involves statistical analysis based on CVI and CVR where experts give opinion in 3-point Likert- Scale such as: 1) Essential; 2) Useful but not Essential; 3) Not Essential. For measuring the CVR of each item, the formula is: $CVR = (Ne - N/2) / (N/2)$, Where Ne is the total number of essential given by the expert and N refers to the total number of experts. After this, CVI is achieved from the mean of CVR.

5.3. Questionnaire design and data collection

Some references were utilized in order to construct and refine the measurement questions in this research. Some studies are used to design the questions of each variable. The researchers design the questions of those variables that are related to wearable healthcare device adoption model (Table 2). The survey questionnaire was distributed in August 2019 and data were validated in early November 2019 by Google form. After getting feedback from the experts, CVI and CVR methods were applied. As a result, 31 items were developed upon expert's opinion with few corrections. The main survey was conducted in the English language to the experienced users of CGMs device. In total, 97 data were collected from Germany and Sweden respectively.

6. Results and analysis

The data analysis in this study is conducted in three phases. In the first phase, the respondents examine demographic statistics. The second phase inspected measurement model analysis and the last phase consisted of structural model analysis using Smart PLS and Structural Equation Modeling (SEM).

6.1. Demographic profile of respondents

In this research, the questionnaire collected demographic information of the respondents along with other questions related to the constructs of CGMs device adoption model. In google form, all questions were required to be answered. Table 3 shows demographic profile of the respondents.

The results (Table 3) reveal that 68% of the sample is male and 32% is female. It can be presumed that the majority of the people who are using the CGMs device are male. Among the respondents, 41.2% are 41–50 years old. The minimum number of ages respondents is 21–30 aged. As early mentioned in the literature review that CGMs device is mostly focused on type 1 and type 2 diabetes patients so, it is very normal of the less use for younger ages. The second-highest users are in the age of 51–60 who is the regular diabetes patients. 31–40 ages people also consider CGMs device for type 1-diabetes patients, which stands for 20.6%.

Table 2
Instrument development.

Construct Code	Items	References
INF 1	I like to know what wearable CGMs devices make good impressions on my friends.	[3]
INF 2	People who concern about my clinical behavior think that I should use a wearable CGMs device.	[28]
INF 3	People who are important to me think that I should use a wearable CGMs device.	[28]
INF 4	People whose opinion I value think that I should use a wearable CGMs device.	[28]
SE 1 1	I feel confident about understanding terms relating to sensor and results given by monitors of wearable CGMs device.	[3]
SE 2	I feel confident about describing or given recommendation through the monitor by the sensor measurement of wearable CGMs device.	[3]
SE 3	I believe I can completely use wearable CGMs device if there is no one around to tell me what to do.	[41]
SE 4	I believe I can fully utilize the wearable CGMs device even if I have never used a similar system before.	[41]
SE 5	I am confident that I can effectively understand the results shown in monitor through a sensor-based system of wearable CGMs device.	[41]
PI 1	My friends think of me as a good source of information when it comes to new technology, such as the use of a health monitoring device.	[3]
PI 2	If I hear about new technology-based tools for health status monitoring, I look for ways to experiment with it.	[37]
PI 3	Comparing myself to others, I am usually the first to try new technology tools or system.	[37]
PI 4	Generally speaking, I like to use new technology.	[37]
ATW 1	I feel wearable CGMs device is useful.	[3]
ATW 2	I think the mechanism of wearable CGMs device is relevant. Mechanism = working procedure of the device	[13]
ATW 3	I feel very pleasant when using wearable CGMs device.	[18]
HI 1	I hope I can change my bad habits to minimize health damage using wearable CGMs device.	[43]
HI 2	I think I can improve my health status effectively using wearable CGMs device.	[43]
HI 3	My smart wearable CGMs device motivates me to do exercise.	[49]
HI 4	I think Wearable CGMs device helps me to have a well-balanced diet.	[49]
HI 5	I hope I will have better control over my daily calorie intake with my smart wearable CGMs device.	[49]
PV 1	Using wearable CGMs device for blood glucose monitoring offers effective value.	[12]
PV 2	Compared to the effort to put in the manual system, using wearable CGMs device is beneficial to me.	[12]
PV 3	Compared to the time spent, using wearable CGMs device is worthwhile to me.	[12]
PV 4	Overall, using wearable CGMs device delivers me good value.	[12]
TW 1	Wearable CGMs device is dependable when I am using it to monitor my regular blood glucose.	[39]
TW 2	Wearable CGMs device is reliable when I am using it to monitor my blood glucose.	[39]
TW 3	Overall, I can trust the wearable CGMs device for monitoring my blood glucose regularly.	[39]
IU 1	I will not hesitate to adopt wearable CGMs device	[13]
IU 2	I feel confident with the procedure of CGMs device.	[13]
IU 3	Overall, I intend to use wearable CGMs device.	[13]

