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Research Progress of Wearable Devices in Predicting the Risk of a Stress Injury in Surgical Patients

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Abstract

The incidence of stress injury in surgical patients can be as high as 8.1%-54.8%. The occurrence of stress injury will increase patients' physiological and psychological burdens, prolong the hospital stay, and affect the prognosis. Accurate evaluation and prevention of surgical stress injury are very important. The existing assessment of surgical stress injury is mainly a self-rating scale, the data lack objectivity and large error. Wearable devices have the characteristics of mobility, sustainability, wearability, simple operation, and interactivity. It has been widely used in disease monitoring and management and can help medical staff analyze the condition's change, and the effect is good. Therefore, this article aims to summarize the application of wearable devices in pressure injuries in surgical patients, and provide a review from the mechanisms of wearable devices in pressure injury and assessment, the predictive role of wearable devices in pressure injury identification and assessment, and the advantages and challenges of wearable devices in pressure injury identification. The aim is to provide new ideas for medical staff to manage pressure injuries in surgical patients, ensure patient surgical safety.

Keywords

Stress injury, Accurate evaluation, Wearable devices

1. Introduction

Studies have shown that the incidence of stress injury in surgical patients was 8.1% (54.8%). The stress injury will not only enlarge the psychosomatic burden of patients, and prolong the time of hospitalization, but also affect their prognosis and treatment [1-2]. Therefore, accurate evaluation and prevention of surgical stress injury is an important way to ensure the safety of patients. The existing assessment of surgical stress injury is mainly a self-rating scale [3], and the collected data lacks objectivity and is affected by measurement errors of different evaluators [4]. Wearable devices refer to portable medical or electronic devices directly worn on the body, which can perceive, record, analyze, regulate, or interfere with health status under the support of software, etc., characterized by mobility, sustainability, wearability, simple operation, and interactivity [5-6]. At present, wearable devices have been widely used in disease monitoring and warning, rehabilitation exercise, and chronic disease management in the medical field [7-9]. Meanwhile, it has been proved that they can provide timely treatment for patients and assist medical staff to analyze disease changes, and has a good application effect. In relevant studies, wearable devices have also been explored to help medical staff identify patients' skin conditions by measuring sweat or pressure on the skin surface [10], but most of them are still in clinical trials and have not been widely promoted yet. Therefore, this paper aims to summarize the application of wearable devices in monitoring and evaluating the skin conditions of surgical patients, discuss its advantages and disadvantages, and provide a reference for promoting the evaluation research of surgical patients with stress injuries.

2. Overview of wearable devices

The concept of wearable technology was first proposed by Edward O Thorp, a mathematics professor at MIT in the 1960s [11]. According to the field of application, it can be divided into commercial consumer devices and professional medical devices. Professional medical devices are generally portable clothes or accessories with clinical monitoring or health treatment [12]. Professional medical wearable devices based on sensor technology show great potential and are widely used in health monitoring, rehabilitation and health care, disease diagnosis and treatment, and other aspects [13]. In terms of health monitoring, wearable devices not only collect physiological data related to basic vital signs such as body temperature, pulse, respiration, and blood pressure [14] but also establish clinical data monitoring systems related to wearable electrocardiograms and wearable continuous monitoring devices [15-16]. Then regarding disease diagnosis and treatment, clinical applications of wearable devices such as kinesia and gait disorders related to Parkinson's disease have been explored [17]. Otherwise, they exhibit an excellent character in rehabilitation and health care. Wearable image capture technology relying on wearable sensors can improve the ability to evaluate nerve rehabilitation in the hands of patients with spinal cord injuries [18]. In addition, wearable devices made by combining flexible sensors with textiles can protect the knee [19], and bio-tactile wearable devices can be installed on patients' prosthetics. To enhance the sensory transmission and motor functions of the prosthesis [20], excitingly, in the "14th Five-Year Plan" of Public Service, we propose to actively develop intelligent medical treatment, to improve the quality and efficiency of medical and health services [21]. As a result, wearables are increasingly becoming a part of the health system in our healthcare, safeguarding the health of citizens and interacting with medical providers.

