Sensor technologies aiming at fall prevention in institutionalized old adults: A synthesis of current knowledge

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Abstract

Background
Falls are a serious health problem in old adults especially in nursing home residents and hospitalized patients. To prevent elderly from falling, sensors have been increasingly used in intramural care settings. However, there is no clear overview of the current used technologies and their results in fall prevention.

Objectives
The present study reviews sensor systems that prevent falls in geriatric patients living in an intramural setting and describe fall rates, fall-related injuries, false alarms, and user experience associated with such systems.

Methods
We conducted a systematic search for studies that used sensor technologies with the aim to prevent falls in institutionalized geriatric patients.

Results
A total of 12 studies met the search criteria. Three randomized clinical trials reported no reductions in fall rate but three before-after studies reported significant reductions of 2.4 to 37 falls per 1000 patient days. Although there was up to 77% reduction in fall-related injuries and there was relatively low, 16%, rate of false alarms, the current data are inconsistent whether current sensor technologies are effective in reducing the number of falls in institutionalized geriatric patients.

The occurrence of false alarms (16%) was too high to maintain full attention of the nursing staff. Additionally including the users opinion and demands in developing and introducing sensor systems into intramural care settings seems to be required to make an intervention successful.

Conclusion
The evidence is inconsistent whether the current sensor systems can prevent falls and fall-related injuries in institutionalized elderly. Further research should focus more comprehensively on user requirements and effective ways using intelligent alarms.
Introduction

The number of old adults increases at an accelerating rate and falls represent a costly but unsolved safety issue with serious negative consequences for quality of life [1–4]. Compared with the 30% fall rate in community dwelling old adults, the 50% fall rate in elderly living in nursing homes is especially alarming [2,5]. Hospitalized patients fall 2 to 25 times per 1000 patient days [6,7] and one half of the elderly who already fell once will fall again [2]. Twenty percent of those who fell need medical attention for minor (28%) and soft tissue injuries (11%) and for fractures (5%) [2,7]. In addition to the physical trauma, fallers suffer from a loss of self-confidence, anxiety, depression, incomplete rehabilitation, increased length of hospital stay, additional costs for health and social care, and increased morbidity and mortality [2,8,9]. Unsurprisingly, fall prevention has become an important topic.

Fall prevention is an even more of a critical issue in old adults who fall in a nursing home or hospital because these patients are more physically and cognitively impaired than fallers living independently in a community setting [9]. Indeed, patients suffering from confusion and those with a high number of comorbidities are also more prone to falling during hospitalization than their peers living in the community [9]. Further, patients with dementia in a nursing home fall twice as often as elderly with normal cognitive function living also in a nursing home [10]. Over the next years, the number of old adults living in nursing homes will increase and concomitantly it is expected that the absolute number of falls will increase in this population [11]. Therefore, there is an urgent need to improve the efficacy of fall prevention especially in senior patients who reside in intramural care setting. Intramural care settings in this review refer to nursing homes, with geriatric and psychogeriatric departments and hospitals.

Health care workers in intramural care settings (e.g. nurses, nurse assistants, caregivers) often use physical restraints to protect immobile, highly dependent, and cognitively vulnerable elderly against falls [12]. The use of restraints ranges between 41% to 64% of patients in nursing homes and 33% to 68% in hospitals [12]. There is a growing interest in minimizing the use of physical restraint because restraints increase the risk of adverse events such as depression, aggression and confinement, but also due to the greater risk of fall-related injuries, breathing difficulties and even premature death [3,12]. More importantly, there is scant, if any, evidence that physical restraints prevent falls [12]. An alternative and rapidly emerging strategy to fall prevention is the development of light, small and cheap sensor systems [1]. Sensor systems are designed to detect and alert patients and staff about critical events: getting out of bed and rising from a chair unassisted. One common goal guides the rapid evolution of a diverse array of sensor technologies: fall prevention. There are two main classes of sensors available in terms of sensor position: wearable and non-wearable. With respect to detection mechanisms, sensors detect movement by pressure, position and infrared light. Detecting a specific event, such as rising from a chair or moving out of bed, is expected to predict a fall and thus the possibility to prevent the patient from falling.
The inconsistencies in the literature concerning the efficacy of conventional fall prevention methods and the emergence of the new sensor systems warrant a synthesis of the current knowledge concerning fall prevention in institutionalized old adults. Therefore, the aim of the present review is to integrate past and current knowledge concerning fall prevention systems used in intramural care settings. We review the effectiveness of these methods in terms of methodological quality, effectiveness of fall prevention technologies on fall rate and fall-related injuries, false alarms, and user experience. Finally, we make recommendations for future directions of sensor technology development in an effort to improve the efficacy of these systems to detect and prevent falls in institutionalized old adults.

