REVIEW ARTICLE

A review on equipped hospital beds with wireless sensor networks for reducing bedsores

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At present, the solutions to prevent bedsore include using various techniques for movement and displacement of patients, which is not possible for some patients or dangerous for some of them while it also poses problems for health care providers. On the other hand, development of information technology in the health care system including application of wireless sensor networks (WSNs) has led to easy and quick service-providing. It can provide a solution to prevent bedsore in motionless and disabled patients. Hence, the aim of this article was first to introduce WSNs in hospital beds and second, to identify the benefits and challenges in implementing this technology. This study was a nonsystematic review. The literature was searched for WSNs to reduce and prevent bedsores with the help of libraries, databases (PubMed, SCOPUS, and EMBASE), and also searches engines available at Google Scholar including during 1974-2014 while the inclusion criteria were applied in English and Persian. In our searches, we employed the following keywords and their combinations: "wireless sensor network," "smart bed," "information technology," "smart mattress," and "bedsore" in the searching areas of titles, keywords, abstracts, and full texts. In this study, more than 45 articles and reports were collected and 37 of them were selected based on their relevance. Therefore, identification and implementation of this technology will be a step toward mechanization of traditional procedures in providing care for hospitalized patients and disabled people. The smart bed and mattress, either alone or in combination with the other technologies, should be capable of providing all of the novel features while still providing the comfort and safety features usually associated with traditional and hospital mattresses. It can eliminate the expense of bedsore in the intensive care unit (ICU) department in the hospital and save much expense there.

Key words: Advantage, bedsore, chronic disease, smart bed, smart mattress, wireless sensor network (WSN)

How to cite this article: Ajami S, Khaleghi L. A review on equipped hospital beds with wireless sensor networks for reducing bedsores. J Res Med Sci 2015;20:1007-15.

INTRODUCTION

Decubitus ulcer is a common and serious problem for inpatients in the hospital. When someone is in the sleep mode, pressure of his body weight enters into certain points and in the long term, this results in bruises and ultimately incurable wounds; therefore, the hospital staff has to rotate these patients on their beds regularly to prevent it from happening. Prevention is more cost-effective than treatment and the cooperation of health care staff can help in the prevention of decubitus ulcer; decubitus ulcer is still as a significant problem for certain patients in the hospital and society. Using wireless sensor network (WSN) in hospital beds, which are known as smart beds, is an appropriate solution to prevent decubitus ulcer and a way to forger the pressures of decubitus ulcer in patients hospitalized for a long time.

Bedsore is the third costly disorder after cancer and cardiovascular diseases. In various studies, treatment costs have been estimated to be about $125-451 for grades 1 and 2 of bedsore and $1,400-2,300 for grades 3 and 4 of bedsore. In Spain 5.20%, in the UK about 3.2%, and in the Netherlands more than 1% of the total health care costs are spent on the treatment of bedsore. In developed countries, the prevalence of bedsore varies 3-30% and its incidence varies 1-50%.[1]

Access this article online

Quick Response Code:

Website: www.jmsjournal.net

DOI: 10.4103/1735-1995.172797

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Received: 25-07-2015; **Revised:** 27-09-2015; **Accepted:** 24-11-2015

Annually, these wounds affect more than 1.3 million adults in the world. Bedsores can cause pain, depression, reduction of performance and independence, higher risk of infection and sepsis, all of which potentially lead to an increase in the duration of hospitalization.[2] Moreover, the mortality rate caused by this disease has been high and can be effective at any age. According to a study titled "Prevention and Management of Pressure Ulcers in Primary and Secondary Care" conducted by Stans *et al*. (2014), even with hospital development and considerable health care resources, the prevalence of patients with bedsore shows a growth of 4.7-32.1% in hospitals and 22% in nursing homes.[3]

In addition to heavy financial costs for health care institutes, bedsore causes consequences such as loss of institutes' credibility and waste of the personnel's valuable time. In a study titled "Evidence-based Medicine: Pressure Sores" conducted by Cushing and Phillips in 2013, it was shown that annually with around 2.5 million bedsores in the USA, a treatment cost of $11 billion was estimated, which represents a costly and labor-intensive challenge for the health care system.[4]

This condition is associated with pain, infection, and complications such as stress. The main groups at risk of bedsore include patients with spinal cord injuries, the elderly, hospitalized patients with low mobility particularly those undergoing orthopedic surgery, and patients hospitalized in the intensive care unit (ICU). The last group is more susceptible than the others because they are often motionless for long periods of time. Currently, there are mechanisms and devices, some of which avoid focusing pressure on specific points (such as mattresses or cushions, which distribute pressure or silicon foams) and some others increase pressure tolerance surface and apply uniform pressure to the human body.[5] Consequently, it helps pressurized points to receive blood and repair themselves.

