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**Person transfer assist systems: a literature review**

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**ABSTRACT**

**Objective:** Novel developments in the robotics field have produced systems that can support person wheelchair transfers, maximize safety and reduce caregiver burden. The purpose of this study was to identify and describe these systems, their usability (or satisfaction), the context for which they have been or can be used and how they have been evaluated to determine evidence for their effectiveness.

**Method:** Available research on Person Transfer Assist Systems (PTAS) was systematically gathered using similar standards to the PRISMA guidelines. The search terms were derived from common terms and via exploring similar review articles. Initial search terms displayed 1330 articles and by using the inclusion/exclusion criteria 96 articles were selected for abstract review. After full-text reviewing 48 articles were included.

**Results:** 29 articles concerned research in robotic transfer systems, 10 articles used both ceiling and floor-mounted lifts and 9 articles used only floor-mounted lifts as an intervention/control group. The results of this analysis identified a few usability evaluations for robotic transfer prototypes, especially ones comparing prototypes to existing marketed devices.

**Conclusion:** Robotic device research is a recent development within assistive technology. Whilst usability evaluations provided evidence that a robotic device will provide better service to the user, the sample number of subjects used are minimal in comparison to any of the intervention/control group articles. Experimental studies between PTASs are required to support technological advancements. Caregiver injury risk has been the focus for most of the comparison articles; however, few articles focus on the implications to the person.

**IMPLICATIONS FOR REHABILITATION**

- Ceiling mounted lifts are preferred over floor-based lifts due to lower injury rates.
- Many robotic transfer systems have been developed; however, there is a paucity of quantitative and qualitative studies.
- Based on the results of this review, rehabilitation settings are recommended to use ceiling over floor assist systems, and it is recommended to provide training on using devices to assist with patient transfers to lower the risk of injuries.

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**Introduction**

Person transfers can be physically taxing for wheelchair users and caregivers, as improper postures can lead to injuries to either party, hence the requirement of Person Transfer Assist Systems (PTAS) \cite{1}. There are around 3.6 million wheelchair users in the US \cite{2}, and many may require an assisted transfer from their own wheelchair by a caregiver using a PTAS. Person transfers increase the likelihood of injury to both caregiver and person if performed incorrectly \cite{3}. Caregivers are prone to excessive back flexion due to bending or reaching during a transfer as persons are unable to alleviate themselves from awkward positioning \cite{4}. A cross-sectional survey design study for occupational and physical therapists in 2012 displayed that transferring or lifting persons were associated with 26.6% of all injuries during work-related activities \cite{5}.

The types of wheelchair user injuries that could occur during a dependent transfer may include skin tears, bruises, and falls if caregivers neglect to assess handling requirements and physical abilities \cite{6}. From a work practice related control, the risk of injury could be decreased using education and training on proper lifting techniques and the use of assistive devices. A study that implemented mechanical lifting devices or other “patient lift devices” showed a 43% reduction in patient handling injury claims \cite{7}.

To reduce the risk of injury to caregivers as well as care recipients, clinical settings are equipped with assistive technology in the form of lift technologies to assist person transfers \cite{8}. There are three aspects that contribute to implementation: administrative, engineering, and work practice controls \cite{9}. Administrative controls include management-controlled policies and regulations that may reduce exposure of injury to both parties. Work practice controls involve caregiver training to perform transfers correctly. Engineering aspects are also potentially critical to the effectiveness of PTAS’s ability to prevent work-related musculoskeletal hazards.
Types of person transfer assist systems

PTAS can be divided into three different categories based on their technological advancements: low-tech devices, mechanical lifts, and powered or robotic systems. Low-tech PTAS include transfer boards, slides, and slings which are predominately used for lateral transfers and are often components incorporated into other PTASs [10]. Purely mechanical lift systems include hydraulic floor-based systems which use a hand crank to operate the lift and placement of a person [11] (Figure 1). Powered lift PTASs have electronic actuators to replace the hand crank in floor-based systems. Ceiling-mounted lift systems also fall into this category [12] (Figure 2). Each of these systems has advantages and disadvantages. Low tech devices are low cost but require more human effort to operate. These devices are unlikely to reduce the person load fully and other forces that could contribute to back, shoulder, neck, leg and wrist injuries [13]. Mechanical lifts reduce loads on caregivers but have a high center of gravity when the person is in transit and may become unsteady and tip over [14]. These systems still require awkward manipulations and significant human effort to operate. Powered lift PTASs provide further reductions in human effort but come with a higher price point. However, a ceiling-mounted lift system cost-benefit analysis over a 3-year longitudinal case study found a significant and sustained decrease in days lost in workers’ compensation claims and direct costs associated with the person handling injuries [15].