Methods

Search strategy
A search of the electronic databases Pubmed, Web of Science and Scopus was conducted between September and December 2011, using the search terms: Fall prevention, Reduce falls, Elderly, Technology, Sensor, Monitoring, Telemedicine, Alarms, Ambient Living, Accelerometer and Risk assessment. Articles included were (1) written in English, (2) original research studies, (3) on elderly patients, and (4) the intervention used a sensor to prevent falls in an intramural care setting (e.g. hospital or nursing home). Articles were excluded when a comparison with and without sensor system was impossible. The citation lists of the articles read in full text were checked to complete the article selection.

Quality assessment and data abstraction
The methodological quality was assessed with a modified Downs and Black checklist [13]. The original checklist of Downs and Black consists of 27 items with a maximum score of 32 points [13]. The questions related to follow-ups and adverse events were removed. In addition, the questions about the confounders and power of the study were scored with one instead of the original two and five points. The adapted checklist consists of 23 items with a maximum score of 23 points. We identified four levels of quality: excellent (18 to 23), good (12 to 17), fair (7 to 11), and poor (≤ 6). Two reviewers assessed the quality of the included studies independently.

Results

Article selection
Figure 2.1 shows the selection process of the final 12 articles from 1020 hits produced by the search. After eliminating 469 items based on title, 470 as duplicates, and 61 abstract-only, 20 articles were qualified for full text reading. Finally, 16 articles were excluded due to the content and 8 articles were added after searching references.
The included articles examined the effects of intervention(s) on fall incident rate, fall-related injuries, user experience, false alarms, physical restraints, and health care costs in the care setting.

**Methodological quality**

Table 2.1 shows the quality score of the studies ranging from 6 to 19 out of maximum 23 points with a mean (SD) and median of 14.4 (4.1) and 15.5. One article was of poor quality [14], one rated as fair [15], eight achieved good quality [3,16–22], and two were of excellent quality [23,24]. There were three RCT’s, eight before-after studies and one control trail included. The scores of the articles were particularly low on the blinding of patients and the outcome assessor (12 of 12), adjustment for confounding factors (8 of 12), and the power to detect whether the outcomes were clinically important (9 of 12). Furthermore, four studies did only report the achieved reduction in falls and did not report the fall rate before and after the intervention or the level of significance.

**Figure 2.1** Flow chart of the article selection.
Table 2.2 summarizes the articles included in the review and the characteristics of patients, study settings, interventions and outcomes. The fall prevention sensor systems were mostly used in elderly/psychogeriatric units, acute hospitals and in residential care facilities. Patients with a high risk to fall were selected to use fall prevention sensors, those patients were identified according to their fall history, mental state and mobility level [3,14,15,20,24]. The sensor systems used to prevent falls can be divided into single and multi-factorial interventions using wearable and non-wearable sensors. The studies using a multi-factorial fall prevention program included besides a sensor, data gathering, risk assessment, drug review, an exercise programme, staff and patient education, environmental and equipment changes, and work practice adaptations [15,16,19,23].