Graves *et al*. (2005) conducted a research titled "Effects of Pressure Ulcers on Length of Hospital Stay" on 2,000 patients during the years 2002-2003. The results indicated that patients suffering from bedsore were hospitalized on an average 4.31 days more than the time expected at reception.[6]

Prevention is the most effective approach to solve this problem and high quality of nursing care is the key factor to resolve the problem. Preventive measures include:

1. Assessing the risk of bedsores' progression.
2. Skin care and primary treatment such as skin health.
3. Use of pressure-reducing supportive surface such as wavy mattress and smart beds.
4. Training.[7]

Moreover, the incidence of bedsore is influenced by predisposing potential factors, which are placed in two groups of internal and external factors. Internal factors include malnutrition, reduction of movement and activities, aging, incontinence, skin moisture, mental status, and medication. External factors, which are known to be effective in creating bedsore include pressure, friction, and tensile force applied by contact devices.[8]

Identifying patients who are at risk of bedsore is crucial for effective treatment.[9] Researchers showed that identifying personal factors effective in the operation such as a sense of individual responsibility, and organizational factors affecting current practices such as collaboration methods between nurses and nursing assistants is necessary to implement effective changes in a particular environment.[10]

Some experts believe that clinical judgment is the only reliable method to identify patients at risk while others believe that professional judgments are subjective criteria and risk assessment instruments are objective criteria, which can identify patients at risk.[11] When nurses use complete, reasonable, and codified information obtained from risk assessment instruments, they lead to completely precise, specific, and defined patients' care instructions.

At present, one of the most common methods for nurses and health care providers to prevent these wounds is to turn and move patients from side to side every 2 h. This allows recovering parts of the body. Therefore, with development of each bedsore, the workload of the nursing staff increases.[12]

In a research titled "Frequent Manual Repositioning and Incidence of Pressure Ulcers among Bed-bound Elderly Hip Fracture Patients" conducted by Rich *et al*. (2010), it was noted that only around 66% of the patients received this treatment regularly, which was probably due to labor shortage in nursing. Also, this is a justifiable reason for back pain in health care workers.[13] Today, various technology developments in health have led to improvement of the quality and speed of service-providing to patients.[14]

WSN is one of these technologies referring to a set of sensors connected wirelessly and all sensing a certain phenomenon. The number of these sensors can be very high and they can be also scattered over a wide domain. The sensors of this sensor can be annually placed and fixed at the desired locations or they can be randomly distributed in the desired location. The main purpose in these networks is primarily collection of information and then further network life.[15,16]

Therefore, with regard to the issues and problems discussed, establishment of a smart bed can be a solution to these

problems. In order to enhance bed capabilities and the physical features of smart beds, smart areas are created from a combination of sensor network, information devices, and computer control; the beds are capable of generating waves and signals for mobility and increasing blood flow in hospitalized patients while they prevent bedsore and lesions resulting from hospitalization. Hence, the aim of this article was first to introduce WSNs in hospital beds and second, to identify the benefits and challenges in implementing this technology.

MATERIALS AND METHODS

This study was a nonsystematic review. The literature was searched for WSNs to reduce and prevent bedsores with the help of libraries, databases (PubMed, SCOPUS, and EMBASE), and also search engines available at Google Scholar including during 1974-2014 while the inclusion criteria were applied in English and Persian. In our searches, we employed the following keywords and their combinations: "wireless sensor network," "smart bed," "smart mattress," "information technology," and "bedsore" in the searching areas of the title, keywords, abstracts, and full texts. In this study, more than 45 articles and reports were collected and 37 of them were selected based on their relevance.