Emerging PTASs include robotic systems that take biomechanical dynamics into full consideration, to mimic human movements [16] (Figure 3). In doing so, such systems minimize human effort and improve both the caregiver and person experience during the transfer process. Research from the “Voice of the Consumer”, “A survey of the future of the provision process for mobility assistive technology” and “Consumer Feedback of the future of Assistive Technology” studies indicated that end-users would prefer a robotic PTAS by giving such systems the highest rank of importance [17–19].

Three prior literature reviews related to assisted transfer devices have been published. These reviews focused on the potential implications for caregivers, particularly with regards to biomechanics and policy requirements [20–22]. However, injuries from the perspective of the person being transferred were not mentioned nor did any of the reviews include robotic transfer technologies. Therefore, the purpose of this study was to address the state of science on PTAs, their development, and effectiveness preventing potentially mitigating forces and injury.

Materials and method

Inclusion & exclusion criteria

Articles were screened by two researchers in accordance with a broad criterion to allow all possibilities of PTASs and their respective studies to be discovered in our search (Figure 4). Basic inclusion criteria initially consisted of articles written in English published between January 1st, 2003 and December 31st, 2018 and focused on PTASs for dependent wheelchair transfers. The type of systems should have at least been mentioned in the article to be able to evaluate context and purpose. Peer-reviewed and conference articles were included, and gray literature was excluded. Articles were excluded if PTASs were not the main topic of the paper or if the focus was on a “training” method for transfer. Studies which focused on low-tech devices like transfer slides and boards were excluded.

Search method

Evidence gathered on PTASs that facilitate dependent wheelchair transfers were searched using PUBMED and EMBASE/MEMLINE. PUBMED and EMBASE/MEMLINE utilized a series of common Mesh terms: “Self-Help Devices”, “Patient Transfer”, “Moving and Lifting Patients”, “Patient lifting” and (combination of) keywords: “Robotic transfer device”, “Dependent transfer”, “Assisted transfer device”, “Wheelchair transfer device”, “Assistive transfer technologies”, “Patient transfer assistive device”, “Patient transfer aid” and “Patient transport device” to obtain a search strings unique for the respective databases. The reference lists of the papers identified were scanned to identify additional PTAS papers.

Results

Using the exclusion criteria, 1330 articles were filtered through title review, abstract and full-text reviews. During title screening, articles were excluded if a transfer device was not mentioned or the research was published before 2003. During the abstract screening, articles were excluded if the type of transfer device or patient safety handling/decreased injury was not mentioned. During full-text analysis articles were excluded because the type of transfer system was not mentioned, the article was an education focused or a training program. A total of 21 papers were selected from PUBMED and EMBASE/MEMLINE, and 27 additional articles were found when searching through references and researching brand named robotic PTASs via a google search.

Floor mounted transfer assist systems

Nine studies were found that included a floor-based lift within their research (Tables 1 and 2). Two observational, four quasi-experimental studies, one expert opinion, one single-subject study, and one qualitative study were found. Within four different studies, the floor-mounted lift was used as part of an intervention program to mitigate musculoskeletal injuries among healthcare workers. An overall conclusion from these articles is that the powered floor-based lifts are more beneficial than mechanical lifts or manual lifting for reducing injuries. Subjects reported lower perceived exertion when using the lift compared to manual lifting, and an increase in comfort and safety [24,26].

Ceiling vs floor transfer assist systems

Ten studies were found that included both ceiling and floor mounted lifts within their research (Table 2). Six quasi-experimental studies directly compared the lifts with each other. Four articles used both systems within their intervention and one observational study determined how safe handling equipment (i.e. floor and ceiling lifts) was used by the staff. Ceiling mounted lifts were the preferred systems over floor-based lifts due to a combination of the least amount of force required to operate, improvement in injury rates, and job satisfaction overall.