**Effectiveness of fall prevention technologies on fall rate and fall related injuries**

The aim of this section is to determine the effect of the fall prevention sensor system on the fall rate and fall related injuries. Figure 2.2 summarizes the effects of sensor interventions on fall statistics after normalizing fall rate per 1000 bed days. Figure 2.3 shows the outcomes for studies in which such normalization was not possible.
Wearable sensors

Wearable fall prevention sensors can be attached to a patient’s thigh or foot [14,20,23]. Sensors affixed to the thigh have the size and shape of a credit card and are light-weight. These sensors have their own battery power source and are water- and shockproof [14,20]. Nurses and patients are alerted when a patient assumes a weight bearing position [20] or shifts the leg from the horizontal to an angle smaller than 45 degrees [14]. Those alarms seem to be effective in both hospital and nursing home settings in reducing fall rate. However, it appears that the sensors were not feasible for use by those elderly patients who wished to ambulate without imposed limitations and also in confused patients who tried to remove the sensors.

A wearable sensor worn on the foot takes the form of a neoprene rubber sock. The sock contains a pressure switch under the heel and a small loud speaker in a pocket at ankle level [23]. When a patient stands up, the alarm alerts the staff that the patient is standing and requires support [23]. The rubber sock was used in a large, multi-factorial RCT lasting three months and included 3999 patients admitted to 24 acute and rehabilitation wards [23]. Nevertheless, the intervention did not reduce fall rate. The negative result might be
attributed to the short time the intervention team spent on each ward, preventing the transformation of the current ward culture into a fall prevention environment.

**Non-wearable sensors**

As an alternative to wearable sensors, several non-wearable sensors have been developed to detect the event when elderly patients get out of bed or rise from a chair unassisted. These systems are non-restrictive and operate without cables, cuffs, leads or electrodes [22]. Non-wearable fall prevention sensors are placed in and around beds and chairs.

A frequently used sensor is the pressure-sensitive mat [3,15,21,24]. Pressure-sensitive mats are light-weight plastic sheets [15] placed between the surface of the mattress and the bed sheet [15,21,24]. Some pressure-sensitive mats have a time delay, of about two seconds between detection and sending an alarm, to prevent false alarms [3,15]. The alarms of the sensor mats are triggered when the patient’s weight is lifted off the bed and the pressure on the sensor mat is relieved [3,15,21,24]. Two RCT’s using the pressure-sensitive mats have failed to observe a reduction in fall rate [3,24], but two before-after studies did find a reduction of 18% and 54% in fall rate [15,21]. The RCT’s may have failed to reduce falls because the fall rate was too low (control group n=3, n= 4 and experimental group n= 4, n=1) [3,24]. However, the exact numbers and the level of significance have not been reported in a consistent manner in the before-after studies. It is difficult to determine

![Figure 2.3 Percentages fall rate reduction.](image)
the effectiveness of the interventions and to compare the results that could suggest which sensor technology and method will be most efficient to use, because of the inconsistent data reporting.

Infrared fall detection systems represent a second category of non-wearable technologies to prevent falls [17,18]. Infrared scanning consists of directional sensors that respond to changes in infrared energy patterns. The infrared beam has an elevation of approximately 90 cm above the floor [18]. The sensors detect a shift in the infrared energy field when a patient sits up in or gets out of bed [18]. In a few cases infrared scanning systems have been successful in reducing falls but only during the night and not during the day [18]. Those sensors can be useful in a small area, however falls are not limited to a bed or chair.

Four of the before-after studies used bed and chair alarms. Unfortunately, these studies failed to characterize in sufficient details the working mechanism of the bed and chair alarms [4,16,19]. Two of these studies were multi-factorial interventions performed in acute care settings, for 3 (n=3961) and 9 years (n=271095). The 3-year during study reduced falls from 12.5 to 10.1 falls per 1000 patient days. The other study did not reduce fall rate, this might be due to the already low fall rate at the start of the intervention, 3.25 falls per 1000 patient days. Additionally, only those two studies investigated the influence of the fall prevention intervention on fall-related injuries [16,19]. The serious fall-related injuries (like; fracture, head injury, permanent disability or death) decreased with 77%, from 0.73 to 0.17 per 1000 bed days [19] and with 64% from 1.48 to 0.72 per 1000 bed days [16]. Unfortunately, it is hard to say which component of the multi-factorial studies reduced fall rate, both studies included bed alarms, toileting protocols, high-low beds and identified patients with a high risk of falling with a sign above their bed [16,19].