RESULTS

Introducing wireless sensor networks in hospital beds

Types of wireless networks

- Infrastructure-based networks: To implement desired wireless networks, one or more central concentrator devices or access points (APs) are applied. The task of AP is to communicate on the network.
- Wireless local area networks (LANs): Usually, radio link[11] or infrared radiation is used. These create high flexibility in the range in which the possibility is placed and have less bandwidth compared to wired networks.
- *Ad hoc* networks: These wireless networks contain a set of distributed nodes, which communicate wirelessly with each other. The most important feature of these networks is a dynamic and variable typology due to the nodes' mobility.[15] WSNs are one of these networks.

A sensor network is composed of a large number of sensor nodes, which are widely distributed in an environment and collect information from the environment. The position of sensor nodes is not necessarily predetermined. Such a feature makes it possible to leave them in hazardous and inaccessible situations.[15]

There are several terms in a sensor network:

Sensor: It is a device that detects objects, events, or the value of a physical quantity and converts it into an electrical signal. There are several types of sensors such as sensors of temperature, pressure, humidity, accelerometer, and magnetometer.

Operate: With electrical simulation, a particular action is performed such as the opening or closing of a valve or switching off a switch.

Sensor node: It is a node, which only includes one or more sensors.

Operate node: It is a node, which only includes one or more operates.

Sensor network: It is a network, which only includes sensor nodes. This network is a particular type of work/sense node and is applied in applications in which the purpose is collection of information and investigation of a phenomenon such as tornados.

Operate/sensor field: The work area in which work/sense nodes are distributed.

Sink: It is a node which is responsible for data collection and establishes the connection between work/sense nodes and task manager node.

Work/sense net: A network of excessive number of nodes where each node can have a number of sensors and operates.[16] These nets take the information of the environment through the sensors and react through operates. Communication between the nodes is wireless. Each node operates independently and without human intervention. It is physically very small and limited in processing power, memory capacity, and power source. These restrictions create problems, which are the origin of many research discussions in this field. Information is collected by sink and commands are distributed through sink [Figure 1].[17]

Task manager node: It is a node through which the person as a user or network administrator communicates with the network. Queries and control commands are sent from this node to the network and collected data are returned to it.[17]

Automated structure: Sensors detect an event or a phenomenon and send the received data to the operate node to process and react appropriately. Adjacent operate nodes, coordinating together, decide and operate. In fact, there is no central control and decisions are made locally [Figure 2].[17]

Semi-automatic structure: In this structure, data are conducted by the nodes to the sink and commands are distributed to the operate node through the sink [Figure 3].[17]

Operate/sensor node: It is a node equipped with a sensor and operates.

Internal structure of each node includes operate/sensor field, data processing field, sender/receiver wireless, and power source. Data processing field consists of a microprocessor and a memory with a limited capacity. It takes data from the sensor, does limited processing depending on the application, and sends through the sender. Field processor performs coordination management with other nodes in the network. Sender/receiver communicates between the node and network.[18]

The sensor unit includes a set of sensors and analog to the digital convertor; it takes analog data from the sensor and delivers it digitally to the processor. The operate unit consists of an operate and an analog to digital convertor; it takes digital commands from the processor and delivers them to the operate. Field energy generator provides consumption power of all sectors, which is often a limited power battery [Figure 4].[19]

Energy source restriction is one of the major constraints, which affect everything in designing work/sense net. Apart from this section, a unit may exist for energy such as solar cells; there is a unit for moving maker in mobile nodes. The finder detects the node physical location. Routing techniques and sensing functions require high-precision location information. One of the main benefits of work/sense network is the ability to manage communication between the nodes on the move.[19]

Applications of wireless sensor networks

WSN applications are divided into three categories of military, commercial, and medical applications. Systems of communication, command, reconnaissance, monitoring, smart minefield, and smart defense systems are of the military applications of these networks. Medical care applications include systems of care for patients with diabetes who do not have a caregiver, smart environments for elderly people, communication networks among practitioners and hospital staff, and patients' monitoring. Commercial applications include a wide range of applications such as security systems to detect and deal with theft, fire (in the forest), detecting environmental pollution such as chemical, microbial, and nuclear pollution, tracking systems, maintaining and controlling of vehicles and traffic, controlling the quality of industrial products, studying natural phenomena such as tornados, earthquakes, and floods, and also research on particular species of animals

