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Vital Sign Measurement in Telemedicine Rehabilitation Based on Intelligent Wearable Medical Devices

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ABSTRACT This paper explores the effects of wearable medical devices (WMDs) in vital sign monitoring, which is the key to telemedicine rehabilitation. First, 60 young patients were selected from the department of oral and maxillofacial surgery in a Chinese hospital. The vital signs of the patients, namely, ear temperature, pulse, blood oxygen saturation, and blood pressure, were measured by both the WMDs and the traditional devices. The measurements were carried out at 6:00, 10:00, 14:00, and 18:00 on the first day of each month in 2018. The comparison between the measured results shows that the WMDs and the traditional devices have no difference in the measured data and measurement time of any vital sign ($P > 0.05$), but the WMDs consumed much less time in data transcription and the entire measurement process. This means the WMDs are suitable for vital sign measurement in telemedicine rehabilitation.

INDEX TERMS Wearable medical devices (WMDs), vital sign measurement, Bluetooth, Internet of Things (IoT).

I. INTRODUCTION

The vital signs reflect the physiological state, organ activities and disease evolution of the patient. The measurement of these signs has a major impact on disease prevention, diagnosis, treatment and nursing care [1]. If measured correctly and timely, these signs could offer a good reference for efficient and quality telemedicine rehabilitation. Many information and artificial intelligence (AI) technologies have been introduced to improve vital sign measurement, such as the Internet of Things (IoT) and the telemedicine.

The telemedicine is a new medical service that integrates computer, communication and multimedia technologies. It relies on a group of sensors to automatically collect the data on human motion, vital signs and health. Telemedicine breaks the space limit, making off-side medical service a possibility.

One of the latest tools to collect vital signs is called wearable medical devices (WMDs). These portable electronic devices can monitor and analyze physiological data [2]. Compared with the traditional measuring tools for vital signs, this type of intelligent devices enhances the software and network links between the device terminal, system platform and the cloud, shedding new light on treatment and nursing. It is meaningful to verify the accuracy, stability and efficiency of the WMDs in vital sign monitoring [3].

In this paper, evidence-based nursing is introduced to verify the effects of WMDs in monitoring vital signs of telemedicine rehabilitation [4].

II. LITERATURE REVIEW

The WMDs can be traced all the way back to 1861, when a French surgeon made a cylinder from a notebook and used it to monitor the heartbeats of a patient. Soon, this simple "stethoscope" spread across Europe [5].

Since then, great efforts have been paid to improve the WMDs. For example, Tada *et al.* [6] created a small, electrode-free wearable monitoring system from a conductive T-shirt, several active electrodes, a signal receiving module and monitoring software. Nassar *et al.* [7] developed a multi-module, fully-automated wearable monitoring system, which contains a detection module of health information, a wireless transceiver module and a low-power data acquisition/processing module.

The IoT and the big data have injected new impetus to the design of WMDs for health monitoring, disease treatment,

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telemedicine rehabilitation, as well as efficacy evaluation in the field of health care [8]. For instance, the "life shirt" designed by Wilhelm *et al.* [9] can record more than 30 physiological parameters in real time, and transmit the data to the system end for further processing and analysis. Based on personal digital assistant (PDA), Liu *et al.* [10] invented a blood pressure monitor that monitors blood oxygen noninvasively anytime and anywhere. Campo *et al.* [11] combined the IoT-related smart home technology and the intelligent wearable technology into an intelligent wearable homecare system for the aged.

In addition, Poon *et al.* [12] set up a telemedicine health monitoring system based on the IoT and determined its parameters according to the main physiological parameters of the human body, providing a reference for applying low-power wireless transmission technology in intelligent wearing devices. Zhou *et al.* [13] designed an intelligent wearable system to monitor physiological parameters like blood oxygen saturation and respiratory signal, and embedded the system with detection algorithms for these parameters, with the aim to improve data acquisition accuracy. Van Steenbergen *et al.* [14] proposed a portable blood glucose and blood pressure monitor, which works in three steps: measuring the health data anytime and anywhere, wirelessly sending the measured data to the back-end database for processing, and forming the electronic health records.

Researchers at Beijing University of Technology have designed a multi-physiological parameter monitoring system for intelligent wearing equipment. The research on the detection algorithm of physiological parameters such as blood oxygen saturation and respiratory signals provides a basis for the correctness of data acquisition. The research on the blood pressure measurement method based on pulse wave conduction time solves the technical difficulties that human blood pressure cannot be monitored continuously, and finally achieves the goal of monitoring blood pressure continuously. The purpose of continuous monitoring of human physiological parameters under normal human activities.

