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Wearable Sensors for Posture and Movement in Patient Handling: A Scoping Review

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Abstract

Nurses experience work-related musculoskeletal disorders (WMSDs) such as lower back pain due to awkward postures or movements during patient handling. Monitoring and education for patient handling are necessary to prevent these WMSDs. Recently, measurement methods for patient handling using wearable sensors have been developed to implement these interventions at various sites. However, the status of these measurement methods has not been comprehensively summarized. The purpose of this study is to summarize the status of measurement methods for patient handling using wearable sensors. Peer-reviewed papers published between January 2013 and November 2023 that included measurements of patient handling using wearable sensors were selected from Google Scholar. Measured patient handlings, postures, and movements were summarized. The type, number, and placement of sensors were also investigated. Furthermore, the applied data processing techniques were also summarized. Inertial sensors and insole pressure sensors were applied for measurement methods. Current methods can measure trunk angle, arm movement, and foot placement during several motions such as patient transfer. In addition, load and correctness of patient handling motion are recognized by a wearable sensor-based system using machine learning techniques. These results indicate that current methods can provide effective kinematic values during patient handling to prevent WMSDs. On the other hand, there were also limitations due to number of sensors. Future studies should develop simpler measurement methods using fewer sensors.

Keywords: Patient handling motion; Wearable sensors; Work-related musculoskeletal disorders.

1. Introduction

Nurses and caregivers experience work-related musculoskeletal disorders (WMSDs) such as lower back pain due to awkward postures or movements during patient handling [1,4]. Thus, monitoring and education of posture and movement during patient handling are important to prevent WMSDs [5,7].

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Measurement of patient handling motion is required for these interventions. Commonly, ergonomic studies about patient handling used vision-based systems such as optical motion capture system to measure three-dimensional posture and movements [8,11]. However, vision-based systems are limited to use because measurement area depends on field of view and occlusions [12,13]. Wearable sensors such as an inertial sensor can measure motion in anywhere because these devices are not limited to measurement area [14, 15]. However, accuracy of wearable sensors is lower than vision-based systems because wearable sensors cannot directly measure human posture [14,15]. To solve these problems, techniques of signal processing and machine learning are applied to measurement using wearable sensors [16,17].

From this background, measurement methods using wearable sensors for various postures and movements to prevent WMSDs as occupational health have been developing [18,21]. In addition, these methods were investigated by several review papers [18, 21]. However, there is no review study that focuses on measurement of patient handling motion using wearable sensors. The status of these measurement methods should be comprehensively summarized for future developments to prevent WMSDs due to patient handling. The objective of this study is to is to summarize the status of measurement methods for patient handling using wearable sensors.

2. Material and Methods

This study was based on the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) [22]. The research question of this scoping review was "How is the current status of developing wearable sensors to measure patient handling motion?".

Table 1 shows search conditions for acquisition of papers. Total 122 papers were identified from the Google Scholar database by search query "wearable sensors" AND "patient handling" (Note that AND is the Boolean operator). Table 2 shows inclusion criteria and exclusion criteria for this review. Figure 1 shows PRISMA diagram of this scoping review. As mentioned, Table 2 and Figure 1, we extracted the peer-reviewed English papers which were published since 2013. The literature reviews and papers which do not relates to wearable sensors for patient handling were excluded from this study. Finaly, total 11 papers [23,33] were included in this review .

We investigated (1) measured patient handling, (2) measured movement or postures, (3) applied sensors, (4) number and placement of sensors, and (5) applied signal processing of each included paper. Current wearable sensors for patient handling motion were revealed from these investigations.