Robotic person transfer assist systems

There were six unique robotic systems identified from a total of 29 articles found in the search. Table 3 shows each emerging system, their patents, and abbreviated study results. The robotic systems predominately published design justification papers compared to user satisfaction studies. In Table 4, there are six articles marked with an asterisk to show that some studies
included a combination of design and single-subject design or qualitative testing. The HLPR Chair has 10 design papers, each describing a design iteration of the system. A mannequin was used in one study to describe kinematics and weight distribution across the system during the transfer; no human trials appear to have taken place yet. The PTAD system has three design papers describing the design and development of this system. For the latest paper, 19 volunteers were enrolled in an usability study that transferred a mannequin to simulate a dependent person transfer. Caregivers reported greater usability in favor of PTAD compared to a Hoyer lift [51].

The AgileLife NextHealth bed was referenced once in a scope review, although it is commercially available. A survey of 18 rehabilitation professionals evaluated the system in a lab setting and concluded that they prefer the AgileLife NextHealth bed to other unspecified lift devices [3]. The RIBA Robot was mentioned in eight articles, four of which included subject testing of their design concepts. The design concepts and modifications tested optimal weight distribution and positioning to ensure the person’s safety.

The SmartHoist was published in two studies involving a semi-structured interview and an updated closed-ended survey with 15, 50 and 60 participants respectively. The studies revealed that after initial feedback on design and software changes that less force was required for operation than an unspecified regular hoist; however, users were reported to be dissatisfied with SmartHoist’s two-second delay [62].

StrongArm articles have described its design attributes, stability testing, and a scoping review which included StrongArm and AgileLife NextHealth bed. The other articles included focus groups and user evaluations of the device among 20 wheelchair users and 7 caregivers. 63% of wheelchair users and 86% of caregivers were neutral or reacted positively to using the lift [65].

### Discussion

Results of the review, as displayed in Tables 1–3, revealed extensive development, usability, and effectiveness research on different person transfer systems. The overview of study strength articles per systems in Table 4 shows that floor-based and ceiling lift systems contained the highest count of quasi-experimental research compared to that of the new robotic systems on the market. Multiple designs of the floor-based lifts have been made commercially available since the original patent from 1954, developed by T. R. Hoyer [11]. This literature review revealed that 19 studies are available including ceiling and floor- mounted lifts with various user testing and comparative studies. These types of systems...
Table 2. Articles including both ceiling and floor-based lifts as an intervention/control group.

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Study Strength</th>
<th>Study Type</th>
<th>Aim</th>
<th>Participants</th>
<th>Overall outcome from results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dickinson et al. (2018) [18]</td>
<td>Observational</td>
<td>Single Cohort Repeated Measures</td>
<td>Discuss how a protocol can influence safety for critically ill patients</td>
<td>21 care units (6 intensive care)</td>
<td>Ceiling and floor lifts should be used during the bed rest, dangling or chair and ambulation with assistance phase and not during independent ambulation.</td>
</tr>
<tr>
<td>Alamgir et al. (2009) [31]</td>
<td>Observational</td>
<td>Prospective Cohort</td>
<td>Evaluating the difference in transfer time between the ceiling and floor lifts</td>
<td>119 transfers</td>
<td>Ceiling lifts require on average less time to transfer than floor lifts. Patients prefer ceiling lifts over floor lifts.</td>
</tr>
<tr>
<td>Risør et al. (2017) [32]</td>
<td>Quasi-Experimental</td>
<td>Non-Randomized Control</td>
<td>Evaluate effect intervention for patient-handling equipment</td>
<td>294 nurses, assistant or therapists</td>
<td>The use of equipment was more prevalent in the intervention group. Both groups used floor lift more frequently than ceiling lift. Ceiling lifts require lower peak hand forces and lower backload (L5/S1) during the transport phase compared to floor lifts. And caregivers prefer to use ceiling lifts.</td>
</tr>
<tr>
<td>Dutta et al. (2012) [33]</td>
<td>Quasi-Experimental</td>
<td>Crossover</td>
<td>Investigated difference in peak external forces between the ceiling and floor lift</td>
<td>21 caregivers</td>
<td>Ceiling lifts require lower peak hand forces and lower backload (L5/S1) during the transport phase compared to floor lifts. And caregivers prefer to use ceiling lifts.</td>
</tr>
<tr>
<td>Marras et al. (2009) [34]</td>
<td>Quasi-Experimental</td>
<td>Crossover</td>
<td>Investigated differences in spinal loads between the ceiling and floor lift</td>
<td>10 university students</td>
<td>Ceiling lifts show less biomechanical loading risk than floor lifts.</td>
</tr>
<tr>
<td>Rice et al. (2009) [35]</td>
<td>Quasi-Experimental</td>
<td>Crossover</td>
<td>Determine the generic characteristics of floor lifts compared with ceiling lifts regarding physical stress</td>
<td>1 male volunteer</td>
<td>Ceiling lifts require lower forces during a push, pull and particularly rotation movements compared to floor lifts.</td>
</tr>
<tr>
<td>Miller et al. (2006) [36]</td>
<td>Quasi-Experimental</td>
<td>Pre-Post Intervention</td>
<td>Determine the effectiveness of ceiling lifts on the risk of injuries in a long-term care facility</td>
<td>32 nurses</td>
<td>Ceiling lifts reduce patient handling injuries and perceived risk of injury. No significant difference in the reduction of injury risk was found between the ceiling and floor lifts. Staff prefers ceiling over floor lifts.</td>
</tr>
<tr>
<td>Nelson et al. (2006) [9]</td>
<td>Quasi-Experimental</td>
<td>Pre-Post Intervention</td>
<td>Design, implement and evaluate a multifaceted program that successfully integrates evidence-based practice, technology, and safety improvement</td>
<td>825 nurses (4 care units)</td>
<td>After the implementation of i.e. ceiling and floor lifts, improvement in injury rates, modified duty dates, job satisfaction, costs, the self-reported performance of ‘unsafe’ patient handling practices (not significant).</td>
</tr>
<tr>
<td>Darragh et al. (2013) [38]</td>
<td>Qualitative</td>
<td>Focus Group</td>
<td>Determine how safe-handling equipment is used</td>
<td>N = 35 physical/occupational therapists</td>
<td>Ceiling lifts are preferred (in comparison with floor lifts) by staff due to time, flexibility and maneuverability.</td>
</tr>
</tbody>
</table>

