International Journal of Medical Informatics xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Medical Informatics

journal homepage: www.ijmijournal.com

Review

Approaches that use software to support the prevention of pressure ulcer: A systematic review

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ARTICLE INFO

Article history:
Received 16 November 2014
Received in revised form 20 May 2015
Accepted 26 May 2015
Available online xxx

Keywords:
Pressure ulcers
Bed sores
Prevention
Software
Technology
Systematic review

ABSTRACT

Context: The incidence and costs for pressure ulcer (PU) treatment remain high even though preventive methods are applied. Approaches that use software to support the prevention of PU are presented in the literature to make it more effective.
Objectives: Identify the state of art of the approaches that use software to support the prevention of PUs.
Methods: A systematic literature review was performed to analyze approaches that use software to support the prevention of PU. ACM, IEEE, PubMed, Scopus, CINAHL and Embase databases have been searched with a predetermined search string to identify primary studies. We selected the ones that met the established inclusion criteria.
Results: Thirty-six articles met the inclusion criteria. To support prevention, most approaches monitor the patient to provide information about exposure to pressure, temperature level, humidity level and estimated body position in bed providing risk factor intensity charts and intensity maps. The main method to perform patient's monitoring is using sensors installed on the mattress, but recently, alternative methods have been proposed such as electronic sensors and tactile sensory coils. Part of the approaches performs automated management of the risk factors using ventilation tubes and mattresses with porous cells to decrease body's temperature and movable cells to automatically redistribute the pressure over the body. Matters as cost of the approach, patient comfort and hygiene of the monitoring equipment is only briefly discussed in the selected articles. No experiments have been conducted to evidence the approached may reduce PU incidence.
Discussion and conclusion: Currently, approaches that use software to support the prevention of PU provide relevant information to health professionals such as risk factor intensity charts and intensity maps. Some of them can even automatically manage risk factors in a limited way. Yet, the approaches are based on risk factor monitoring methods that require patient's contact with the monitoring equipment. Therefore, some matters need to be considered such as patient's comfort and the hygiene or replacement of the equipment due to the risk of infection. With the emergence of new alternative methods of monitoring, new technologies that do not require contact could be explored by new researches. Randomized Control Trials could also be conducted to verify which approaches are really effective to reduce PU incidence.
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http://dx.doi.org/10.1016/j.ijmedinf.2015.05.013
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Please cite this article in press as: F.G. Marchione, et al., Approaches that use software to support the prevention of pressure ulcer: A systematic review, Int. J. Med. Inform. (2015), http://dx.doi.org/10.1016/j.ijmedinf.2015.05.013

1. Introduction

In the hospital setting, bedridden patients with limited movement may not change their position regularly. In this scenario, the same set of body regions is exposed to pressure for a long time and, thus, becomes more susceptible to lesions called pressure ulcer (PU).

PU is a lesion caused by prolonged exposure to pressure. When a part of the body is under pressure, nutrients are not properly provided for the tissue cells resulting in their death and therefore the appearance of the lesion. Apart from exposure to pressure, elevated body temperature and high skin humidity may also contribute to the formation of the PU's, which appear as an irritation in the upper layers of the skin and may be increased to reach muscles and bone tissue [29].

There is a direct impact of PU's on the quality of life of bedridden patients because they are extremely painful, they may extend the hospital stay so that it can be treated and may even be the cause of the patient's death. In order to minimize these risks, preventive methods are applied. The most common preventive method is the change of decubitus. This method consists in health professionals changing the patient's position in bed from time to time to switch regions under pressure to decrease the risk of PU's formation.

Even though preventive methods are applied, there is still a high incidence of PU. In Brazil, for example, a study in a Brazilian Hospital verified an incidence of 39.81% [31]. In addition, there are high costs arising from the extension of hospitals stay and the treatment itself, as in the United States, where an average of $11 billion is spent annually [3]. Based on these facts, the importance of approaches that can support the prevention of PU to avoid patient's suffering and increased hospital costs is evident.

In the literature, several approaches that use software to support the prevention of PU can be found. Like in [8], which presented an application called Pressure Ulcer (PU) Manager that can predict a patient's PU risk based on electronic health record data. More specifically, some of these approaches are able to automatically monitor bedridden patients and provide real time information to support health professionals' decision making. As an example, in [40], that presented a system consisting of pressure sensors and classification algorithms to automatically monitor the patient's position.

In order to objectively identify the state of art of the approaches that use software to automatic monitor bedridden patients and support the prevention of PU, a systematic review of the literature is presented in this article.

2. Methods

This systematic review is based on the process established by [19], which defines three phases for its realization: planning, conducting and disseminating results. Initially, in the planning phase, the article databases used to identify primary studies, the search string and the criteria for selecting articles are defined. Then, during the conduct of the review, the search and selection of articles following the defined protocol are executed. In this systematic review, both steps were performed by one of the authors and reviewed by the others. Finally, the extracted data from the selected articles where analyzed by the authors and the results were presented. At all stages of this systematic review, the StArt tool was used to assist in the organization and execution [42].

Table 1
Systematic review databases.

Name	Electronic address
ACM	http://dl.acm.org/
IEEE	http://ieeexplore.ieee.org/Xplore/guesthome.jsp
Pubmed	http://www.ncbi.nlm.nih.gov/pubmed/
Scopus	http://www.scopus.com
CINAHL	https://www.ebscohost.com/nursing/products/cinahl-databases
Embase	http://www.elsevier.com/online-tools/embase

2.1. Inclusion and exclusion criteria

Articles that present approaches to prevention of PUs that use software were selected. More specifically, the ones that provide some kind of automatic monitoring. The following inclusion criteria was used:

- The paper presents an approach that uses software to automatically monitor patients and support the prevention of pressure ulcers.