3. The mechanism of wearable devices in the recognition and evaluation of pressure ulcers

Studies have shown that high ambient temperature and humidity may lead to local wet skin, increased metabolism, and decreased tolerance. While low temperature and humidity may lead to dry and fragile skin, poor blood circulation, and loss of protective layer [22]. In terms of measuring skin surface moisture, changes in electrical properties in the skin are caused by changes in skin hydration level. Therefore, skin electrical activity has been used to monitor physiological or sympathetic nerve conditions that can affect skin hydration levels [23]. When measuring skin surface moisture, wearable devices can accurately and reliably measure skin electrical signals mainly by forming conformal contact between the device and the skin, as shown in Figure 1 [24]. In measuring skin surface pressure and temperature, wearable devices measure skin surface pressure and temperature by using a new capacitive pressure sensing mechanism based on the change of contact area, as well as the layered contact behavior of the pyramid microstructure of the surface fold. And they can use an impedance analyzer to simultaneously and truly detect and distinguish pressure/temperature stimulation [25]. In terms of measuring blood circulation and oxygen content on the skin surface, wearable devices can be fully integrated with the curved surface of the human body through a deterministic pattern electrochemical biosensor, while mechanically adapting to natural stresses imposed on the skin and allowing mass transfer of gases and liquids, and incorporating lattice structure biosensors for continuous assessment of lactic acid and oxygen [26]. By measuring the above risk factors of stress injury and quantifying them, wearable devices enable nursing physicians to intuitively observe the injury prediction, timely adjust the position of surgical patients, and reduce the incidence of a stress injury in surgical patients.

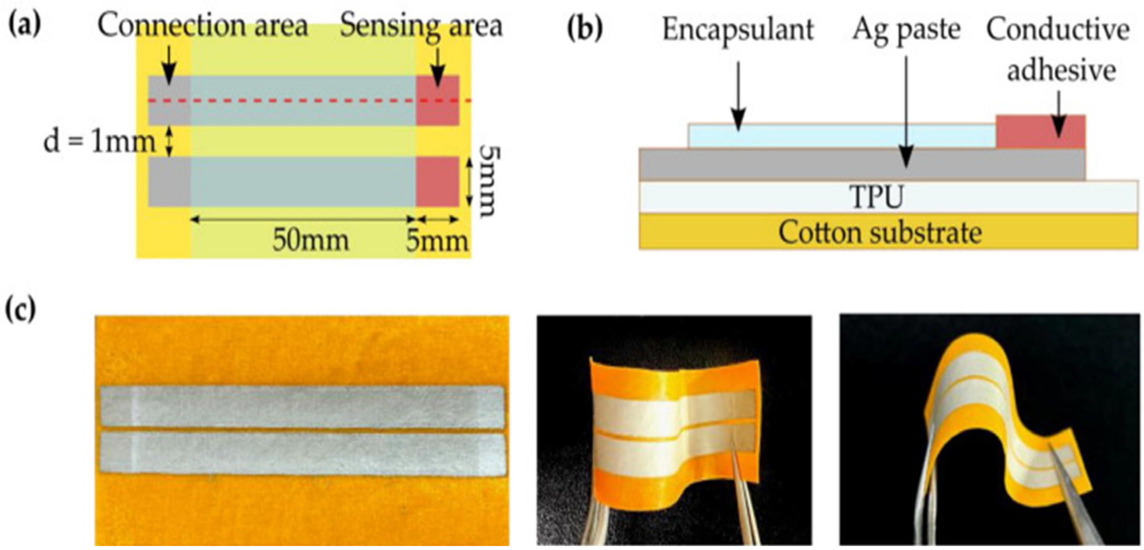

Figure 1. Textile-based skin hydration wearable sensor [24].