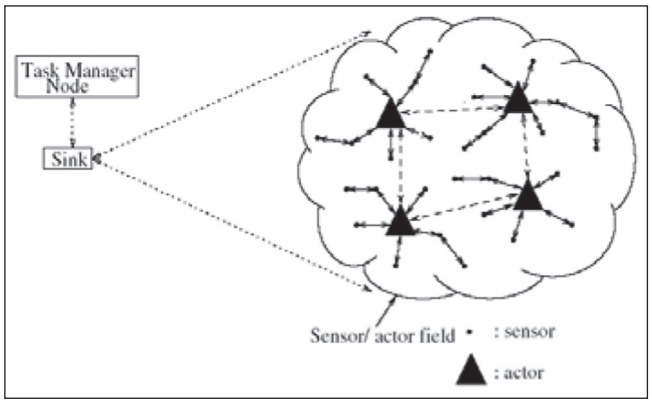

Figure 1: General structure of work/sense net[17]

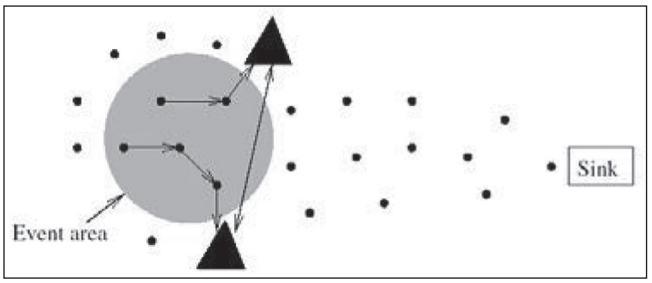

Figure 2: Automated structure[17]

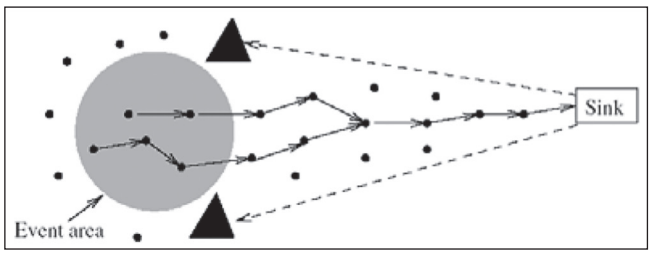

Figure 3: Semi-automatic structure[17]

and plants. In some applications, work/sense net is applied as a group of small robots, which work together to perform a specific activity.[20]

Technology application in health care is considered to be the most important issue to improve the quality of health care and researchers have indicated that it is the best instrument to improve and promote the quality of patients' care and ultimately leads to promotion of the community's health.

Advantages and challenges of implementing wireless sensor network

In addition to what already stated about WSN, implementation of these networks has also a series of features, disadvantages, and challenges, the most important of which are summarized in Table 1.

Unfortunately, information systems in many countries are inadequate to provide the required management support.[21] It is clear that an information system can

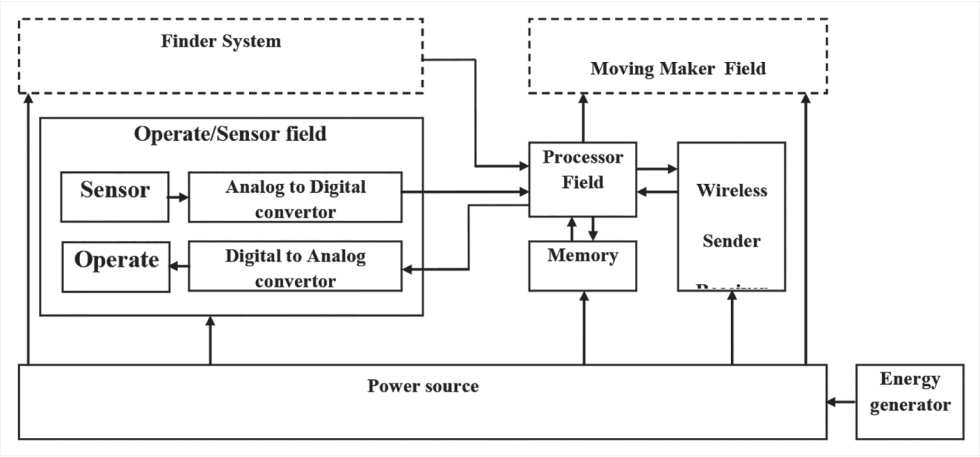

Figure 4: Internal structure of operate/sensor node[19]