Bedridden patients are the risk group that is in the scope of this review. Therefore, articles which present an approach that does not include that group were rejected. There was no restriction regarding date of publication.

2.2. Search strategy

The scope of the selected articles involves both the prevention of PUs and the use of software. Therefore, search for primary studies was conducted on article's databases focused on researches in the fields of medicine and computer science. The list of these databases and their electronic addresses is presented in Table 1. The search was conducted on 02/22/2015.

Synonyms of pressure ulcers and words related to the use of software (system, technology, software and algorithm) were considered to formulate the search string that is presented below:

- ("pressure ulcer" OR "pressure ulcers" OR "bed sores" OR "pressure sores" OR "decubitus ulcers") AND ("system" OR "technology" OR "software" OR "algorithm")

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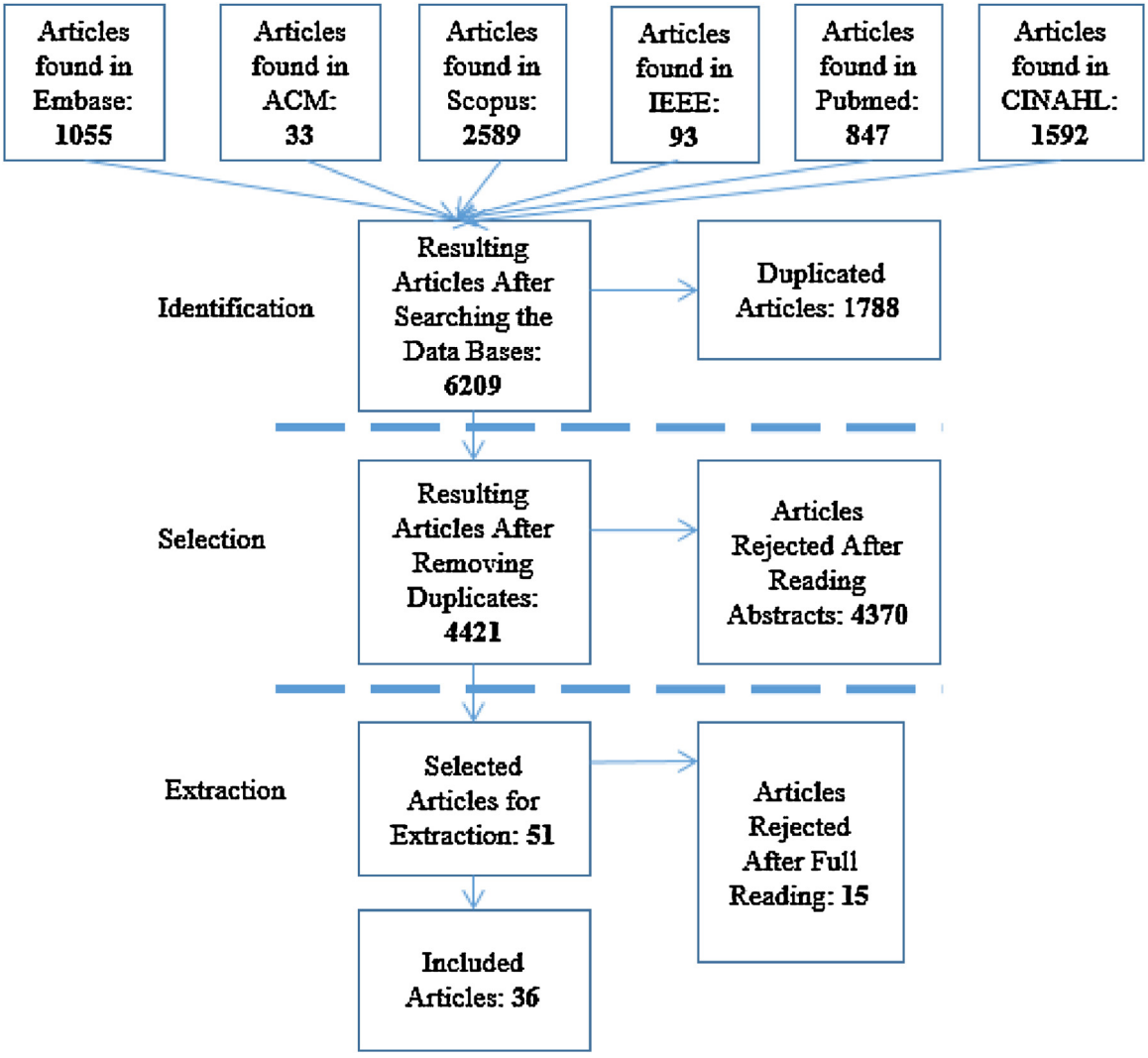

Fig. 1. Inclusion and exclusion flow of the articles.

2.3. Review procedures

The selection was performed by checking which articles met the inclusion criteria, but did not meet any exclusion criteria by reading titles and abstracts. The selected articles were entirely read for the extraction of the data used in the dissemination of results.