4. The predictive role of wearable devices in the recognition and assessment of pressure ulcers

4.1 Identify the physiological indicators related to stress injury and pay attention to its influencing factors

Professional and systematic evaluation is a key step for the early identification of risk factors and high-risk groups of stress injuries, as well as a primary task for the prevention of stress injuries and an important reference for adopting prevention strategies [27]. Effective risk assessment can significantly decrease the risk of a stress injury in surgical patients, which is of profound significance for reducing the economic burden of patients and prognostic recovery. Gao L et al. [28] measured skin surface pressure by using a wearable all-paper-based piezoresistive (APBP) pressure sensor, showing that the sensor has a high sensitivity of 1.5 kPa-1 within the range of 0.03-30.2 kPa, which can promote the development of wearable pressure sensor electronic devices. Meanwhile, Bae GY et al. [25] developed for the first time a linear sensitive peak electronic wearable device that can simultaneously detect and recognize pressure and temperature stimuli, achieving nearly perfect resolution of physiological indicators of pressure injuries. The device has a linear and high-pressure sensitivity of 0.7 kPa-1 to 25 kPa and displays a linear and reproducible resistance temperature coefficient of 0.83% in the range of 22-70℃. It responds quickly to temperature changes within 100ms, with extremely high sensitivity and specificity. In addition to the recognition of pressure and temperature, wearable devices also show a good effect in the recognition of skin surface moisture. In a study by the Chinese Academy of Sciences, researchers used a wearable sweat detection device to measure hydration and thermoregulation of the skin surface. The results showed that the sensor can measure sweat loss in a wide range, but further optimization research is needed to expand its test range and improve its accuracy [29]. The research results of Saha T et al. [30] also confirmed its advantage in skin moisture measurement. In addition, wearable devices also show reliable detection functions in the monitoring of blood flow in deep skin tissues. In a study designed by Tomioka Y et al. [31], a wireless, continuous, multi-point wearable sensor was used to monitor circulation in transplant patients. The system used an algorithm to analyze the data of patient risk in real-time by measuring the color of skin, and the results showed that the overall agreement rate between doctor assessment and sensor inspection results was 99.2%. It is confirmed that the device can improve the success rate of reconstructive surgery, and its probable mechanism is shown in Figure 2. The above studies show that wearable devices can effectively identify changes in physiological indicators related to stress injury, and medical staff can identify the risk level of patients with stress injury through objective physiological indicators data measured by wearable devices, to take targeted protective measures.

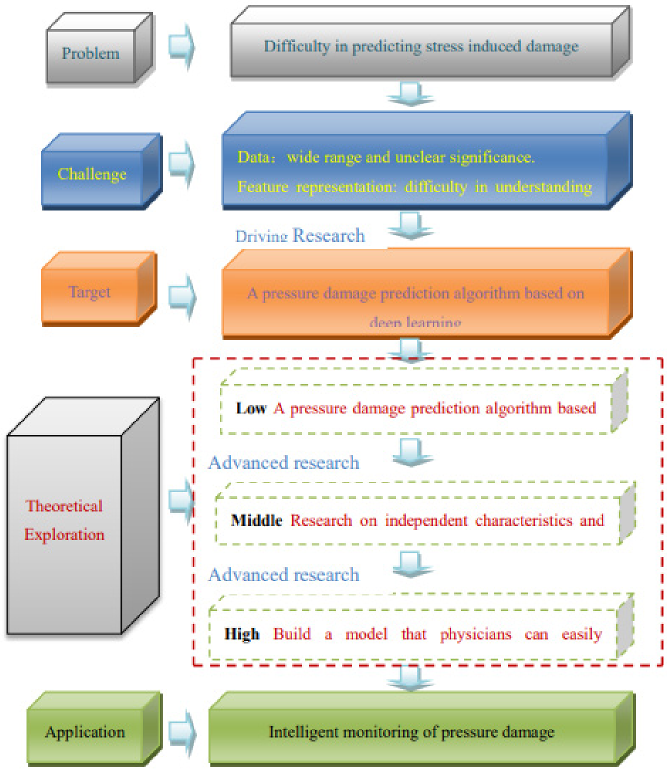

Figure 2. Research block diagram of wearable device predicting stress injury occurrence.

4.2 Physiological indicators measured by the wearable device were used to quantify the level of stress injury

In recent years, with the development of machine learning and prediction model, the evaluation of stress injury gradually tends to be quantified. As shown in Figure 3, it also provides an effective reference for medical staff to accurately evaluate stress injury [32]. Shirogane S et al. [33] used a wearable tablet sensor (0.9mm thick) to measure the sacrococcygeal pressure and shear force to reduce the occurrence of sacrococcygeal stress injuries in wheelchair users. In this study, sensors were placed at four positions on the hips to measure the pressure by tilting the wheelchair. The results show that the device can quantify the sacrococcygeal pressure and shear force in wheelchair users to facilitate the user to adopt the optimal sitting position. Sen D et al. [34] also developed a wireless, autonomous, and site-specific power supply sensor system, which was placed in the dangerous area of the patient's skin to monitor local contact pressure, temperature, relative humidity, and movement. These measurements are transmitted to the base station and machine learning algorithms are set up to raise the alarm for immediate, direct intervention by medical staff to prevent the formation of stress injuries. Experimental results show that it can effectively prevent stress injury, improve the independence of mobile high-risk patients, and reduce the workload of nursing staff, and it is recommended to use in the operating room, which may benefit patients. Wearables can also quantify stress injury levels, according to a study at the University of Pittsburgh, Pennsylvania, in which wearable electronics were attached to patients' gowns to quantitatively monitor their movements. The results showed that the sensor could effectively capture the patient's relocator with up to 85% reliability. It is suggested that this device can be further combined with a mobile alarm system in the future to improve the repositioning behavior of nursing staff [35]. All the above studies have confirmed that wearable devices can quantify the occurrence level of stress injury, but most of them are quantified by a single influencing factor. Future studies can optimize wearable devices to quantify the impact of comprehensive influencing factors on the occurrence level of stress injury.