The third study used a more advanced system to reduce falls, combining bed sensors with a recording of physiological measurements [22]. A passive sensor array placed under patients’ beds measures heart rate and respiration and the bed sensors are incorporated into the sensor array [22]. The heart rate and respiration are determined by a sophisticated algorithm designed to identify potential problems but also eliminating noise in the data to reduce false alarms [22]. If a patient’s heart rate and/or respiration rises beyond his/her expected physiological range, a patient is considered to be at risk for a bedside fall, and the system alerts the patient and/or the caregivers [22]. It seems that bedside falls were reduced while using this sensor system. Nevertheless the authors did not report the level of significance, which makes it difficult to draw any firm conclusions.

The fourth study including bed and chair alarms removed the sensor systems systematically from the residential care setting [4]. Due to the false alarms and the dependency of the nurses on the alarms the facility decided to eliminate the bed and chair alarms. After three months phasing out the sensors the fall rate decreased for the next 5 months [4]. The success of this intervention might be distorted by the negative attitude of nurses against the sensor systems and the positive attitude towards the new ward culture without the sensors. Time was spent for education, adaptation and integration of the new...
<table>
<thead>
<tr>
<th>Article</th>
<th>Design</th>
<th>Study characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barker et al.</td>
<td>Before-after design</td>
<td>Setting: acute hospital</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration: 9 years (3 years before and 6 years after intervention)</td>
</tr>
<tr>
<td>Bressler et al.</td>
<td>Before-after design</td>
<td>Setting: 60 bed residential care</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration: 11 months</td>
</tr>
<tr>
<td>Cumming et al.</td>
<td>Cluster randomised</td>
<td>Setting: 24 elderly care wards in 12 hospitals</td>
</tr>
<tr>
<td></td>
<td>Ex &amp; Con</td>
<td>Duration: 3 months</td>
</tr>
<tr>
<td>Diduszyn et al.</td>
<td>Before-after design</td>
<td>Setting: 3 telemetry floors and 1 neurology floor at a hospital</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration: 4 months</td>
</tr>
<tr>
<td>Dubner et al.</td>
<td>Before-after design</td>
<td>Setting: 18-bed PG unit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration: 21 months: no rooms scanned; 17 months: 4 rooms scanned; 15 months: all 9 rooms scanned</td>
</tr>
<tr>
<td>Fonda et al.</td>
<td>Before-after design</td>
<td>Setting: 4 elderly wards of a hospital</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration: 3 years</td>
</tr>
<tr>
<td>Kelly et al.</td>
<td>Crossover design</td>
<td>Setting: medicare unit of a medical facility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration: 5 months</td>
</tr>
</tbody>
</table>
## Table 2.2: Characteristics of the included articles.

<table>
<thead>
<tr>
<th>Article</th>
<th>Design</th>
<th>Study characteristics</th>
<th>Intervention</th>
<th>Outcome measure(s) &amp; Key finding(s)</th>
</tr>
</thead>
</table>
| Barker et al. (2008) [16] | Before-after design         | Setting: acute hospital                                                                 | MF programme including bed and chair alarms                                  | **Number of falls**
Fall rate increased from 3.25 (2.71, 2.69, 3.63) to 3.75 (3.65, 3.63, 3.71, 4.21, 3.55) per 1000 occupied bed days after programme implementation  

**Number of fall related injuries**
Rate of fall related injuries reduced sign. from 1.66 (1.55, 1.39, 1.65) to 0.61 (1.31, 0.98, 0.61, 0.65, 0.71, 0.68) per 1000 occupied bed days after programme implementation (p < 0.001) |