aParticipants operating the transfer device.
bCeiling and floor lifts are compared.
cCeiling and Floor lifts part of the intervention program.
dAuthors’ perspective.
Table 3. Robotic patient transfers assist systems.

<table>
<thead>
<tr>
<th>System</th>
<th>Type of Study</th>
<th>Study Strength</th>
<th>Study Type</th>
<th>Participants</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>HLPR-Chair [39]</td>
<td>Design</td>
<td>Stability</td>
<td>N/A</td>
<td>The dynamic stability tests showed that slipping occurs before tipping. Therefore, the chair is only designed to traverse horizontal surfaces.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Specifications and Improvements</td>
<td>N/A</td>
<td>Patient rehabilitation is enhanced through a load sensor and control on the lift actuator resulting in continuously monitoring and the amount of the participants’ weight distribution on the legs could be adjusted. Commercialization is considered.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 papers</td>
<td></td>
<td></td>
<td>Development was inexpensive, and the power source is like powerchairs. Further explanation of potential transfer and reaching capabilities is also included.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 papers</td>
<td></td>
<td></td>
<td>The PTAD includes an increased range of motion, reduces forces acting on the caregiver, and reduces transfer times. Caregivers also report usability in favor of PTAD compared to a Hoyer lift.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bostelman et al. (2008) [41–44]</td>
<td>Quasi-Experimental</td>
<td>Crossover</td>
<td>19 volunteers</td>
<td>Includes a discussion of the impedance control scheme using Redundant Sensing (RS) of both force and proximity. This significantly reduces undesirable interaction forces allowing for small external interaction forces if the operator desires.</td>
</tr>
<tr>
<td></td>
<td>Bostelman et al. (2007) [45–48]</td>
<td>Design Specifications</td>
<td>N/A</td>
<td>Needs assessment, prototype development, compliant control, and obstacle avoidance approach of the PTAD are presented. Forces less than 15 lbf are necessary to move the PTAD, required less time. Reductions of 53% in collision forces were visible in all phases with interactive feedback and remained below the ISO standards.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Humphreys et al. (2017) [50]</td>
<td>Design Specifications</td>
<td>N/A</td>
<td>The pre-prototype, system model, actuator model, control formulation and passivity analysis were shown.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Humphreys et al. (2016) [51]</td>
<td>Design &amp; Qualitative</td>
<td>Closed-Ended Survey</td>
<td>The experiment showed that a human force amplifying control with velocity coordination, has the potential to be effective, with some modifications.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Humphreys et al. (2014) [52]</td>
<td>Design Specifications</td>
<td>N/A</td>
<td>Development and design were shown. Average Participant Ratings for Tasks Completed showed more favorable results for the AgileLife compared to other transfer devices.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Humphreys et al. (2013) [53]</td>
<td>Design Specifications</td>
<td>N/A</td>
<td>A musculoskeletal model was developed based on the amount of load on the patient and body softness to determine the optimal lift up motion generation.</td>
<td></td>
</tr>
<tr>
<td>AgileLife NexHealth [54]</td>
<td>Review</td>
<td>Scoping Review</td>
<td>18 rehabilitation professionals</td>
<td>The stiffness distribution was measured to determine the optimal robot arm position to lift the patient. The developed model and estimating method are effective for comfort estimation during lift-up.</td>
<td></td>
</tr>
<tr>
<td>PTAD Patent not found</td>
<td>Single Subject</td>
<td>Mixed-Method</td>
<td>4 subjects</td>
<td>The RIBA successfully transferred the patient from the bed to the wheelchair and reverse. The lifting is considered stable lifting a maximum weight of 63 kg over a time period of 1 transfer (40 s).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design &amp; Single Subject</td>