The ECG monitoring service realizes the function of real-time monitoring, recording and transmission of ECG by using the cell phone for ECG measurement. The research and development can provide users with standard ECG data management, blood pressure, blood sugar, fatigue detection and other services, but also for patients with diseases, sub-healthy people to provide heart disease prevention and early warning services.

To sum up, the previous studies have discussed at length about the application of WMDs in monitoring, but rarely examined the use of WMDs in telemedicine rehabilitation.

III. METHODOLOGY

A. DATA ACQUISITION

Our research targets 60 patients, 28 males and 32 females, admitted to the department of oral and maxillofacial surgery in Affiliated Hospital of Jining Medical University in 2018. All of them are between 18 and 70 and at least graduated from junior high school. They can read and comprehend basic information, knew about our research purpose, and volunteered to joint our research. In addition, none of these patients have serious mental illness, cognitive impairment, hemiplegia or trauma of the right upper extremity, or serious organic diseases. However, twenty of them suffer from mandibular odontogenic cysts, 18 from maxillary cysts, 13 from benign parotid gland tumors, 5 from sublingual gland cysts, and 4 from benign submandibular gland tumors.

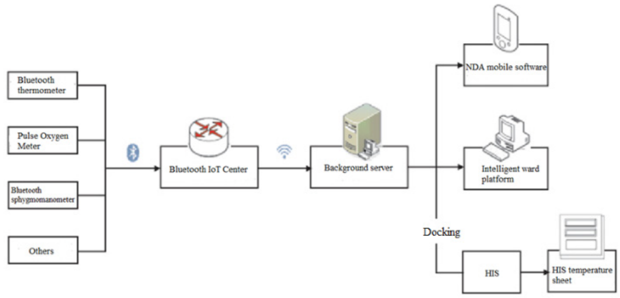

FIGURE 1. Topology of intelligent sports health vital sign acquisition system.

B. SYSTEM DESIGN

Besides the traditional devices for vital sign measurement, the author designed an intelligent vital sign acquisition system. As shown in Figure 1, our system contains such WMDs as an IRT101B medical infrared thermometer, an AM-807B-C pulse oximeter and an ESM201B-01 arm type electronic sphygmomanometer; there are also a Bluetooth IoT center (blue bridge), and an nurse digital assistant (NDA) with an Android app.

The WMDs and the blue bridge are the centerpieces of our system. All the WMDs have been certified by The China Food and Drug Administration (CFDA). With the aid of the built-in Bluetooth module, the WMDs can connect to the blue bridge in a short time and provide real-time data. The blue bridge mainly transmits the collected data to the server through the wireless network. This module at once inherits the terminal mobility and access flexibility of the IoT, as well as the low power consumption and high security of Bluetooth. In this way, the rigid information network of the hospital is turned into a flexible net, creating a stable path for data acquisition.

The patients and the WMDs are identified via NDA scan code, such that the Android app in the NDA can bind the patients with the WMDs. The app can also display and screen the records generated from the data uploaded by the WMDs, and export them to the intelligent ward platform.

Once our system is docked to the hospital information system (HIS), the collected data can be sent to the corresponding location.

C. MEASUREMENT METHOD

On the first day of each month, five patients were selected randomly to receive measurements on the right upper extremity. The measurements were performed under the patients' own control. The ear temperature, pulse, blood oxygen saturation, and blood pressure of each patient were measured by the WMDs at 6:00, 10:00, 14:00, and 18:00, respectively, and recorded as experimental data. Before the very first measurement, the patients should be identified and bound with the WMDs through NDA scanning. This procedure is not needed for the subsequent measurements. The process of each official measurement is explained below.

To begin with, the nurse carried the WMDs and the NDA into the ward, and scanned the wristband of each patient with the NDA to check the patient identity. Once booted, the WMD devices automatically connected to the blue bridge. The measured temperature, pulse, oxygen saturation and blood pressure of each patient were displayed simultaneously and uploaded in real time. Finally, the transcription button was pressed to associate the temperature sheet to the HIS.

During the measurement, the ear temperature of the patient was recorded after the IRT101B medical infrared thermometer gave off a tick sound. The pulse and oxygen saturation were measured by the AM-807B-C pulse oximeter (the meter was clamped in the distal segment of the index figure, and the sensor sheet attached to the nail surface), and the results were displayed after the start button was pressed. The blood pressure was measured by the ESM201B-01 arm type electronic sphygmomanometer (the patient sat comfortably with the right limb at the same level as the heart, and the cuff of the meter was tied 2cm above the right elbow, leaving the room to accommodate one finger), and the result was displayed on the screen after the start button was pressed.