Bressler et al. (2011) [4] | Before-after design         | Setting: 60 bed residential care                                                       | Removing bed exit alarms, chair alarms and tabs with clips to the residents   | Pre-intervention (with sensors) 5.41 falls per 1000 bed days, intervention (removing sensors) 3.50 falls per 1000 bed days and post intervention (without sensors) 2.12 falls per 100 bed days. Sign. (p=0.3) between pre and post intervention period. |

Cumming et al. (2008) [23] | Cluster randomised controlled trial | Setting: 24 elderly care wards in 12 hospitals                                             | MF including a neoprene rubber sock                                           | **Number of falls**
381 falls; no difference in fall rates between Ex & Con (respectively 9.26 and 9.20 falls per 1000 bed days (p = 0.96))  

Sensor type: pressure sensor  
The Posey Sitter II wireless Nurse Call Monitor  
Sensor type: pressure sensors |

Diduszyn et al. (2008) [21] | Before-after design         | Setting: 3 telemetry floors and 1 neurology floor at a hospital                            | The Posey Sitter II wireless Nurse Call Monitor                               | 18% reduction in falls between falls before (n=78) and after the intervention (n=64).  

Sensor type: Infrared scanning system |

Dubner et al. (1988) [18] | Before-after design         | Setting: 18-bed PG unit                                                                  | MF including a bed alarm                                                      | **Number of falls**
19% reduction in number of falls from 12.5 falls to 10.1 per 1000 occupied bed days (p = 0.001)  

**Number of fall related injuries**
77% reduction in number of falls resulting in serious injuries from 0.73 falls to 0.17 per 1000 occupied bed days (p < 0.001)  

Staff compliance with the risk assessment  
staff compliance increased from 42% to 70% |

Fonda et al. (2006) [19] | Before-after design         | Setting: 4 elderly wards of a hospital                                                   | MF including a bed alarm                                                      | **Number of falls**
19% reduction in number of falls from 12.5 falls to 10.1 per 1000 occupied bed days (p = 0.001)  

**Number of fall related injuries**
77% reduction in number of falls resulting in serious injuries from 0.73 falls to 0.17 per 1000 occupied bed days (p < 0.001)  

Staff compliance with the risk assessment  
staff compliance increased from 42% to 70% |

Kelly et al. (2002) [20] | Crossover design            | Setting: medicare unit of a medical facility                                             | NOC·watch device                                                             | **Number of falls**
fall rate decreased sign. from 4.0 to 0.3 to 3.4 falls per 100 patient days (p = 0.02)  

Effects on skin integrity  
no adverse effects on skin integrity  
Staff and patient acceptance  
high staff acceptance of the device, 6 patients tried to remove the device  
False alarms  
two false alarms |
working method [4]. However, the study failed to report if indeed there were changes in the education, adaptation and integration system before and during the introduction of the sensor systems. Maybe more time and a good education program about the use of bed and chair alarms would have had a positive effect on fall-rates.

**Feedback**

Fall prevention sensor systems give feedback to patients and nurses when an alarm is triggered. There are a variety of alerts possible. Alarms can go to the nurses’ station and beepers in the form of audio and visual alarms [3,15,21,24]. Bedside alarms warn...
the patients that they have to sit or lay down again. A previously recorded message (e.g. “please stay in bed”) [24] tells the patients what to do, or an audio (bleeping sound) or visual signal (flashing light) alerts the patient [3]. Bedside call buttons and dim lights can be activated [17,18] and there are systems with flexible settings, allowing caregivers to customize alerts (tones, voice recording, lights, and other messaging methods) [22]. Nursing home residents can respond negatively to an audio alarm; become agitated or attempt to move away from the unpleasant sound [17]. On the other hand, cognitively impaired patients were sitting down again as a response to the sound of the alarm [20]. It depends on the individual patients which kind of feedback is appropriate and successful.