Table 3
Respondent's demographic profile.

Profile		Number of respondents	Percentage of respondents (%)
Gender	Male	66	68
	Female	31	32
Age	21–30	1	1
	31–40	20	20.6
	41–50	40	41.2
	51–60	26	26.8
	61–70	10	10.3

Finally, older ages people are also less in usage compare to 51–60 ages people. Because CGMs is a smart device and need to fix the sensor on the body. For the using period of CGMs, this study got maximum 7 years 2 months where the lowest used time was only 1 month. Moreover, most of the users are using this device more than 3 years. These all output indicated that respondents are quite experienced of using CGMs device in their blood glucose monitoring.

6.2. Measurement model analysis

In here, reliability, convergent and discriminant validity were measured for the measurement model analysis. One study by [48], declared about Confirmatory Factor Analysis (CFA) and Exploratory Factor Analysis (EFA) approaches for measurement model assessment. Here, CFA is used for validating the measurement model in standing with reliability (Composite & Cronbach's Alpha) and validity (Discriminant & Convergent). For each item, the external load should be greater than 0.70 [48] to have proper validity and reliability results. In this study, one item PV [3] = 0.441 is less than the threshold value of 0.70. For validity and reliability test, researchers removed this item PV [3].

Table 4
Construct reliability value.

Construct Code	CA Value (>0.70)	CR Value (>0.70)
INF	0.892	0.925
SE	0.857	0.898
PI	0.958	0.969
ATW	0.864	0.916
HI	0.954	0.965
PV	0.707	0.836
TW	0.872	0.921
IU	0.924	0.952

Table 5
AVE value for construct validity.

Construct Code	AVE Value (>0.50)
INF	0.756
SE	0.639
PI	0.888
ATW	0.786
HI	0.845
PV	0.629
TW	0.796
IU	0.868

6.2.1. Construct reliability

Constructs reliability consists of Cronbach's alpha and Composite reliability due to measuring internal consistency reliability in this research [45]. If the value of Cronbach's alpha (CA) is greater than 0.6 or 0.7, then it is fitted [49]. In other sites, composite reliability (CR) is considered to measure indicator's value whether it is reliable or not. For CR, the threshold value is greater than 0.70 [50]. In Table 3, it shows CA and CR value for each construct of this study. In here, the value for each of the construct is fitted with the threshold value where all the CR values are above of the criteria and CA value also (Table. 4).

Here, from Table 4, it is clear that INF, TW, ATW, HI and IU have the highest value in CA and also CR as well which also shows significant influence in structural model assessment.

6.2.2. Construct validity

For measuring construct validity, the Average Variance Extracted (AVE) is included in this study. AVE signifies the average amount of variance, which a construct explains in its indicator variables relative to the overall variance of the indicators [49]. If AVE value is greater than 0.50, then construct validity is confirmed [45]. Table 4 illustrates AVE value for each construct in this study where all AVE value exists in between 0.639 – 0.888 which is accepted. As this AVE is measured for the level of variance captured by a construct versus the level due to the measurement error, so here in this research all the value satisfies with the criteria for measurement model assessment.

Here in Table 5, it is observed that all the values crossed the cut off points whereas INF, TW, ATW, HI and IU again shows higher value than PV and SE.

6.3. Structural model analysis

A Structural Equation Model (SEM) approach was used to test the CGMs device adoption model in this research. T-statistics and *p*-value are measured for identifying the significance level of hypotheses. R^2 is calculated for identifying the coefficient of determination of each dependent variable. Here, dependent variables are ATW, HI and IU. Finally, f^2 is calculated for understanding the effect size of each path relationship of the proposed model. Table 6 indicates the assessment criteria for structural model analysis [48].