2.4. Data extraction

The following data were extracted from the selected articles:

- Authors
- Title
- Summary
- Publication year
- Considered risk factors
- Key technologies used for monitoring the patient
- Reports provided
- Risk alerts
- Automatically monitored risk factor
- Has patient comfort been considered?
- Has effectiveness of the approach been considered?
- Has a randomized control trial been conducted to test effectiveness?
- Has hygiene of the equipment been considered?
- Cost of the approach

3. Results

From the 6209 articles found after searching the databases, 1788 were duplicated. In the selection stage, 51 articles were selected and 4370 were rejected after reading their titles and abstracts. In the extraction stage, the articles were read entirely and 15 of them were rejected because they met exclusion criteria not identified during the selection stage. After the extraction stage, 36 articles were included in this systematic review. The flow of identification, selection and extraction stages is presented in Fig. 1.

After the selection of articles, data extraction was performed and are presented in Tables 2–4. Based on the extraction, it was possible to identify the state of art of approaches for prevention of PUs that uses software which is presented according to three perspectives in the following subsections: monitoring of risk factors, methods to support prevention of PUs and relevant information for applying the approaches.

3.1. Risk factor monitoring

Risk factor monitoring is performed by the approaches to obtain data to generate reports, charts and to identify risky situations that can be useful to support health professionals in PUs prevention. In this systematic review, we identified which are the risk factors monitored by the approaches presented in the selected articles and

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Table 2
Extraction part 1.

Id	Authors	Title	Summary	Publication year
[32]	Tamura et al.	Temperature monitoring for prevention of pressure sores	The article presents a system composed of 16 temperature sensors installed on the mattress for monitoring the patient's body temperature. The sensors are connected to a microcontroller for receiving, processing, and displaying temperature data on a computer monitor	1989
[2]	Babbs et al.	A pressure-sensitive mat for measuring contact pressure distributions of patients lying on hospital beds	A system that provides the pressure distribution over the body of the patient on a computer display is presented. The system is composed of a mattress with pressure sensors connected to a computer that displays the amount of pressure along the mattress	1989
[25]	Myers and Duncan	Computer-controller, air-modulated mattress for the prevention of decubiti	The article presents a prototype of a mattress composed of pressurized air cells controlled by a microcontroller. A control device which allowing redistribution of pressure over the patient's body can alter pressurization of different regions of the mattress	1991
[14]	Fulton and Lipczynski	Body-support pressure measurement using electrical impedance tomography	The article presents a system for measuring the distribution of the body pressure of a patient on the mattress surface by a mat composed of a pressure sensitive sensors set	1993
[38]	Williams et al.	A remote electronic monitoring system for the prevention of pressure sores	A system for monitoring the position of the patient's body in bed is presented. It consists of a vest that has four sense coils (one for each side of the body) and a main coil that is installed under the mattress. Based on the radio communication between the coils, the patient's position is estimated	1997
[7]	Chiou et al.	A multi-channel microprocessor system for interface pressure, temperature and humidity measurement	The paper presents a system consisting of sensors installed on a bed and connected to a microprocessor. The systems allows the measurement of pressure, temperature and humidity of bedridden patients	1999
[23]	Moon et al.	Control of air-cell mattress for preventing pressure ulcer based on approximate anthropometric model	The article proposes a mattress formed by 18 air cells which pressure is customized according to body weight and body region. The air cells are made of porous material so that air can pass through them and cool the body temperature	2005
[21]	Lowne and Tarler	Designing a low-cost mattress sensor for automated body position classification	The paper presents the design of a system that uses pressure sensors for low cost detection of body position through neural networks	2005
[16]	Jaichandar et al.	A semi autonomous control and monitoring system for bed sores prevention	A system for prevention of pressure ulcers is displayed by controlling the body temperature of the patient which is monitored by sensors and microcontroller, which turns on or off a built-in fan module able to heat or cool the bed surface	2007
[33]	Vuillerme et al.	Pressure sensor-based tongue-placed electrotactile biofeedback for balance improvement – Biomedical application to prevent pressure sores formation and falls	The article proposes the use of electro-tactile sensors for pressure monitoring. They are placed in the patient's mouth and, in contact with the touch receptors of the tongue, generate electrical signals which are transmitted by a cable to an electronic device capable of determining the distribution and intensity of the pressure in the patient's body	2007
[6]	Chen et al.	Design and clinical evaluation for patient status monitoring system of air-mattress	The paper presents a system consisting of humidity sensors, a thermostat and a force sensor connected to a computer. The data generated by the sensors are stored and, based on them, the computer generates graphs of the intensity of temperature, humidity and pressure over time. The system can be configured to trigger an audible and visual alarm if a risk factor exceeds a threshold	2008
[22]	Manohar and Bhatia	Pressure detection and wireless interface for patient bed	The article discloses a system comprising a set of sensors installed on a mattress and connected to a microcontroller which transmit pressure data to a computer station	2008
[39]	Yip et al.	A flexible pressure monitoring system for pressure ulcer prevention	A system able to determine the magnitude, location and duration of the pressure points of the body is presented. The system consists of a nylon blanket covered with sensitive electrodes placed between the patient and the mattress. This blanket is used to determine the pressure points that are displayed on a monitor	2009
[15]	Hsia et al.	Analysis and comparison of sleeping posture classification methods using pressure sensitive bed system	The paper presents a system to assist health professionals by automated monitoring of patient's position over time. The system is composed of pressure sensors installed on the bed and connected to a computer, which receives data from the sensors and uses the techniques Principal Component Analysis (PCA) and Support Vector Machines (SVM) to estimate the position of the patient	2009
[24]	Mukai et al.	Physiological and care monitoring of anti-decubitus mattress patients	The paper presents a system composed of polyvinyl tubes installed on the mattress whose format and pressurization are changed by breathing movements, heart rate and the patient's body to prevent pressure ulcer	2009
[35]	Wang et al.	A wireless biomedical instrument for evidence-based tissue wound characterization	The paper presents a portable system for measuring sub-epidermal moisture to detect and monitor the emergence of symptoms of pressure ulcers. The moisture content of the skin is measured by a set of electrodes that also capture the intensity of pressure and transmit data to a server. Data from pressure and humidity can be monitored by professionals in a Web application	2010
[34]	Wai et al.	Lying posture classification for pressure ulcer prevention	The article discloses a system for classification of body position of a patient in bed based on the pressure data provided by pressure sensors installed in the mattress	2010