Table 1: Search conditions

Parameters	**Status / Value**
Search Date	November 27, 2023
Database	Google Scholar
Search Query	"wearable sensors" AND "patient handling"
Identified Paper	122
Included Paper (based on Figure 1)	11

Table 2: Inclusion criteria and exclusion criteria

Parameters	**Inclusion Criteria**	**Exclusion Criteria**
Published Date	Since January 2013	Before January 2013
Language	English	Other than English
Research Design	Quantitative or qualitative studies	Literature review
Methodology	Used wearable sensors	Not used wearable sensors
Motion / Posture	Patient handling	Other than patient handling
Full Text Available	Available from author's institution without charge	Not available from author's institution without charge
Publication	Journal or proceeding	Other than journal or proceeding
Peer-reviewed	Peer-reviewed	Not peer-reviewed

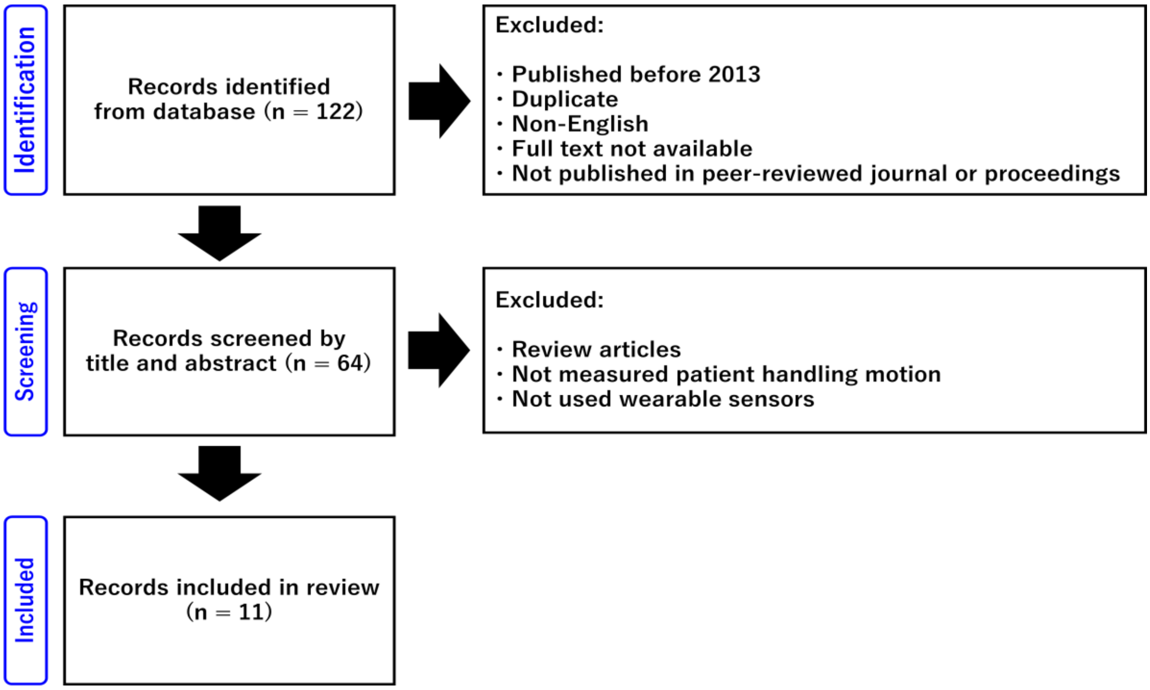

Figure 1: PRISMA diagram of this study

3. Results and Discussion

3.1. Results for target of measurement

Results are shown in Table 3 and Table 4. As showed Table 3, wearable sensors were used to measure patient handling related to transfer, rolling, repositioning, and lifting. Various movements and postures such as trunk angle and foot position during patient handling were measured by wearable sensors. In addition, wearable sensors were used to recognize movements based on load and correctness of patient handling.

Table 3: Results about patient handling

Reference	Patient Handling	Movement / Posture
[23]	Changing posture of patient on the stretcher	(1) Trunk angle (2) Trunk velocity
[24]–[27]	(1) Lifting leg of patient (2) Lifting patient from wheelchair (3) Rolling patient on the bed (4) Carrying patient by wheelchair	(1) Activity (task) recognition (2) Load level recognition
[28]	Rolling patient on the bed	(1) Foot position recognition (2) Arm movement recognition
[29]	Patient transfer	Recognition for correct and incorrect movement
[30]	(1) Patient transfer between chair and bed (2) Sliding patient on the bed (3) Repositioning patient on the bed	Trunk angle
[31]	Patient transfer	Full body movement
[32]	Patient lifting from wheelchair	Foot position
[33]	Patient transfer	Recognition for correct and incorrect movement

3.2. Results for wearable sensors

As showed Table 4, inertial sensors and insole pressure sensors were used as wearable sensors to measure patient handling motion. The results show that multiple inertial sensors are required to measure patient handling motion without insole pressure sensors. Especially, when full body movement or posture are measured by only inertial sensors, 6 to 17 inertial sensors are required. Machine learning techniques were used to predict movement or posture during patient handling in several papers.