For analyzing the significance level of hypotheses in this research model, p-value and t-statistics are measured. Table 7 indicates the value (*p*-value, t-statistics and f^2) for the structural model assessment. Overall, 4 hypotheses were supported by data from 7 hypotheses (Table 6). The results indicate that INF ($p < 0.01$, $t > 1.96$) and TW ($p < 0.05$, $t > 1.96$) both have significant relationship with ATW. Thus, H1 and H3 were supported. PI ($p = 0.638$, $t = 0.471$) showed no significance with ATW. Hence, H2 was not supported. SE ($p = 0.158$, $t = 1.414$) also showed an insignificant relation with HI, so H4 was not supported as well. ATW ($p < 0.05$, $t > 1.96$) and HI ($p < 0.01$, $t > 1.96$) were found to be significant in influencing IU for CGMs device adoption. As a result, H5 and H6 were supported. Finally, PV ($p = 0.937$, $t = 0.079$) was not found to be significant in influencing IU, thus rejecting H7. Table 7 shows the p-value, t-statistics and f^2 of this study.

In this study, R^2 value is moderate for ATW (=0.335) whereas weak for HI (=0.084) and IU (=0.270).

Table 6
Structural model assessment criteria.

Test	Criteria
Path coefficient (p-value)	<0.01 (***)
	<0.05 (**)
	<0.10 (*)
Standard error (t-statistics)	>1.96 (significant)
Co-efficient of determination ($R^{2)}$	Around 0.670 (substantial)
	Around 0.333 (moderate)
	Around 0.190 (weak)
Effect size (f^2)	= 0.35 (large)
	0.15 to 0.35 (medium)
	0.02 to 0.15 (small)

Table 7
Shows *p*-value, *t*-statistics and f2 of the path relationship.

Path relationship	*p*-value	*t*-statistics	f^2 value	Status
INF→ATW	0.012	2.511	0.077 (small)	Supported (***)
PI →ATW	0.638	0.471	0.003 (small)	Not Supported
TW→ATW	0.041	2.045	0.075 (small)	Supported (**)
SE→HI	0.158	1.414	0.092 (small)	Not Supported
ATW→IU	0.020	2.330	0.049 (small)	Supported (**)
HI→IU	0.000	3.734	0.161 (medium)	Supported (***)
PV→IU	0.937	0.079	0.000 (small)	Not Supported

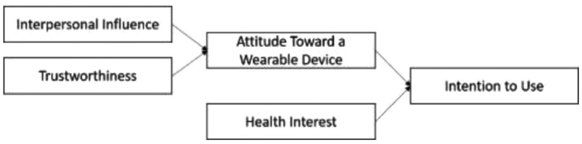

Fig. 4. CGMs adoption – structural model.

6.4. Final structural model

In the measurement model assessment, this study found all the test values passed the cut-off point. In contrast, 4 paths showed significant relationship from a total of 7 paths. Significant path relationships are indicated in Table 6. In below, Fig. 4 illustrates the final structural model for CGMs device adoption in this research. In proposed model, all the constructs assumed to create an influence for the intention to use of a CGMs device (Fig. 2). In contrast, the structural model shows that 3 paths have no significant influence to measure the intention of CGMs device adoption. Therefore, in Fig. 4, only significant paths are shown below.

7. Discussion

In this section, we discuss the main results in the proceeding section. At first, the objective was to identify the factors that influence the user's intention to use wearable CGMs device.

The findings of this study exhibit that the relationship of interpersonal influence (INF) and trustworthiness (TW) on attitude toward a wearable device (ATW) is significant in the adoption of intention to use CGMs device. These results suggest that people tend to know the benefits of CGMs device from his/her closed contacts and friends. Here, users also consider the recommendation from others whom the user's value most and who are always very much concern about his/her health status. If a user gets all the positive reference from others, then s/he intends to have an intention to try a new technology which may influence the adoption of CGMs in diabetes management. This finding is consistent with the results of the previous study conducted in mobile recommender for health status monitoring [15, 55].