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Table 2 (*Continued*)

Id	Authors	Title	Summary	Publication year
[18]	Jaichandar et al.	An intelligent FPGA based anti-sweating system for bed sore prevention in a clinical environment	The paper presents an improvement on [16] with the proposed replacement of the microcontroller by a Field Programmable Gate Array (FPGA) system. The FPGA is more flexible and has a shorter design than the Application Specific Integrated Circuits (ASICs) previously used	2011
[27]	Ostadabbas et al.	A posture scheduling algorithm using constrained shortest path to prevent pressure ulcers	The article presents an algorithm for scheduling the position of the patient based on two metrics: stress and effort for changing position. Stress is defined as the effects of excess pressure in a region. Effort to exchange position is the time to change the patient's position and the number of nurses needed for activity. Based on monitoring of the user's body parts under pressure and in an effort to exchange position is mounted an agenda for change of position that optimizes the work of nurses and the time pressure exerted on the patient's body	2011
[41]	Yousefi et al.	A smart bed platform for monitoring &ulcer prevention	The article presents a platform for preventing pressure ulcers. The platform consists of sensors that are scattered around the patient's bed to collect data on the pressure points to determine the position of the patient, level of humidity, temperature, mobility and blood pressure	2011
[40]	Yousefi et al.	Bed posture classification for pressure ulcer prevention	The article discloses a system for estimating the position of the patient. By means of pressure sensors installed in the bed, images are obtained from the pressure map. Using this image and the classification algorithm k-nearest neighbor, the patient's position is estimated	2011
[4]	Boissy et al.	Carbon nanotubes (CNTs) based strain sensors for a wearable monitoring and biofeedback system for pressure ulcer prevention and rehabilitation	The article presents a system composed of an array of carbon nanotubes (CNTs), which are resistant and capable of capturing high sensitivity pressure sensors. The array of CNTs sends pressure data for a data collection platform to provide clinical feedback to health professionals	2011
[11]	Elfehri et al.	Novel approach of ulcer prevention based on pressure distribution control algorithm	The paper presents an algorithm able to verify and optimize the pressure distribution on a mattress. The algorithm automatically detects the shape of the human body and distribute the pressure over the body. The mattress is divided into cells of a matrix of 20 rows and 10 columns. Each cell consists of pressure sensors and an engine capable of distributing the pressure. The pressure is alternated between the body parts from time to time to prevent the formation of pressure ulcers	2011
[13]	Farshbaf et al.	Pressure ulcer monitoring and intervention: a software platform	The paper presents a software that consists of a module with pressure sensors that identifies body parts under pressure and estimates the patient's body position. The system monitors each body part and each time it has been exposed to pressure. Based on the risk of developing pressure ulcers, an algorithm determines how often the patient should be shifted position	2011
[26]	Ostadabbas et al.	Pressure ulcer prevention: an efficient turning schedule for bed-bound patients	The paper presents a scheduling algorithm for exchanging position to optimize the prevention of pressure ulcers. The algorithm makes use of pressure sensors to determine regions under pressure and their risk level to suggest the next position	2011
[30]	Pereira et al.	Textile moisture sensor matrix for monitoring of disabled and bed-rest patients	The article presents a mantle composed of an array of humidity sensors, capable of giving moisture and its distribution over a given area. The sensors are integrated with a software that displays a graph of intensity of moist spots	2011
[36]	Wang et al.	The development of an intelligent monitoring and caution system for pressure ulcer prevention	The article presents a system composed of pressure sensors that are placed in areas of the body at high risk of PU development. These sensors are integrated with a network of ZigBee sensors that stores the data from all sensors and transmit via wireless to a central station that displays monitoring data	2011
[17]	Jaichandar and Garcia	Intelli-sense bed patient movement sensing and anti-sweating system for bed sore prevention in a clinical environment	The article presents a system composed of temperature sensors installed on the surface of a bed for monitoring the temperature of the patient. Sensors are integrated with a microcontroller which manages the air flow of the pipes installed below the mattress to regulate the body temperature. Moreover, inflatable cushions with pressure sensors are coupled to the mattress. If the intensity of the pressure does not change for a certain period of time, the system emits sound and light alerts	2011
[37]	Wang et al.	A ZigBee-based wireless monitoring and automatic information pushing and caution system for pressure ulcer prevention	The paper presents a system composed of interconnected wireless sensors in a ZigBee network. Based on pressure data the position of the patient lying in bed is estimated and monitored. An alarm is triggered if the patient stays in the same position for too long	2011
[28]	Ostadabbas et al.	A resource-efficient planning for pressure ulcer prevention	The article presents an algorithm that uses data of a mat with pressure sensors and provides a sequence of positions for repositioning the patient. The algorithm takes into account the level of pressure exerted on each body part and the effort of health professionals to change the patient's position	2012