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Outcome measure(s) &amp; Key finding(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bed and chair sensors</td>
<td>Physical restraints use</td>
</tr>
<tr>
<td><strong>Sensor type:</strong> pressure sensitive bed mat</td>
<td>no sign. differences in physical restraint use</td>
</tr>
<tr>
<td><strong>Time delay:</strong> 2 seconds</td>
<td>Mobility and transfer ability</td>
</tr>
<tr>
<td>no improvements in mobility and transfer ability</td>
<td>Number of falls</td>
</tr>
<tr>
<td>no improvement in fall rate between Ex (n=4) &amp; Con (n=3)</td>
<td>MF, after 2 years a bedcheck alarm was added</td>
</tr>
<tr>
<td><strong>Sensor type:</strong> pressure sensitive bed mat</td>
<td>Number of falls</td>
</tr>
<tr>
<td>one year after adding the Bedcheck alarm falls reduced with 47%, and after another year with 60%</td>
<td>Number of recurrent falls</td>
</tr>
<tr>
<td>the percentage of recurrent falls dropped with 29% in two years</td>
<td>LG1 Intelligent Medical Vigilance® system</td>
</tr>
<tr>
<td><strong>Sensor type:</strong> passive sensor array with bed-exit sensors</td>
<td>Cost-effectiveness</td>
</tr>
<tr>
<td><strong>Sensor type:</strong> pressure sensitive bed mat</td>
<td>cost saving compared to patient sitters</td>
</tr>
<tr>
<td>The RN+ OnCall bed monitoring system</td>
<td>Number of falls</td>
</tr>
<tr>
<td><strong>Sensor type:</strong> pressure sensitive bed mat</td>
<td>fall rate decreased between Ex (n=2) and Con (n=15)</td>
</tr>
<tr>
<td>LG1 Intelligent Medical Vigilance® system</td>
<td>Number of falls</td>
</tr>
<tr>
<td><strong>Sensor type:</strong> pressure sensitive bed mat</td>
<td>no sign. difference in bed falls between Ex (n=1) &amp; Con (n=4) (p=1.00)</td>
</tr>
<tr>
<td><strong>Sensor type:</strong> passive sensor array with bed-exit sensors</td>
<td>Performance of bed alarm system</td>
</tr>
<tr>
<td><strong>Sensor type:</strong> pressure sensitive bed mat</td>
<td>system functioned properly</td>
</tr>
<tr>
<td>LG1 Intelligent Medical Vigilance® system</td>
<td>Staff and patient acceptance</td>
</tr>
<tr>
<td><strong>Sensor type:</strong> pressure sensitive bed mat</td>
<td>well accepted by patients, families and nurses</td>
</tr>
<tr>
<td>Ambularm</td>
<td>Number of falls</td>
</tr>
<tr>
<td><strong>Sensor type:</strong> movement sensor</td>
<td>(1) no falls</td>
</tr>
<tr>
<td>(2) general medicine unit reduced falls with 45%; orthopedic unit reduced falls with 33%</td>
<td>Patients acceptance</td>
</tr>
<tr>
<td>A few confused patients tried to remove the Ambularm</td>
<td></td>
</tr>
</tbody>
</table>
False alarms
Bressler et al (2011) removed bed and chair alarms because false alarms desensitized the support staff [4]. False alarm reporting is still scarce in the current literature as only one study presented the numbers of alarms and false alarms. Tideiksaar et al. (1993) used sensitive pressure mats to prevent falls in an acute care setting [24]. There were 143 alarms noticed during 4425 hours of sensor use, 16% of those being false alarms [24]. Another study with a wearable sensor worn on the thigh reported two false alarms and a study with a pressure sensitive mat reported a low number of false alarms without specifying the exact numbers [20,21]. A part of the false alarms were the consequence of mats lying under the patient shoulders instead of under the buttocks [24]. Restlessness in patients resulted in frequently false alarms and a part of the false alarms could not be explained [24]. It is important to have a sensor system with a low number of false alarms to maintain full attention of the health care workers.