Trustworthiness also showed a significant relationship with attitude toward a wearable device. It is believed that if a person finds a CGMs device as a reliable and valid source, then s/he intends to use this new technology for long term adoption in their blood glucose monitoring. TW might possess positive insights with ATW for the intention to use the system. That is, the respondents who think CGMs device as reliable and valid might have a higher intention to use CGMs through the ATW of the device. This result is also consisted with existing studies [13,38,39].

Table 8
Shows final findings of the hypotheses.

Hypotheses	*p*-value	Prestige	Explanation
H1	0.012	Significant	It is important for the users how other close friends or contacts relate with this device and give recommendation.
H2	0.471	Insignificant	Individual's decision does not affect for the attitude of adopting CGMs device.
H3	0.041	Significant	Users feel wearable CGMs as a trustworthy device to monitor their health status.
H4	0.158	Insignificant	Self-efficacy has no direct influence on health interest to adopt CGMs device as users mostly close contact's recommendation.
H5	0.020	Significant	Positive thinking and self-belief about CGMs device helps users to adopt it.
H6	0.000	Significant	Health conscious people are more aware of this CGMs device to have a healthier life.
H7	0.937	Insignificant	Perceived value has no direct influence on intention to use CGMs.

The strength of a person's health interest (HI) also showed a significant relationship with intention to use (IU) of CGMs device adoption. People who are interested in health had an intention to use the CGMs device in measuring their blood glucose. This finding suggests that respondents considered CGMs as a helpful device for health status monitoring and improving health condition as well. Moreover, when a person is concerned about his//her health condition, then s/he tends to use the CGMs device as this device is self-monitored. The finding for HI also consists of the existing studies where HI is relevant to measure IU for wearable healthcare devices [3,43].

The relationship between ATW and IU is significant for the adoption of CGMs device in smart healthcare where INF and TW influence ATW. In explaining a person's intention to use CGMs, ATW showed strength relation. The results suggest that the ATW variable mediates the effects of interpersonal influence and trustworthiness. In contrast, Personal Innovativeness showed an insignificant relationship with ATW for wearable CGMs device adoption. If the respondents feel CGMs device is useful, relevant, then they feel the pleasure of using CGMs, which influence the intention to use CGMs device regularly. In particular, the results are in line with the existing studies, which noted that attitude is a good predictor for the wearable healthcare device adoption [3,13,18].

We also found that personal innovativeness (PI) was statistically insignificant associated with the attitudes for the intention to use the CGMs device. This result indicated that PI plays a less significant role for adoption of CGMs. It means that when a person intends to use the CGMs device, s/he did not think himself/herself as just a source of others. They also did not use CGMs as considering it just a new technology. It might be because users thought to measure blood glucose 24/7 where they can get feedback in every 5 min. The result does not consist of a wearable fitness tracker device adoption [3]. The reason for this is that the respondents in this study were older aged people who do not think about the fashion of the new device. Therefore, their adoption level of CGMs device was high for their health status monitoring.

The hypotheses between self-efficacy (SE) and health interest (HI) was examined and found not to be significant in this study regarding CGMs device adoption. It is because CGM s device is very easy to install and use in further process. Users use this device for monitoring their health status when s/he got suggestions from closed contacts. There, users did not think about the understanding of the device as this device is already approved by the Food and Drug Administration (FDA). The finding is consistent with the result of the previous study for wearable fitness tracker adoption [3,51].

Besides, to measure IU, perceived value (PV) has been found to be an insignificant predictor. The results of this study for PV might contradict with the existing study [11, 12] for wearable device adoption. It might be the reason for the device differences, as CGMs is expensive and the sensor needs to change after 7 to 14 days. The results indicate that the target audience is not much concerned about the price of the device, as the maximum of the respondents had been using CGMs for more than 3 years. Besides, users considered CGMs as more reliable than manual system and FDA approves it. As a result, the respondents intended to use this device only considering their health status monitoring where close friends influence them.

It is important to note that users are more influenced by close contacts to use a new health-related device. When users intend to use CGMs, they also consider their health status improvement along with the reliable and valid system of CGMs device. Finally, a person tends to have a higher intention to adopt a wearable CGMs device where interpersonal influence, trustworthiness, health interest and attitude are the strong predictors rather than personal innovativeness, self-efficacy and perceived value.