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Table 2 (*Continued*)

Id	Authors	Title	Summary	Publication year
[10]	Dobbins et al.	Remotely monitoring and preventing the development of pressure ulcers with the aid of human digital memories	The article proposes the use of digital human memories for patient monitoring. Digital human memories are a set of digital data of a person, for example, pictures and data about his activities throughout the day. The paper presents a prototype that consists of motion sensors that are placed next to the patient's body which determine whether it is sitting, lying down or raised, in addition to its location. As a complement to determine the patient's activities during the day, he needs to carry a smartphone attached to the neck so that photos are constantly taken by the DigMem application	2012
[12]	Fard et al.	Pressure ulcer risk assessment by monitoring interface pressure and temperature	The article presents a system for monitoring the temperature and pressure between the mattress and the patient's body to prevent PU's. It is composed of temperature sensors and pressure sensors installed in a mantle which covers the mattress. The mantle is connected to a computer via a USB cable that receives data from the sensors and displays maps of pressure and temperature intensity	2013
[9]	Chung et al.	Fabric-based pressure sensor array for decubitus ulcer monitoring	The paper presents a low cost pressure-sensitive mat connected to a microcontroller. In the article, a tablet is used to receive data from the microcontroller via bluetooth and displays a map of intensity of the pressure over the patient's body	2013
[20]	Liu et al.	Sleep posture analysis using a dense pressure sensitive bedsheet	The paper presents a pressure sensitive sheet and a framework for recognition of body position. The sheet is composed of a comfortable textile material which is able to generate pictures of high pressure intensity resolution used by a classifier for recognizing the position of the body	2014
[5]	Chang et al.	An enhanced sensing application based on a flexible projected capacitive-sensing mattress	A system composed of a flexible sensing mattress capable of measuring the distribution of pressure is presented. The system displays an intensity map based on the pressure data which can be used by the health professionals to determine the patients position in bed	2014
[1]	Akbari and Heravi	Designing and constructing blood flow monitoring system to predict pressure ulcers on heel	The article presents a system composed of three infrared optical transmitters that is able to monitor blood flow on the heel tissue	2014

which technologies are applied to perform the monitoring. In total, four risk factors are monitored: pressure, temperature, humidity of the patient's body and blood flow.

In order to monitor the pressure over the patient's body, the most common technology used are pressure sensors. Pressure sensors are devices capable of measuring the pressure exerted on them. They are installed along the mattress and can identify the amount of pressure exerted on them by the patient's body. This technology is used by twenty-six of the approaches, more specifically, the ones presented in [2,14,7,23,21,6,39,15,35,34,27,28,41,40,4,11,13,26,36,17,37,12,9,22,20,5].

Alternative methods of pressure monitoring are proposed by part of the articles. In [38], a system that makes use of a brace comprising sense coils installed in each of its sides was presented. The coils communicate with a central coil located on the mattress so that the distance between them is determined. Based on the identification of the smallest distance, the side of the jacket that is in contact with the mattress is identified and consequently the body part which is under pressure. In [33], the pressure monitoring was accomplished through electro-tactile sensors. These sensors are located in the patient's mouth and in contact with the touch receptors of the tongue, they generate electrical signals which are transmitted by a cable to an electronic device capable of determining the distribution and intensity of the pressure in the patient's body. In [10], sensors attached to the patient's body are used to identify whether he is sitting, lying or standing.

Low blood flow was considered by one of the approaches. In [1], infrared optical transmitters were applied in order measure the heel blood flow. If it is too low, that means that the tissue is not receiving nutrients properly and may be lead to death if exposed to this condition for a long period of time.

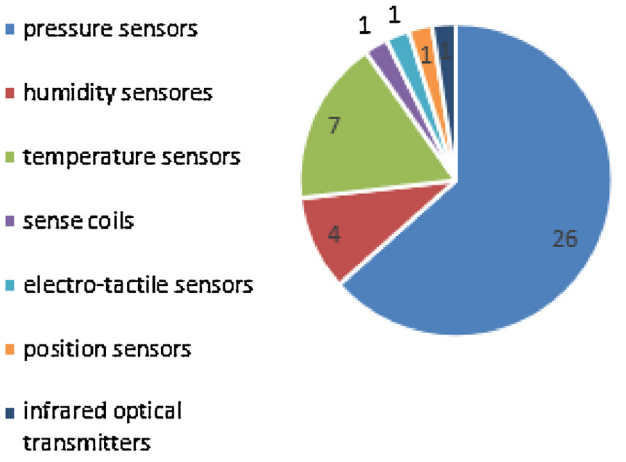

Fig. 2. Top technologies used to monitor risk factors.

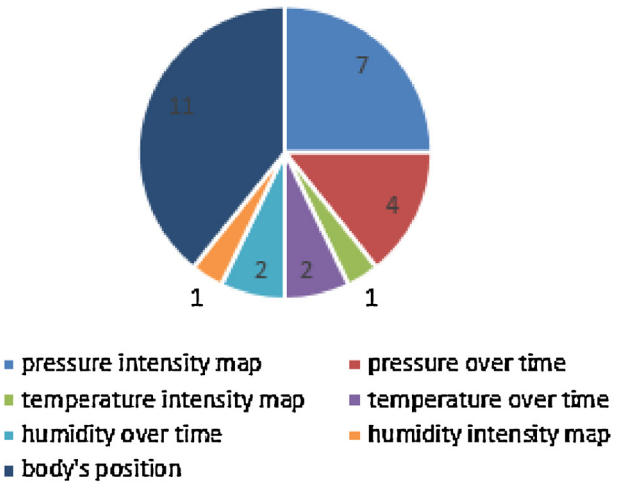

Fig. 3. Relevant information provided by the approaches to support PU's prevention. (For interpretation of the references to color in text, the reader is referred to the web version of this article.)