User experiences
User acceptance influences the effectiveness of an intervention. When health care workers do not see the need of using sensor systems or there is no time to get used to a device the sensor systems won’t be used correctly or won’t be used at all. The few studies investigating staff acceptance reported that health care workers accepted the fall prevention sensors well in their care setting [19,20,24]. Health care workers asked to add patients with a high risk of falling to the intervention group [20], and caregivers preferred sensor systems above mechanical restraints [24]. However, studies who introduced a sensor system without success, reported the lack of acceptance and awareness of the fall prevention sensor system as a limitation in their study [21,23]. Inexperience with the use of the sensor system and the amount of time required to program and install the sensor systems are barriers for health care workers to use sensor systems [21]. Bressler et al (2011) removed the sensors from the residential care institution because the health care workers relied too much on the sensors and the level of care has decreased [4]. Working without sensors was slowly introduced in combination with education. The management team modified the environment, leading to a new culture associated with sensor use [4]. It seems that the staff accepted the changes, leading to a large degree to the success of the intervention.
Discussion

The aim was to review the effects of fall prevention sensor technologies in patients residing in intramural care facilities. We addressed four specific issues: 1) fall and 2) fall-related injury rates in the presence of sensor systems, 3) the number of false alarms, and 4) the experiences of health care workers and patients with fall prevention sensor systems.

There is no consistent evidence that the implementation of current sensor technologies in intramural care settings would reduce fall rates. Wearable sensors attached to the thigh and a non-wearable infrared sensor seem to reduce falls, however the wearable sensors are not feasible for confused patients and the infrared sensor is only effective at night. There is no consensus concerning efficacy of pressure-sensitive sensors and bed-exit alarms to reduce fall rates, the reported outcomes were possibly related to the poor quality of the sensors. The simplest sensors monitor only one variable (e.g., standing up) in a small area (e.g., around the bed or chair) but it is well-established that falls occur in a variety of conditions characterized by a wide array of spatial and temporal distribution. Hospital and nursing home patients fall not only when they get out of bed or rise from a chair. Falls also occur as a result of trips and slips in bathrooms, hallways, and living rooms, 24 h a day [1,25]. The results of the present review suggest that sensor systems monitoring a small area and a single variable are not appropriate to prevent falls in nursing home residents or in hospitalized elderly.

Sensors may not prevent the total number of falls per se but could reduce the severity injuries caused by falls. Multi-factorial studies using a sensor system in combination with other fall prevention methods revealed a reduction in fall-related injuries. Unfortunately, a consistent problem with multi-factorial interventions is that it is not clear which component of the intervention causes reductions in fall-related injuries [16,19] and fall rates [19]. It is possible that not the sensor itself but other elements of the multifactorial fall prevention program or the interaction between the sensor and elements of the multifactorial intervention might cause the reduction in fall-related injuries. There is a need to conduct carefully designed studies that examine the independent and the potentially interactive effects between sensor system and other elements of the intervention.

More research is also needed towards the number of false alarms. A high number of false alarms can desensitize caregivers against alarms [26]. To maintain caregivers’ responsiveness, 90% of the alarms must be accurate [27]. However, there is only one study that reported the rate of false alarms, 16% [24], a rate we consider still too high. A time threshold can reduce the number of false alarms so that the alarm is triggered after a certain period of time [26]. A time threshold relative to the event will decrease false alarms but is unclear if it would decrease fall risk. Actually, to prevent falls health care workers have to be with the patient before the patient stands up or gets out of bed. In reality, an early warning system is needed that predicts fall risk in a nursing home setting that would allow care givers to act in time to prevent a fall [26].
Reducing false alarms will change the attitude of health care workers towards a sensor system. Attitude towards and integration of fall prevention sensor systems into daily care is a major determinant whether an intervention succeeds or not [4,19,20,25]. Currently the acceptance of fall prevention sensor systems is not universal, with a few studies reporting positive [19,20,24] and other studies reporting somewhat mixed results in terms of incorporating sensor systems in care [3,23]. These latter studies highlight the difficulty of integrating fall prevention sensor systems into the clinical environment because designers and technicians very often approach the problem from a technical and not from a user perspective. The data from this review suggest that health care providers and sensor manufacturers must work together more closely in an effort to develop a dependable, accurate, and user-friendly sensor system [26]. Besides the user-involvement during the development and introduction of the sensor system there is time needed to introduce and integrate the system into the care setting. Optimal conditions have to be created to implement a sensor system.