This study attempted to identify the influencing factors that increase the adoption intention to use wearable CGMs device in measuring regular blood glucose for the diabetes patients. The results presented in the previous section, displayed measurement and structural model assessment with regards to the behavioral intention to use a CGMs device, which is different from other studies. In Table 8, summary of the findings is presented based on the hypotheses.

From previous discussion it is almost clear that the users who get the actual recommendation from the experienced users then new patients wish to adopt this device. If users can get the regular feedback in a common platform like mobile application or website, then it might create intention to the users to make decision for CGM s device adoption intention. The person who is much concern about health and gets suggestions from other users, feels secure to use CGMs device in their diabetes status monitoring. If the users can get feedback from the nearby users by mobile apps, then it can influence other users as well as create support among the users. It is necessary to mention about online platform, which can assist the new users and also the existing users to communicate easily for any query.

8. Theoretical implications

Here, researchers studied some factors that influence user's intention to use CGMs device in this study mainly based on theory of planned behavior (TPB) [2], theory of reasoned action (TRA) [2], self-efficacy theory (SE-theory) [34] and technology acceptance model (TAM) [12]. Also, the authors added other factors that have been a significant influence on wearable healthcare device adoption which include trustworthiness and health interest from existing literature [3,13].

Investigating certain behavior of a person for a new device should be considered from commonly used theories and models for identifying accurate adoption predictor. CGM is a health-related device and less popular than the manual system of diabetes management, so it might be considered about the other technological devices in the market, which is wearable [4]. Especially, this CGMs device is still in early stage, where not many people are aware of this device. As a result, the additional factors, which are discussed in existing smart healthcare wearable devices adoption, need to be measured [3].

The additional factors named Trustworthiness and health interest have affected the existing theories in this study (i.e. TW→ATW & HI→IU). These relationships showed significant influence on CGMs device adoption. For example, among all the factors, ATW showed the most significant relationships with IU, where TW and INF also influence ATW.

The result of the study found that personal innovativeness has no direct influence on the attitude of CGMs device uses. Self-efficacy also showed an insignificant relationship with health interest as this device is easy to use and it is automated as well. The results of the analysis revealed that perceived value had no direct influence for CGM s device adoption where health interest was found as an important predictor to improve patient's health status. The finding of this study also implies that modification of the existing theories with other factors can influence the user's intention to use CGMs in diabetes management.

9. Practical implications

Researchers found a significant influence of attitude toward a wearable device on CGMs device adoption through interpersonal influence and trustworthiness. This study suggests that if attitude toward a CGMs device were changed, then there would be more people who purchase a CGMs device to monitor their blood glucose. According to [13], a person intends to use the wearable CGMs device if s/he finds CGMs device as a reliable and valid device and also recommended by other close people whom s/he trusts.

In the other side, consumers who adopt this device can monitor their health improvement status through blood glucose measurement every 5 min. Thus, it is important to provide more advertisements to make this device popular from the significant factors, which can increase the adoption rate of CGMs.

10. Conclusion

CGMs device helps diabetes patients to improve their health status. There is a need to successfully implement an adoption model for CGMs device, which can help the users and also the developers. The statistical analysis concluded that interpersonal influence; trustworthiness, health interest and attitude have a positive influence on CGMs device adoption. Also, self-efficacy, personal innovativeness and perceived value were found not to be significant for CGMs device adoption. This study contributes an adoption model for CGMs identifying the critical factors that influence user's intention to use CGMs device. The findings of this study provide greater insight for inclusive factors and appreciated suggestions for the developers of CGMs device.

11. Limitation and future research

Though this study proposed an adoption model for CGMs device through the adamant procedure, there remain some possible limitations that could be identified and discussed in future studies. The following points are summarizing the limitation of this study along with some future work directions.

- Firstly, the response rate of participants was very low, which is less than 100. All the data were collected from European countries, so the findings and implications might be treated with caution for the developing countries for cultural differences.
- Secondly, this study focused on the experienced users only whereas the inexperienced users were not included which might predict different imagination for the adoption intention of CGMs device.
- Thirdly, this research did not include the user's income status although this device is expensive. Therefore, developers could consider the price of this device for the developing countries people.
- Finally, this research can be extended with other factors of wearable healthcare devices to examine the post-adoption satisfaction of the users and also lower adoption rate might be possible to point out.

Declaration of Competing Interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. We confirm that the manuscript has been

read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He/she is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

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