For monitoring the patient's body temperature and humidity, all approaches use sensors installed in the mattress which are capable of measuring the intensity of temperature or humidity. Seven approaches perform monitoring of temperature [32,7,16,6,18,17,12] and four of them perform the monitoring of moisture [35,7,6,30]. The technologies used to monitor risk factors and the amount of approaches that employ them are shown in Fig. 2.

3.2. Provision of relevant information for the prevention of PU

The approaches presented in the articles of Tables 2–4 may contribute to the prevention of PU with the provision of information to support medical decision. Such information and the number of approaches that offer them are listed in Fig. 3.

Seven approaches provide pressure intensity maps [2,14,33,35,12,9,22], which are graphs that represent colors by means of the pressure intensity of points on the mattress. The closer the color is to red, the higher is the intensity at a given point. Only one approach provides temperature intensity maps [12] and one of them provides humidity intensity maps [30].

Graphs showing the temperature level over time are provided by two approaches [32,6]. Four of them provide graphs that show the intensity of pressure over time [6,39,4,17] and two of the humidity level over time [35,6].

Eleven approaches provide reports that show the body position of the patient in bed [38,34,27,28,41,40,13,26,36,37,20]. Such reports are obtained by using classification algorithms that estimate the position based on the intensity data of the pressure sensors installed on the mattress.

3.3. Alerts

Alerts are used by the approaches to indicate the possible need to control a risk factor. In the literature, three types of alerts were identified: light, sound and text messages. To indicate prolonged exposure to pressure, three approaches use light and sound alerts [38,6,37] and one of them uses text messages [36]. To indicate high temperature, four of them use sound and light signals [16,6,18,17].

3.4. Automated management of risk factors

Based on the monitoring of the patient, part of the approaches can identify critical situations and automatically manage risk factors. Approaches that can automatically manage, in a limited way, exposure to pressure and body temperature were found in the literature.

Three approaches perform the body temperature management using a similar method [16–18]. They make use of a ventilation system composed of pipes installed under the mattress which cools it with a stream of cold air. The ventilation system is switched on by a microcontroller when the body temperature of the patient exceeds a certain threshold. In [23], a mattress containing 18 air cells made of porous material is presented to control the temperature. The air passes through these cells and cools the body temperature.

Two approaches perform pressure exposure management by means of a segmented mechanical moving bed that is activated at intervals to redistribute the pressure over the body of the patient [41,11].

3.5. Relevant information for applying the approaches

Some points should be taken into account before applying the approaches in hospitals. In this study, we checked if the selected articles considered three of them: cost of the approach, effectiveness in pressure ulcer prevention, equipment hygiene and patient comfort.

Cost for the application of the approach was considered by seven of the selected articles. Six of them [21,36,17,9,5] cites they use low cost equipment. Yet, only in [39] price details are provided.

Patient's comfort is issued in four of the selected articles: [5,20,11,39]. This is an important issue, since contact with the monitoring equipment might compromise comfort when the patient is lying on the bed.

Effectiveness of the approach is another relevant point to consider its relevance in PU prevention. Effectiveness was issued in twelve of the selected articles: [16,6,15,34,18,27,41,40,26,36,17,28]. Yet, no randomized control trials were applied to verify the approach effectiveness. None of the selected approaches has considered the hygiene of the monitoring equipment.

4. Discussion

As shown in the results of this systematic review, approaches that use software have been proposed in the last year to support the prevention of PU. Their main method is to monitor risk factors, like pressure, and use the extracted data to provide relevant information to health professional or to automatically monitor these risk factors.

According to Table 3, the main monitored risk factor is the body exposure to pressure, but there are some approaches that also monitor blood flow, humidity and body temperature. In order to monitor these risk factors, in almost all cases, pressure sensors, temperature sensors and humidity sensors are used. Recently, however, alternative forms of monitoring were proposed as a vest with sensory coils [38], electro-tactile sensors that are in contact with the patient's tongue [33], a sensor to detect if the patient is lying, sitting or standing [10] and infrared optical transmitters that are able to monitor blood flow [1]. Based on the monitoring data, most of the approaches provides information about the patient, more specifically, the position of the body, maps of intensity and level of temperature, pressure and humidity to support health professionals in PU prevention.

In order for the approaches to monitor risk factors, there is contact of the patient with the monitoring equipment installed on the mattress or on the vest. Therefore, two matters must be considered: patient's comfort and hygiene of the monitoring equipment. Contact with the monitoring equipment might reduce patient's comfort and implies that the equipment must be properly sanitized or replaced when the patient being monitored changes. Yet, as show in Table 4, none of the approaches consider the hygiene of the monitoring equipment and only four of them [5,20,11,39] briefly discuss patient's comfort.

In order to apply the proposed approaches in hospital, beyond the comfort and the hygiene matters, another two questions should be taken into account: the effectiveness of the approach and the cost of the approach (more specifically, the price of the monitoring equipment).

The cost of the approach was considered by seven of the thirty-six articles as shown in Table 4. Yet, they briefly point out that they use low cost material. Only in [39] price is provided.