Table 1: Advantages and challenges to implement wireless network sensors

Advantages	Disadvantages and challenges
Dependence on the application[15]	Hardware constraints[16,17]
Interaction with the environment[15,16]	Typology[17,19]
Scalability[15]	Reliability of use[16,18]
Energy[16,19]	Scalability[18]
Self-configuration[16-18]	Environmental conditions[16,18]
Reliability and quality of service[16-19]	Cost[19]
Data-driven[17,18]	Increasing network lifetime[16,20]
Simplicity[15,18]	Power consumption of the nodes[17,20]

influence decision-making only if the information is reliable, related, and available to decision-makers at the appropriate time.[22] Reliable and updated information can affect destructive factors and prevent them.[23] Information systems play an important role in the continuity of activities related to health care, management, and planning of health services. Such systems can be considered to be an instrument, which facilitates processing, storing, and transferring of data in health management relations.

Smart materials and their application

Applications of smart materials in clothing

The first generation of smart materials can be termed the generation of electronic clothes since a number of electronic components have been added to conventional clothes. The first successful step to make them wearable was taken by an American company in the 1990s, which supplied clothing for army.[24] Since birth, the first application interface for the body is soft and reassuring materials of the fabric. Fabric usually covers more than 80% of the skin and in the new generation of textile materials, new intuitive and interactive functions have been applied to implement personal security systems, measurements, transmission, and expansion through textile technology.[25] To achieve this clothing, electrical properties and calculations with traditional mechanical properties have been used, which are not comparable to the fabric normally used to produce ordinary clothes. A German company invented a miniature MP3 player, which could be placed in the clothing. Its completed design consisted of a central microchip, a phone, a battery, a special card to download music, and an internal communication system through conductive sinew fabric. Waterproof packages protect all the components against water. Nevertheless, components added to clothes always created problems when being worn and the communication between clothes and components always caused trouble.[24,25]

Application of smart materials in textile

In the next generation, textile materials were tried to be used as the components.[25] An English company, Eleksen, provided a new technology, which enabled it to combine sensors and sensor switches with textile warp and woof. These smart fabrics with flexibility and folding features could be washed and sewn. This property will be applied in special clothing, making dolls, mobile phone covers, aircraft seats, and hospital bed mattresses.[26]

These fabrics are a combination of conductive fibers and conventional textile fibersm which have been made of two exterior plastic electric layers between which a woven layer of conductive fiber is placed. The voltage to measure the suppliers is guided by batteries; when pressure is exerted on the outer layers (such as finger pressure), a sensor's voltage changes. A sensor which detects the change can change the exerted pressure according to the conditions.[26,27] Moreover, this company has manufactured a fabric, which is sensitive to hand contact and the smart fabric of this company called Elektext is composed of three layers of fabric. The layered feature of this fabric makes it possible to transfer generated electric charge by computer software to other layers after being touched by he hand.[27]

A flexible keyboard for personal digital assistant (PDA), which can be applied in bed sensors in hospitals is another product of this company.[28]

Electrorheological fluid (ERF)

Another category of smart materials is electrorheological fluid, which is controlled by applying a potential difference. These fluids frozen by applying an electrical voltage are called smart fluids. Until recently, their naming did not seem so meaningful. However, now some engineers comment that smart fluids will be the initiator of the third era of the machine. Smart fluids are not new materials and are not so smart. It is more than 70 years that scientists have found that some liquids are converted to solid by applying electrical voltage. This phenomenon is called electrorheological effect. ERF is smart in that when high voltage is applied, it is converted into gelatinous solid called viscosities. These fluids can be used in smart beds. A network of plates equipped with ERF is placed in these beds and electrical potential difference is applied to different locations at appropriate times. This way we increase the viscosity of these locations compared to other locations to transfer the point bearing pressure to desired places or distribute the pressure and prevent bedsore in the patient's skin.[29]