Health care workers are not the only users of sensor systems, but patients are also involved. The severity of patients’ medical condition further complicates user experience with sensor systems and affects effectiveness of interventions. Alternative options to wearable sensors are needed for patients who are unable to cope with the inconveniences and physical limitations presented by the sensors, suffer from confusion or simply remove the sensors [14,20]. One option is the installation of non-wearable sensors that altogether eliminate contact between sensors and patients. However, dementia patients in nursing homes often suffer from restlessness a condition that is associated with a high rate of false alarms [28]. Taken together, the data suggest that there is an urgent need to integrate the process of designing and manufacturing wearable and non-wearable sensor technologies for individual patient and health care staff needs.

Besides the individual demands for the physical qualities of a sensor system it is important to know which patient has a high risk to fall. Although there are numerous instruments for fall risk assessment there is no consensus about a tool or protocol that predicts a fall. If there are criteria for the use of a fall prevention sensor system it is often based on a single fall risk factor or on the opinion of the health care worker [21]. However, falling is a complex phenomenon and a multivariate approach is needed to find patients who require fall prevention systems. Fall risk factors and underlying mechanisms need to be monitored with an intelligent system. Intelligent systems use algorithms to interpret raw data and provide predictive models [26]. The challenge is to make a model and alarm system working for all patients, even for patients who differ from the general patient population. An intelligent alarm system predicting falls for individual patient is the next step in fall prevention to improve accuracy and efficacy.

**Limitations**

Two factors, the relatively low methodological quality of the included studies and the low number of the studies qualifying for inclusion, limit the conclusions and recommendations
the current review can offer. We noticed especially substantial methodological deficiencies concerning the subscales ‘internal validity – confounding’ and statistical ‘power’ and the subscale ‘reporting’ with the subscale ‘internal validity – bias’ suggested somewhat higher qualities. Additional methodological weaknesses included unreported significance level, sample size, and number of (false) alarms. Many additional critical details were lacking in articles published before 1990 [14,15,18]. Such methodological issues make it difficult to compare the outcomes across studies and make recommendations for improving the effectiveness of intervention. Further research about fall prevention systems should include randomised control trials with sufficient power to improve the methodological quality and make the results generalizable.

Besides the methodological issues our review focuses only on sensor technology used in intramural care settings. Hospitalized elderly and old adults living in nursing homes have more risk to fall than old adults living in the community [2,4]. Additionally, the organisation, patient population, care (nurses, caregivers) and consequently the implementation of sensor technology in intramural care facilities differ largely from that of smart home technologies for independent living elderly and/or patient groups [29,30]. There is however, a wide field of sensor technologies used in health care (e.g., ambient intelligence, smart homes and e-health services) to support and monitor older adults with and without cognitive impairments living in the community [31,32] which are not discussed in the present review. Further research should be done to get an overview of the used fall prevention systems in home based situations and the effectiveness of those sensor systems.

Conclusion and recommendations

Currently there is still an absence of high-quality, multi-centre randomized trials using wearable or non-wearable fall detection and prevention sensor systems, implicitly suggesting that the overall quality of the reviewed studies is average at best. Clinical applications of these sensor systems have not been defined yet in an evidence-based manner. New technologies will provide new options to improve the clinical application of sensor systems. However, additional studies that will address the following issues are indicated:

• To develop sensor systems which cover rooms and units for 24 hours a day. Sensor system should be applicable in a large variety of circumstances and not only around the bed or a chair.
• To map the individual risk of falls and the underlying processes which will provide an algorithm predicting falls.
• To include the users opinion and demands in developing and introducing sensor systems into intramural care settings. Time and space is needed to practice and get used to the sensor system and to use it correctly.
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