Table 4: Results about wearable sensors

Reference	Applied Sensors	Number of Sensors	Placement of Sensors	Signal Processing
[23]	Inertial sensor	17	Full body	Not mentioned
[24]–[27]	Insole pressure sensor	2	Both feet	Spatio-temporal warping based machine learning
[28]	(1) Inertial sensor (2) Insole pressure sensor	Inertial sensor: 1 Insole sensors: 2	(1) Trunk (2) Both feet	Machine learning
[29]	Inertial sensor	6	(1) Trunk (2) Both legs (3) Both arms	Deep recurrent neural network
[30]	Inertial sensor	2	Trunk	Not mentioned
[31]	Inertial sensor	17	Full body	Not mentioned
[32]	(1) Inertial sensor (2) Insole pressure sensor	Inertial sensor: 1 Insole sensors: 2	(1) Trunk (2) Both feet	Machine learning
[33]	Inertial sensor	17	Full body	Temporal convolutional neural network

3.3. Effectiveness of current wearable sensors

The results that current wearable sensors can be applied for various patient handling motions such as transfer, rolling, and lifting. These patient handling motions are known as risk of WMSDs among nurse and caregivers [1,3,34]. Current wearable sensors can measure trunk angle, arm movement, and foot position. These movements and postures are related to physical load during patient handling [35,37]. The results show that combination of wearable sensors and machine learning technique can recognize patient handling motions based on load level or correctness. These correctness and load level are important parameters to prevent WMSDs due to patient handling [6,38,39]. From these results and reports, it is considered that current methods can provide effective kinematic values during patient handling to prevent WMSDs.

3.4. Limitations of current wearable sensors

On the other hand, the results show limitations of current wearable sensors too. Full body measurement including trunk angle, arm movements, and foot position require 6 to 17 inertial sensors or combination of a single inertial sensor and insole pressure sensors. Insole sensors have problem for useability that these sensors cannot adjust for each shoe size of user [40]. Thus, if possible, it is recommended to measure patient handling without insole pressure sensors. Inertial sensor is implemented in exiting smart device such as smartphone and smartwatch [41,42]. These inertial sensors of smart device could be used to measure human movement such as gait [43,46]. There is possibility that if measurement methods using inertial sensor can be implemented in smart devices, patient handling motions might be monitored by only smart device of user. However, the results of this study show that exiting measurement methods require multiple inertial sensors. Therefore, it is recommended to develop novel measurement methods for patient handling using only a single inertial sensor in future studies. It is considered that signal processing techniques such as machine learning might be necessary to develop measurement methods using only a single inertial sensor.

3.5. Limitations of this review

The limitation of this review is that performances such as accuracy cannot be compared because there are differences of target patient handling, posture, and movement in investigated reports. Another limitation of this review is that database and search query for report identification are limited. If future works will focus on technologies for wearable measurements, the additional database in technical field such as the IEEE Xplore and technical specific words about wearable sensors and signal processing are necessary. In addition, if future works focus on clinical application using wearable sensors, the additional database in clinical field such as the PubMed and clinical specific words about patient handling and WMSDs are necessary too.

4. Conclusion

In this study, we summarize the status of measurement methods for patient handling using wearable sensors. The results show that current methods can measure trunk angle, arm movement, and foot placement during several patient handling motions. These results indicate that current methods can provide effective kinematic values during patient handling to prevent WMSDs. On the other hand, there were also limitations due to number of sensors. Future studies should develop simpler measurement methods using a single inertial sensor.

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