Since in other solutions, patients or people who help them have no perception of the pressure value and distribution, the changes may lead to patients' more critical conditions. Therefore, the main advantages of applying these fluids in the bed design include the ability to detect pressure points, measure the pressure field, elimination of the need to move the patients, and control of patients' recovery terms by the computer without the need for the constant presence of doctors and nurses.[30]

The company Wellsense in the USA is a leader in continuous bedside pressure mapping technology and a mobile health company dedicated to patient safety throughout the continuum of care. The company's founders and management have a strong track record of innovating and commercializing breakthrough technologies in consumer electronics, patient safety, and monitoring. Wellsense is a privately held company. For long-term hospital patients or people who are otherwise bedridden, bedsores can be a major problem. Technically known as decubitus ulcers, they form when one area of the skin is subjected to prolonged pressure. In order to keep them from occurring, the hospital staff regularly turn patients over in their beds. The monitor, alert, protect (MAP) system is designed to aid those caregivers, by providing them with real-time imagery of the pressure points on the patient's body. Made by the medical technology firm Wellsense, MAP consists of two main parts: A pressure-sensing mat that is placed on an existing mattress and a bedside monitor. Thousands of sensing points within that mat continuously register how much pressure is being exerted upon them by the patient, and relay that information to the monitor. There, a corresponding pressure distribution map of the patient's body is displayed, indicating high- and low-pressure areas. Using that information, the staff can ensure the relieving of pressure in the crucial places when repositioning the patient. A countdown also appears on the screen, indicating the amount of time left before the next repositioning will be required. The general idea of using pressure-sensing mattress pads to minimize the occurrence of bedsores is not particularly new in itself. In most cases, however, it is done to obtain a single snapshot-style reading, which is then used as a reference. MAP is reportedly unique in that it provides continuous, real-time feedback. Wellsense certainly is not the only group working at alleviating bedsores. The Swiss research group Empa has created sheets that produce fewer points of contact with the skin, along with a bed that repositions the patient by moving the mattress. Two clinical studies were done at two ICUs in two hospitals. One of them used MAP and other one did not. Results demonstrated significantly cost reduced and in some cases down it to zero, and economic benefits ranging was from $125,000 to 650,000 in saving per ICU over 6 months [Figure 5].[31]

The pilot study showed that the smart bed system recorded a total of 1,037 in bed alerts; 1,033 bed exit alerts (with manual adjustments making up the difference in number). Within that period, there were zero reported and documented falls. Alerts were set for the 2-h turning of bedbound residents. The Touch-Free Life Care (TLC) system recorded that the staff performed 576 documented turns on schedule, and the system recorded that 318 scheduled turns were missed. This turn performance data were used by the staff to improve their timely performance of turns. Within the study period, the facility did not report any development of new pressure ulcers and, in fact, reported the improvement in staging of one resident's pressure ulcer. The system also gathered the heart rate and respiratory rate trends for all residents,

Figure 5: The MAP monitor and pad[31]

rest time and time in bed per day, and the identification of motion in the bed as it correlated to documented turn events [Figure 6].[32]

DISCUSSION

In this regard, the results of Chenu *et al*. study in 2013 entitled "An innovative embedded device for pressure ulcer prevention" showed that the decubitus ulcer prevention device for patients with spinal injuries, which has the size of cigarette box and is embedded in a wheelchair, can be effective in preventing them. The device sensor is 100% textile, washable, and inexpensive. The device function is to announce acquired alarm via watch or short message service (SMS) in smartphones before the symptoms develop into decubitus ulcer and by measuring the pressure between the seat mattress and the patient's hip.[33]

Yousefi *et al*. in their study in 2011 entitled "A smart bed platform for monitoring and ulcer prevention" defined the hospital smart bed as a bed with a sensor network, information devices, tile-like surface, and computer control. This bed function was to analyze data by creating touch and pressure on surface sensors and create irritation and then announce the acquired alarm to the nurse to prevent ulcer pressure. Thus, the nurse spends more time assessing adverse events and outcomes and the patient's care instead of rotating the patient every moment.[34]

Since decubitus ulcer is a big problem in health care of patients with spinal injuries and these patients have no feeling for changing their status in comparison with healthy people, using a mattress with a sensor is useful to diagnose the patient's problem and the patient's tactile response. Using such a system is useful in rehabilitation and is suitable for preventing decubitus ulcer.