As show in Table 4, thirteen of the approaches has considered effectiveness. In all of them, experiments were applied to show that the approaches are effective in controlling risk factors (as in [17] or in correctly generating reports like estimating patient's position (as in [36]). Yet, no experiments were performed to verify if the proposed approach may reduce pressure ulcer incidence when applied in hospitals.

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Table 3
Extraction part 2.

Id	Authors	Considered risk factors	Key technologies used for monitoring the patient	Reports provided	Risk alerts	Automatically monitored risk factors
[32]	Tamura et al.	Temperature	Temperature sensors	Temperature over time	None	None
[2]	Babbs et al.	Pressure	Pressure sensors	Pressure intensity map	None	None
[25]	Myers and Duncan	Pressure	None	None	None	None
[14]	Fulton and Lipczynski	Pressure	Pressure sensors	Pressure intensity Map	None	None
[38]	Williams et al.	Pressure	Sense coils	Body position over time	Sound and light alarm	None
[7]	Chiou et al.	Pressure temperature humidity	Pressure sensors temperature sensors humidity sensors	None	None	None
[23]	Moon et al.	Pressure and temperature	Pressure sensors	None	None	Temperature
[21]	Lowne and Tarler	Pressure	Pressure sensors	None	None	None
[16]	Jaichandar et al.	Temperature	Temperature sensors	None	Sound and light alarm	Temperature
[33]	Vuillerme et al.	Pressure	Electro-tactile sensors	Pressure intensity map	None	None
[6]	Chen et al.	Pressure, temperature and humidity	Temperature sensors pressure sensors humidity sensors	Pressure, temperature and body humidity over time	Sound and light alarm	None
[39]	Yip et al.	Pressure	Pressure sensors	Pressure over time	None	None
[15]	Hsia et al.	Pressure	Pressure sensors	None	None	None
[35]	Wang et al.	Pressure and humidity	Humidity sensors pressure sensors	Pressure intensity map humidity over time	None	None
[34]	Wai et al.	Pressure	Pressure sensors	Body position over time	None	None
[24]	Mukai et al.	Pressure	Polyvinyl tubes	None	None	None
[18]	Jaichandar et al.	Temperature	Temperature sensors	None	Sound and light alarm	Temperature
[27]	Ostadabbas et al.	Pressure	Pressure sensors	Body position over time	None	None
[28]	Ostadabbas et al.	Pressure	Pressure sensors	Body position over time	None	None
[41]	Yousefi et al.	Pressure, temperature and humidity	Pressure sensors	Body position over time	None	Pressure
[40]	Yousefi et al.	Pressure	Pressure sensors	Body position over time	None	None
[4]	Boissy et al.	Pressure	Pressure sensors	Pressure over time	None	None
[11]	Elfehri et al.	Pressure	Pressure sensors	None	None	Pressure
[13]	Farshbaf et al.	Pressure	Pressure sensors	Body position over time	None	None
[26]	Ostadabbas et al.	Pressure	Pressure sensors	Body position over time	None	None
[30]	Pereira et al.	Humidity	Humidity sensors	Humidity intensity map	None	None
[36]	Wang et al.	Pressure	Pressure sensors	Body position over time	Text message	None
[17]	Jaichandar and Garcia	Pressure and temperature	Pressure sensors temperature sensors	Pressure over time	Sound and light alarm	Temperature
[37]	Wang et al.	Pressure	Pressure sensors	Body position over time	Sound alert	none
[10]	Dobbins et al.	Pressure	Position sensors	–	None	None
[12]	Fard et al.	Pressure and temperature	Pressure sensors temperature sensors	Pressure intensity map temperature intensity map	None	None
[9]	Chung et al.	Pressure	Pressure sensors	Pressure intensity map	None	None
[22]	Manohar and Bhatia	Pressure	Pressure sensors	Pressure intensity map	None	None
[20]	Liu et al.	Pressure	Pressure sensors	Body position over time	None	None
[5]	Chang et al.	Pressure	Pressure sensors	Pressure intensity map	None	None
[1]	Akbari and Heravi	Blood flow	Infrared optical transmitters	None	None	None

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Table 4
Extraction part 3.

Id	Has patient comfort been considered?	Has effectiveness of the approach been considered?	Has a randomized control trial been conducted to test effectiveness?	Has hygiene of the equipment been considered	Cost of the approach
[32]	No	No	No	No	Not covered
[2]	No	No	No	No	Not covered
[25]	No	No	No	No	Not covered
[14]	No	No	No	No	Not covered
[38]	No	No	No	No	Not covered
[7]	No	No	No	No	Not covered
[23]	No	No	Experiment with 7 subjects showed that the approach is able to determine and set an appropriate optimal air-cell pressure for each user. Yet, no experiments with a control group has been done to prove	No	Not covered
[21]	No	No	No	No	The approach uses inexpensive sensors for automated body position classification.
[16]	No	Yes. Experiment's results showed that the use of the approach is able to save the time of the nurse by more than 80 percent defining an optimal repositioning time for each patient	No	No	Not covered
[33]	No	No	No	No	Not covered
[6]	No	Yes. Experiment's results showed that the approach is able to decrease body humidity, temperature and interface pressure	No	No	Not covered
[22]	No	No	No	No	Not covered
[39]	The system consists of a flexible pressure sensitive sheet made of a nylon substrate and embedded stainless steel electrodes which is comfortable to lie	No	No	No	The approach uses a fabrication sheet which costs less that $50 per squared meter
[15]	No	Yes. Experiment's results showed that the average classification accuracy of the approach is 81.43%	No	No	Not covered
[24]	No	No	No	No	Not covered
[35]	No	No	No	No	Not covered
[34]	No	Yes. According to experimental outcomes, the approach is able to correctly classify different lying postures with an accuracy of up to 93%	No	No	Not covered
[18]	No	Yes. Experiment's results showed that the patient sweats less when the approach is applied	No	No	Not covered
[27]	No	Yes. Experiment's results showed that the approach is able to provide a customized repositioning agenda in order to reduce health professional's effort to reposition the patient	No	No	Not covered
[41]	No	Yes. Experiment's results showed that the approach is able to determine patient position with an average accuracy of 97.7%	No	No	Not covered
[40]	No	Yes. Experiment's results showed that the approach is able to determine patient position with an average accuracy of 94.3% with the use of PCA and ICA with kNN classifier	No	No	The approach uses a high resolution pressure mapping system which is commercially available with reasonable cost
[4]	No	No	No	No	Not covered