Three minutes after the measurement, the vital signs were measured again by the traditional devices. The results were recorded by the nurses and manually imported to the temperature sheet of the HIS.

During the measurement, the ear temperature of the patient was recorded after the Braun-6520 ear thermometer gave off a tick sound. The pulse and oxygen saturation were measured by the PM-9000 monitor (the meter was clamped in the distal segment of the index figure, while the sensor sheet attached to the nail surface) and the results were displayed instantly on the monitor screen after the power button was pressed. The blood pressure was measured by the same procedure as above.

The collected data on each vital sign and the measurement time of our method and the traditional method were recorded separately for further analysis. Here, the term ''measurement time'' refers to the period from the start of data acquisition to the end of recording.

D. QUALITY CONTROL AND EVALUATION METHOD

Before the measurements, the nurses were fully trained on the use of the WMDs, the specific steps and the relevant standards, such as to avoid unnecessary actions and reduce the measurement error. The patients were told not to exercise fiercely, get excited, eat food, have hot/cold drinks, go for a massage, take a bath/ethanol rubbing 30min before each measurement, and asked to take the resting state during the measurement. The data measured by the traditional devices were recorded in a unified form, and the measurement time was counted with the same stopwatch.

The measured data and measurement time of each patient by both methods were fully recorded for subsequent comparison. The whole measurement process can be divided into two parts: device operation and data transcription.

The raw data was analyzed on the SPSS. The paired sample t-test shows that the data obey the normal distribution, while the Wilcoxon signed-rank test [15] indicates the otherwise with the test level $\alpha = 0.05$.

IV. MEASURED RESULTS

list the results on the four vital signs, namely, ear temperature, pulse, blood oxygen saturation and blood pressure of the patients, which were measured by the traditional devices and the WMDs. Obviously, the two sets of tools had no significant difference in these signs.

TABLE 1. Measured results on ear temperature.

Method	Time	6:00	10:00	14:00	18:00
Traditional method	60	35.47±0.28	35.68±0.24	35.71±0.25	35.66±0.24
Our method	60	35.52±0.29	35.69±0.23	35.73±0.24	35.64±0.23
t		1.677	0.332	1.856	1.838
P		0.102	0.739	0.063	0.068

TABLE 2. Measured results on pulse.

Method	Time	6:00	10:00	14:00	18:00
Traditional method	60	72.88±10.73	71.67±11.09	75.09±11.05	72.98±11.14
Our method	60	73.82±10.59	72.01±11.12	74.88±11.03	73.07±11.12
t		1.468	1.689	0.965	0.876
P		0.146	0.097	0.356	0.419

TABLE 3. Measured results on blood oxygen saturation.

Method	Times	6:00	10:00	14:00	18:00
Traditional method	60	0.96 (0.95,0.97)	0.96 (0.95,0.97)	0.96 (0.95,0.97)	0.96 (0.95,0.97)
Our method	60	0.96(0.95,0.97)	0.96(0.95,0.97)	0.96(0.95,0.97)	0.96(0.95,0.97)
Z		1.62	1.451	1.536	1.231
P		0.251	0.149	0.131	0.222

Table 5 compares the total measurement time and the time consumption in each part of measurement of the two sets of devices. The comparison shows that the WMDs consumed much less time than the traditional tools, as the nurse spent a slightly more time in device operation and much less time in data transcription.

TABLE 4. Measured results on blood pressure.

Method	Time	6:00		10:00		14:00		18:00	
		SBP	DBP	SBP	DBP	SBP	DBP	SBP	DBP
Traditional method	60	130.72±24.19	80.57±12.87	135.58±22.17	83.87±12.91	131.10±22.38	82.07±12.87	131.85±21.95	81.93±12.77
Our method	60	130.59±24.10	80.77±12.88	135.53±22.32	83.80±12.87	131.28±22.36	82.10±12.64	131.88±22.03	81.83±12.99
t		0.856	0.767	1.501	1.356	1.314	1.831	1.515	1.518
P		0.397	0.459	0.117	0.192	0.197	0.076	0.138	0.127

TABLE 5. Measurement time of the two methods.