In a study conducted by Verbunt *et al*. in 2010 entitled "Tactile feedback for the prevention of decubitus ulcers," a technology is defined, which is able to diagnose the patient's inappropriate status and present an instruction to change his/her status. Changing the status results in less risk of decubitus ulcer. This device includes a belt that receives a simple tap to a strong pressure as a signal and this signal announces changing of the patient's natural status to the patient and health care providers.[35]

Figure 6: The BAM Labs Smartbed Mat Slides under the mattress[32]

WSNs are increasingly changing for telemedicine applications, monitoring patients, both in clinical conditions and at home. Using them will reduce the user's discomfort and expenses, and increase mobility. Using smart systems and WSNs, depending on users' needs, will also collect information regarding users and their environment.[36,37]

CONCLUSION

Today, life cannot be imagined without wireless communication. Health care providers are very mobile, and the adoption of enhanced wireless technology by health care organizations, especially when harnessed properly, can help to improve, even automate patient care and monitoring, save costs, and reduce staff injuries. It is indisputable that computer networks are commonplace in health care organizations and in some places are indispensable. However, most of the computer devices and monitoring devices are connected through the use of wires; this usually means that their use is limited to a fixed place. A smart mattress eliminates many of the wires associated with the current methods and allows for greater flexibility in patient monitoring. The smart mattress, either alone or in combination with the other technologies, should be capable of providing all of the novel features while still providing the comfort and safety features usually associated with traditional and hospital mattresses. For example, the smart mattress should be designed to reduce the potential for pressure ulcers.

In fact, the power of WSNs is the result of applying a large number of tiny nodes, which are capable of being organized and applied in various cases such as simultaneous routing, monitoring environmental conditions, and monitoring the health of structures or equipment of a system. Also, progress of technology and the creation of increasingly smaller circuits have made the application of wireless circuits possible in most electronic devices. Therefore, applying these wireless circuits in hospital beds is helpful for elderly people, long-term hospitalized patients or patients without movement, and also for hospital staff to monitor patients' treatment and to prevent bedsore. However, the widespread use of this technology requires focusing on related systems and the help of professional experts.

Sensor nets have provided a new range of applications, particularly in the field of monitoring chronic diseases. In heart diseases, smart sensor nodes can be attached on patients' bodies and prevent death, which occurs due to heart failure. In cancer detection, sensor nodes are placed in suspected locations and measure the amount of nitric acid produced by these glands. People with Alzheimer's are not aware of the time and location where they are and always act abnormally. These networks inform the

person's neighbors and relatives of any unusual situation. Monitoring of the glucose level is performed by a sensor attached to the patient's body and it measures the blood glucose level. To monitor epilepsy, sensors detect the seizures before they occur by monitoring brain activities in these patients. Patients' vital signs such as heart rate, respiratory rate, and body temperature can be monitored permanently and continuously by the sensors. Thus, the patient's health status can be supervised during the day and even during sleep or exercise.

Imagine a person who is with an irregular heart rhythm. In some cases, the irregularities in the patient's heart rate are severe and there is slow heartbeat for a long time while revascularization does not occur completely and brain injury occurs. Therefore, these patients should be supervised permanently so that if there is an irregularity, the necessary operations can be performed. Normally, it is necessary to hospitalize the patient and take electrocardiogram (ECG) for a certain time but using WSN, patients can be monitored remotely all the time without the need to be hospitalized and confined to hospital beds.

Overall, according to the care method and costs of the care, patient care is very important for caregivers and also for patients and their families. Finding the best and most economic method of patient care has engaged the minds of many experts in various fields of medical services or information technology (IT) and electronic engineering. With the application of smart materials or microsensors in medical equipment and attaching the same to patients as well as physicians, these conditions can be controlled to a great extent and the standard care can be provided for patients.

Acknowledgments

Support and source of funds: This article resulted from a part of the master thesis in the School of Medical Management and Information Sciences, Isfahan University of Medical Sciences, Iran.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

AUTHOR'S CONTRIBUTION

SA contributed to the conception and design of the work, conduct of the review study, preparation and revision of the manuscript, approval of the final version of the manuscript, and agreed with all aspects of the work. LKh contributed to the conception and design of the work, revision of the manuscript, approval of the final version of the manuscript, and agreed with all aspects of the work.

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