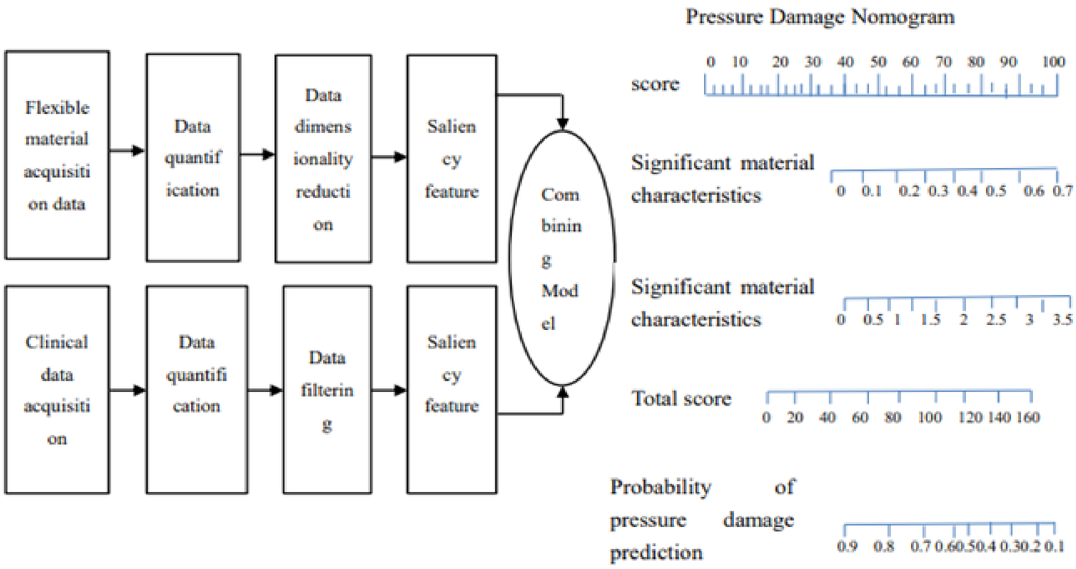

Figure 3. Flow chart of an algorithm for quantifying stress damage levels for wearable devices.

4.3 Continuous monitoring and recording of stress injuries can be achieved with wearable devices

By collecting physiological indicators related to stress injuries, wearable devices can not only quantify the occurrence level of stress injuries but also continuously monitor and record them. A study at Yonsei University in Korea [36] used a fabric-based multifunctional sensing system for wireless and continuous communication and developed a pressure damage sensor that could continuously send data to a customized mobile phone application. Tests demonstrated that the pressure damage sensor could successfully measure applied pressure, skin temperature, and electrical skin impedance. It can continuously monitor and record pressure damage for 24h. In addition, Farooq M et al. [37] developed a flexible wearable sensor for continuous pressure measurement used in various medical fields. With good linearity and high sensitivity within the range of 0-100mmHg and 0-300mmHg, it can be as a wireless continuous monitoring platform for pressure and provide continuous recording of physiological indicators related to pressure injury. As shown in the picture. Pickham D et al. [38] used a wearable sensor for continuous recording in the monitoring of stress injuries in ICU patients. The results showed that the sensor could effectively measure factors to prevent stress injuries and reduce the incidence of stress injuries in ICU patients. This is consistent with the research results of Renganathan BS et al. [39], which indicate that a continuous monitoring system of wearable devices can effectively improve the level of caregivers to identify the risk of stress injury and reduce the incidence of stress injury. All of these studies demonstrate the effectiveness of wearable devices in continuous monitoring and recording of stress injuries, which can provide an effective risk assessment for caregivers and guide caregivers to take targeted measures to reduce the occurrence of stress injuries. However, most of the above studies were for ICU patients, and there was a lack of experimental studies on surgical patients. In the future, the device can be further used in surgical patients to verify its effectiveness.