<td>Concept design and case study</td>
<td>Mannequin and 10 adults</td>
<td>Presented design concept, basic specifications, and tactile guidance method. The RIBA can lift a patient with a weight up to 63 kg. Each lift in and out of the wheelchair took approximately 40 s.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design &amp; Single Subject</td>
<td>Concept design and testing/case study</td>
<td>10 subjects</td>
<td>The human model is successfully applied to the RIBA prototype and can hold a mannequin (max 18 kg) safely and reliably.</td>
<td></td>
</tr>
<tr>
<td>Smart Hoist Patent not found</td>
<td>Design</td>
<td>Success Rates</td>
<td>N/A</td>
<td>Presented the design, development, and implementation. Results showed that most users were able to perform complex manoeuvring tasks on their first attempt with less physical demand using the Smart Hoist. However, many participants were not comfortable with the 2-s delay within the system. The design process, user intention recognition, and navigation assistance were applied to two user trials. Based on feedback trial 1, hardware and software changes were made. The feedback of trial 2 upheld the outcomes of trial 1.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td>Updated &amp; Closed Qualitative</td>
<td>60 participants</td>
<td>Design adjustments were included. The wheelchair users agreed with the importance of the development of RATD and 63% were either neutral or agreed in using the RATD. 86% of the caregivers were either neutral or agreed in using the RATD.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design &amp; Qualitative</td>
<td>Semi-structured interview</td>
<td>Trial 1: 15 volunteers</td>
<td>Used technology, manifold control, and design review and evaluation were shown. Focus group testing showed that the main difference between caregivers and wheelchair users is the difference between focus, safety versus usability. A user evaluation was performed. Power wheelchair users were neutral (56%) or more likely (38%) and would like a transfer device that would be attached to a powered wheelchair. 56% of the participants were neutral or agreed (19%) in using the RATD. Caregiver, user and robotic controls were important features to be included in the device.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td>Focus Group</td>
<td>20 wheelchair users and 7 caregivers</td>
<td>A quasistatic stability model was created and tested. Analysis under different circumstances showed that Strong Arm could successfully transfer the whole range of motion up to 60 kg. As for the 0°–45° zone up to 90 kg.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td>Focus Group</td>
<td>16 wheelchair users</td>
<td>The hardware, software and intuitive interaction design were presented. To move Strong Arm, the user must apply intentional force on any of the given axes by surpassing the axis threshold. Unintentional movement could lead to injury.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scoping Review</td>
<td>Scoping Review</td>
<td>20 wheelchair users and 7 caregivers</td>
<td>Design adjustments were included. The wheelchair users agreed with the importance of the development of RATD and 63% were either neutral or agreed in using the RATD. 86% of the caregivers were either neutral or agreed in using the RATD.</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td>Stability Testing</td>
<td>N/A</td>
<td>A quasistatic stability model was created and tested. Analysis under different circumstances showed that Strong Arm could successfully transfer the whole range of motion up to 60 kg. As for the 0°–45° zone up to 90 kg.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td>Stability Testing</td>
<td>N/A</td>
<td>The hardware, software and intuitive interaction design were presented. To move Strong Arm, the user must apply intentional force on any of the given axes by surpassing the axis threshold. Unintentional movement could lead to injury.</td>
<td></td>
</tr>
</tbody>
</table>