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Table 4 (*Continued*)

Id	Has patient comfort been considered?	Has effectiveness of the approach been considered?	Has a randomized control trial been conducted to test effectiveness?	Has hygiene of the equipment been considered	Cost of the approach
[11]	The paper cites the control algorithm is designed to be efficient in ulcer prevention and in the same time guarantees some comfort to the patient	No	No	No	Not covered
[13]	No	No	No	No	Not covered
[26]	No	Yes. Experiment's results showed that the approach is able to provide a customized repositioning schedule in order to reduce health professional's effort to reposition the patient	No	No	Not covered
[30]	No	No	No	No	Not covered
[36]	No	The position prediction for the free lying positions was completed using the established model from the assigned positions. There were 168 data records from pressure sensors completely identified for predicting the position state. The experimental results for the participant showed that the lying positions were analyzed as 29 data records for FL, 121 data records for RL, and 18 data records for FL, in sequence. With the comparison between the observed data from video recording and the position predicted by the system during the free position period, the accuracy of position prediction was 100% correct	No	No	The approach uses a low-cost wireless sensor network
[17]	No	Yes. Experiments showed that the system is able to reduce patient's sweat and body temperature	No	No	The approach uses a low cost Microcontroller based anti-sweating system
[37]	No	No	No	No	Not covered
[28]	No	Yes. Experiment's results showed that the approach is able to provide a customized repositioning schedule in order to reduce health professional's effort to reposition the patient	No	No	Not covered
[10]	No	No	No	No	Not covered
[12]	No	No	No	No	Not covered
[9]	No	No	No	No	A low-cost fabric-based pressure sensor was developed for pressure monitoring
[20]	The paper cites the use of pressure sensors embedded in the mattress that is unobtrusive and does not interfere in the comfort of users	No	No	No	Not covered
[5]	The paper cites the use of a flexible mattress for improved comfort of the user	No	No	No	The approach uses a low cost capacitive-sensing mattress
[1]	No	No	No	No	Not covered

5. Conclusion

This systematic review presents the state of art of the approaches that use software to prevent PU. As shown in the previous sections, these approaches are based on monitoring patient's risk factor in order to provide relevant informant to assist health professionals. Most of them use sensors to monitor the patient's exposure to pressure, temperature and humidity and generate reports regarding the intensity of each one of these risk factors as well as the patient's position in bed. Although, many advances have been made in the technological perspective to monitor risk factors and generate reports, clinical matters like patient comfort and

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Summary points
What was already known on the topic:

- There is still a high incidence of PU.
- Several approaches that use software to support pressure ulcer prevention have been proposed.

What this study has added to our knowledge:

- Most of the approaches monitor risk factors to provide information for prevention and requires patient's contact with the monitoring equipment.
- Current monitoring techniques need to consider equipment hygiene and patient comfort.

hygiene of the monitoring equipment were not strongly explored, as well as the price of the approach and experiments to prove they can reduce PU incidence.

Since, there is contact of the patient with the monitoring equipment patient's comfort and the equipment hygiene must be taken into account. Only few studies briefly discuss the comfort issue and none of them discusses the equipment hygiene. Therefore, future studies could analyze the proposed approaches considering how they may impact patient's comfort and how the equipment should be sanitized or even replaced every time a new patient needs to be monitored. With the emergence of new alternative forms of monitoring, new technologies that do not require contact could also be explored by new research.

Cost to apply the approaches is briefly discussed by only a few articles. Future studies could specify the price of each monitoring equipment and compare it to how much would be saved with pressure ulcer treatment if the approach was applied.

The selected studies present experiments to prove their approaches can correctly generate reports or control risk factors, yet none of them provides any evidence that their approach is capable of reducing PU incidence when applied in hospitals. Therefore, future studies could perform Randomized Control Trials to verify which approaches are really effective to reduce PU incidence and to verify which information provided by each of the approach is relevant to health professionals in order to support them on PU prevention.

Author contributions

All the authors performed the conceptualization of the study. FGM and LVA developed the systematic reviews' planning. FGM selected the included articles by screening titles and abstracts and performed the data extraction. LVA reviewed included articles and extracted data. All authors performed the results analysis and preparation of the manuscript.

Competing interests

The authors declare no conflict of interest.

Acknowledgements

We would like to thank Zamboni et al. for developing the StArt tool which helped us through all the stages of the systematic review.

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