5. The predictive role of wearable devices in the recognition and assessment of pressure ulcers

5.1 Advantages of wearable devices in the recognition and assessment of stress injuries

American Association of Operating Room Nurses (AORN) pointed out that stress injuries caused by postures were the fourth-place of safety hazards in operating rooms [40]. For surgical patients, once the stress injury occurs, it is not easy to heal and prone to secondary infection, which brings additional pain and difficulty in follow-up treatment and nursing [41]. Therefore, with the development of the current intelligent medical system, artificial intelligence, and electronic devices have been widely used to identify and evaluate stress injuries. In relevant studies, wearable devices have been widely used to detect different physiological indicators of stress injuries. In future studies, more portable wearable devices should be designed to identify and evaluate the skin condition of surgical patients. And the skin condition data monitored by wearable devices should be connected with the hospital information system to realize the multi-department comprehensive management of stress injuries of surgical patients, which can avoid the loss of information exchange between different departments, unnecessary medical treatment of patients, and increasing health care costs. In addition, wearable devices can also be used for home care of patients with stress injuries, and the collected data can be fed back to the hospital through the terminal. Professional medical staff can guide patients and take medication to ensure the continuity of care for patients, reduce the pressure of offline treatment, and implement personalized skin care for patients.

5.2 Challenges of Wearables in the Recognition and Assessment of stress injuries

5.2.1 Privacy Ethics Problem of wearable devices in the Identification and Evaluation of stress damage

Wearable sensors can continuously collect data from the human body and timely capture meaningful changes in health status for preventive intervention, playing a crucial role in realizing personalized medicine [42]. Researchers must confirm the reliability and effectiveness of wearables through patients using them. Security is the first issue to be considered for wearable devices, which is closely related to the reliability of devices [43]. In the applied process, wearable devices need to collect patients' skin conditions in real time accurately and transmit the collected data to the online system. However, patient safety and privacy issues are often ignored, and many engineers and materials scientists may not realize that they should obtain the approval of an independent review board before testing their devices on humans [44]. Information leakage caused by network attacks or any other improper handling behavior during the application may lead to an incorrect interpretation of an individual's health status, which can lead to serious consequences [45]. Therefore, researchers must understand and abide by relevant research ethical requirements and regulations when developing new wearable devices and conducting human testing [46]. In addition, studies on the safety of wearable devices at home and abroad are still inconclusive, and whether various electromagnetic waves and sensors used in wearable devices will cause harm to the human body remains unknown [47]. Relevant studies have reported that magnets contained in Fitbit, Apple Watch buckles, and other accessories can interfere with the normal function of human cardioverters and permanent pacemakers under certain conditions, posing certain safety risks [48]. Therefore, the protection of patient privacy and ethical review should be strengthened in future research on wearable devices.

5.2.2 Material Problems of Wearables in the Identification and Evaluation of stress injuries

The wearable devices developed for pressure damage are mainly flexible fabric sensors made of intelligent conductive fibers. This flexible fabric sensor not only meets the physiological indexes of monitoring the occurrence of pressure injuries but also has the advantages of low elastic modulus, large strain, bendability, foldability, and washable, which is comfortable and can be used for long-term monitoring of skin conditions of surgical patients[49]. Although the flexible material has good advantages, most of the equipment is still in the research stage under controllable conditions, and there are few studies on factors affecting the function and comfort of the equipment such as high temperature, sweating, skin, and equipment contact pressure [50]. In addition, the processing cost of flexible sensors is high, and their use and promotion are also limited. The evaluation criteria of this device also lack systematic and authoritative theory and are mostly the consensus formed by researchers in different disciplines for a long time. Its safety and biological effects need further study [51]. At the same time, the endurance and durability of the flexible sensor should be considered in the process of monitoring the pressure injury of surgical patients, and the stress relaxation and fatigue effects may occur with more using time the equipment [52]. Therefore, in future research, we need to further produce wearable devices with new materials and new processes, not only to ensure the comfort of their application process but also to achieve durability of function and accuracy.

6. Conclusion

Efficient and scientific risk assessment of stress injury is important to effective nursing. Wearable devices are emerging products under the rapid development of science and technology, providing new ideas for quantifying and continuous monitoring of stress injuries and a reliable basis for effective intervention. More and more research has been done on wearable devices for stress injury, but most of them are foreign research and only focus on a single influencing factor. In the future, wearable devices suitable for monitoring the skin condition of Chinese people should be further developed, and multiple factors of stress injury should be taken into account to effectively verify their sensitivity and accuracy.

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