N/A: not available.
have been around for a long time and are widely available to support healthcare professionals and caregivers in facilities (hospitals, clinics, rehabilitation centers, assisted and long-term care) and residential settings to individuals who require assistance with transfers. The research outcomes on floor-mounted lifts indicate a preference towards floor-mounted lifts versus manual lifting and or low-tech devices. However, ceiling-mounted lifts were favored over floor-mounted lifts. Ceiling mounted lifts require lower peak external hand forces and lower backload (L5/S1) during the transport phase, on average less time to transfer, less muscle activity and biomechanical load than floor-mounted lifts [31,33,34,37]. This review made no distinction between different types of floor-mounted lifts or ceiling lifts and while differences in their design characteristics could affect the outcomes the general level of assistance that they provide is similar across devices.

The robotic PTASs listed in Table 3 are emerging in this industry and have not had the same intensity of the type of research conducted to those of ceiling and floor-mounted lifts, but different design concepts, thus justifying their separation in the research. These emerging devices could be compared to the ceiling and floor-mounted lifts to help determine the value and decrease in caregiver and person being transferred injury risk. Currently this has not been executed nor has further studies in comparing robotic technology to standard technologies. The potential benefits of robotic technology may not be realized yet. A majority of the robotic PTASs except AgileLife NextHealth bed is still in the development phase and few quasi-experimental studies with human subjects have been published. Many developers have only tested person handling aspects with the use of a mannequin or using simulation models. Developers publish their work using the prototype code name thus only two out of the 28–29 of the robotic papers were found using the MeSH terms. One StrongArm and one RIBA paper were found. Twenty-seven articles were found due to hand search where the assumption was that these articles should have been identified through the search terms enlisted on the robotic PTASs research. This could be a possible limitation of this study.

The existing literature lacked detail on the risks and benefits of home modifications and the addition of PTAs into a user’s personal life. Though they are often welcomed, some individuals report discontent with home modification as they feel it takes away from what makes their home so personal [56]. This would suggest a psychological component to adding assistive technology in the home environment and that potentially installing a

<table>
<thead>
<tr>
<th>Transfer system</th>
<th>Scoping review</th>
<th>Design</th>
<th>Expert opinion</th>
<th>Single subject</th>
<th>Observational</th>
<th>Qualitative</th>
<th>Quasi-experimental</th>
<th>Total papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor-based lift</td>
<td>0</td>
<td>0</td>
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* / ** / *** Every asterisk stands for 1 article in which the study type is part of the design paper.
ceiling lift or requiring a floor lift would take away from the independence of one moving around in their own home. Installation costs and maintenance of such equipment may also be too expensive. Under the original Medicare Part B insurance, lifts are designated as durable medical equipment, which a user would pay 20% of the cost [57]. For systems that are potentially thousands of dollars, this may be a difficult cost to cover. Additionally, some systems, such as a Hoyer Advance, require assistance from a caregiver [3,53]. For more intimate Activities of Daily Living (ADLs), such as using the restroom or taking a bath, this may affect pride and dignity from those who desire independence [58]. Robotic technologies may introduce avenues to circumvent these barriers. The portability and foldable nature of the Strong Arm Robotic Assisted Transfer Device (RATD) for instance, would allow for increased workspace with a smaller device, thus creating a more efficient system while maintaining as much of the home environment as possible [52–55]. Future research should investigate the appeal of portable RATDs compared to standards of care in a home environment to determine the better system.

This literature review’s original intent was to focus on the engineering controls rather than administrative or work-related aspects to PTASs; however, the research throughout all articles mostly focus on these latter two areas. Research from Iwakiri et al showed no increase in lower back pain in places where a reeducation program using transfer systems was introduced, but the control group showed an increase in lower back pain [69]. Still, these results were not statistically significant. Further research should address the effort caregivers need to follow training.
protocols for various devices and which systems will be more resilient to the amount of education or training that a caregiver needs to effectively operate these devices. Further research should address comparison studies of different patient transfer assistive systems.

**Conclusion**

Comparisons among all types of PTASs are required to justify technological advancements. Future research should focus on addressing the gaps in robotic PTAS research. There has not been enough research from a person’s perspective for transfer systems. Studies with a stronger study design such as quasi-experimental studies although these would be expensive to conduct. Human subjects and comparative studies with floor-mounted or ceiling lifts need to be explored with respect to both caregiver and person injury perspective.

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