Time		6:00			10:00		
		Device operation	Data transcription	Total	Device operation	Data transcription	Total
Traditional method	60	126.87±1.68	27.52±2.67	151.36±3.18	126.88±2.69	28.66±2.88	156.58±3.79
Our method	60	132.33±3.13	5.18±0.86	149.38±3.97	137.08±3.85	5.78±1.87	149.71±3.65
t		30.512	63.572	15.662	28.072	64.470	14.986
P		0.000	0.000	0.000	0.000	0.000	0.000
	Time		14:00			10:00	
		Device operation	Data transcription	total	Device operation	Data transcription	total
Traditional method	60	128.73±1.66	27.83±2.58	151.87±3.12	128.53±1.66	28.66±2.53	149.67±3.19
Our method	60	140.53±3.22	5.18±1.82	143.78±3.92	147.41±3.76	5.17±1.05	140.18±2.64
t		30.627	68.828	14.619	31.975	71.558	16.889
P		0.000	0.000	0.000	0.000	0.000	0.000

V. DISCUSSION

The traditional devices wasted lots of time and energy in repeated data transfers and imports, resulting in inefficiency, illegible writing and transcript errors. In this case, special personnel are needed for regular verification of the data, which pushes up the labor cost. The repetitive and mechanical labor also takes time away from direct care, making it hard to provide good nursing care. This contradicts the call from Chinese National Health Committee to further increase the amount of basic care and service time by responsible nurses. What is worse, it is extremely hard to squeeze out the manpower from the constant number of hospital staff to fully utilize the traditional devices [16].

By contrast, the WMDs achieved a low labor cost, accurate data acquisition, automatic data transfer, as well as thorough utilization of Bluetooth and the IoT. These devices enabled automatic import of data, eliminating the errors and saving the time of manual entry. In data transcription, the WMDs could load data into the healthcare system in just a few seconds.

To promote the information and intelligence levels of hospitals and nursing care, more and more WMDs have been developed based on medical IoT and health big data [17]. In our system, the WMDs include a thermometer, a sphygmomanometer and a pulse oximeter. These modularized devices integrate miniaturized sensor detection with Bluetooth function. During measurement, the data were measured by miniaturized sensors and transmitted to the blue bridge via Bluetooth. As long as the HIS is accessible, the data could be uploaded automatically to the server platform and transcribed automatically to generate a nursing record (e.g. a temperature sheet).

In telemedicine rehabilitation, the accuracy of medical records, especially the data on vital signs, directly affects the safety of the patient. In our study, the WMDs and the traditional devices measured the same batch of patients, and achieved consistent results on the four vital signs ($P > 0.05$). This means the WMDs can realize accurate measurement of vital sign for telemedicine rehabilitation, and serve as a feasible alternative to the traditional devices.

Efficiency is critical to the manpower allocation and performance evaluation in telemedicine rehabilitation. It reflects how much work a nurse can complete in a specified period. Our research shows that the WMDs worked much faster than the traditional devices ($P < 0.01$). The nurses participating in our research expressed their preference for automatic transcription than manual entry, although they spent more time in the operation of the WMDs than the traditional devices (as they were not yet familiar with the new devices and the compulsory wristband scanning before first measurement).

The above results fully illustrate the application value of WMDs in vital sign measurement for telemedicine rehabilitation. However, there are still some limits in our research. For example, all the subjects are young patients from the oral and maxillofacial surgery departments. Unlike patients with malignant diseases, our subjects tend to have a good overall state and their vital signs are basically in the normal range. These defects will be tackled in the future research.

VI. CONCLUSIONS

In conclusion, the WMDs can achieve the same level of accuracy as traditional devices in the monitoring of such vital signs as temperature, pulse, blood oxygen saturation and blood pressure, and outperform the latter in efficiency, quality and safety, due to its automatic transfer transcription based on Bluetooth and the IoT. The application of these devices makes it possible to extend the HIS to the ward, exchange medical data timely in remote environment, and promote the application of information technologies in telemedicine rehabilitation.

To further improve the WMDs performance in telemedicine rehabilitation [20], [21], the future research will select patients from other departments, divide the vital signs into different levels for hierarchical analysis, evaluate the WMD performance through repeatable, continuous measurement, and introduce more mature early warning mechanisms (e.g. the early warning scoring system-EWSS) [19] to the monitoring process.

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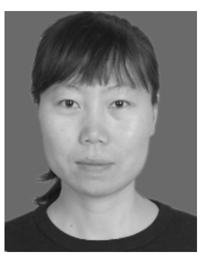

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