Robotics: A new paradigm in geriatric healthcare

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R. Agnihotri, S. Gaur. Robotics: A new paradigm in geriatric healthcare. Gerontechnology 2016;15(3):146-161; doi:10.4017/gt.2016.15.3.004.00 A rapid increase in the number of elderly with chronic conditions has stressed the crumbling healthcare system worldwide. Accordingly, there is an urgent need for innovations to cater for the reduced workforce in this sector. Over a decade ago robots were introduced in health care to overcome these problems. **Objectives** Robots have numerous applications in healthcare ranging from initial diagnostics to surgeries, patient monitoring, social assistance and disability limitation. Considering their widespread applications, the current review aims to provide an overview of general applications of robotics in healthcare followed by studies that investigate the role of assistive robots in maintaining the health and well-being of the elderly. **Data sources** Databases like Pubmed, Google scholar and IEEE explore were searched and studies related to the applications of assistive robots in geriatric healthcare from Jan 2011 to April 2016 were retrieved. **Study selection and data extraction** A combination of keywords like assistive robots, robotics, elderly, geriatrics, healthcare, PARO and social robots were applied to search the relevant studies. About 28 studies reporting applications of assistive robots in elderly were included. Their salient features, results and conclusions were recorded. **Results and conclusion** The identified studies reported promising applications of assistive robots for social and daily healthcare of elderly. These results were mainly based on the experimental and observational studies as well as field trials involving elderly subjects and hence cannot be generalized for the populations worldwide. There is a need for well-designed multicenter large scale studies to reliably include robotics in geriatric healthcare.

Keywords: assistive robots, robotics, elderly, geriatrics, healthcare, PARO, social robots

The demographics around the globe foresees a boom in the 'greying population', aged ≥65 years, bringing their number close to 560 million, which is more than 10 percent of the world population[1]. In Western Europe and Japan, this proportion would be around 20 and 27 percent respectively[1]. This implies that the aging population would create additional demand for health care services in 2014 and beyond[1]. This was revealed in an earlier report by the American Medical Association which concluded that *"one of the most important tasks that the medical community faces today is to prepare for the problems in caring for the elderly in the 1990s and the early 21st century"*[2,3].

According to WHO, about 110 million to 190 million i.e. 2.2 to 3.8 percent of the people above 15 years of age have significant difficulties in functioning[4]. Furthermore, the rates of disability are increasing in part due to ageing populations and an increase in chronic health conditions[4]. This requires greater workforce to meet their needs. In recent years, greater amalgamation of technology into health services has answered a few of these problems. Analogous to this, healthcare robotics has emerged as a promising field to provide accurate and cost effective health care provisions.

The Robot Institute of America defined a robot as, *"a reprogrammable, multifunctional manipulator designed to move materials, parts, tools or other specialized devices through various programmed motions for the performance* of a variety of tasks[3]." This definition is more apt for *"industrial robots"*[5].

In healthcare, the robots have been widely used in diagnostics, surgeries, cognitive therapy, postoperative care and rehabilitation. A variant of these are the assistive robots, which function both as rehabilitation and assistive social robots[6]. The latter has been classified into the service and the companion types[6]. The service robots support independent living of elderly by helping in activities of daily needs like eating, bathing, toileting, dressing, mobility and household functions, for example, the nursebot. On the other hand, the companion robots are communicative and promote health and psychological well-being of elderly. The most widely investigated robot in this category is the pet type seal robot, PARO. Some other assistive robots include Vgo, Care-o-bot, RIBA, NAO, AIBO, Leonardo, iCat and Nadine. Since the assistive robots are widely involved in healthcare of elderly, the current review aims to provide first an overview of general applications of robotics in healthcare followed by studies that investigate the role of assistive social robots i.e. service and companion types in health and well-being of the elderly.

ROBOTICS IN HEALTHCARE

Robots are an integral part of healthcare where their applications range from initial diagnosis to minimally invasive and accurate telerobotic surgeries, intervention and therapeutic tools for behavioral disorders, disability limitation and rehabilitation. In 2008, a workshop entitled 'Research Roadmap for Medical and Healthcare Robotics' gave a comprehensive classification of healthcare robotics[7].

Medical diagnostics

The robots have made medical diagnostic tools less invasive and more accurate. They have been incorporated with magnetic resonance imaging (MRI), computed tomography (CT), fluoroscopy and ultrasound imaging devices. Examples of these include AcuBot for active needle insertion under CT or fluoroscopy, the B-Rob system for needle placement using CT or ultrasound, the INNOMOTION for MRI and CT interventions, and the MRBot for MRI procedures[8]. Lately, a robotic capsular endoscope was developed for diagnosis in gastrointestinal tract.

In addition to these, robotic pills have been introduced which may be helpful in early screening[9]. These pills, also called, the 'indigestibles' are of the size of sand grain[9]. They transmit the health data directly to a smart phone and ultimately to the patient's physician and related medical authorities. They were approved by FDA in 2012.

Telerobotic surgery

The initial concept of robotics in surgeries was developed in late 1980s by the National Aeronautics and Space Centre (NASA) and Stanford Research Institute[10]. This was followed by the development of robotic systems like the Zeus (Computer Motion, Goleta, CA, USA) and the da Vinci robots (Intuitive Surgery, Mountain View, CA, USA) in the 1990s[10]. Both of them had remote manipulators that were controlled from a surgical workstation.

Currently, the da Vinci robot is the most widely used telerobotic system. It was permitted for laparoscopy procedure by the United States Food and Drug Administration (FDA) in the year 2000[10]. Later, it got approval for cardiac, gynaecological, urological, colorectal, general, head, neck and thoracic surgeries. Its advantages were better ergonomics, clarity of vision and real time control of the robotic system. Another related system is the Robodoc, developed for advanced orthopaedic hip surgeries[11]. These surgical robots are precise, durable and enable automation of the tasks. Furthermore, they help in preoperative planning, surgical training, intra-operative navigation (image guided surgery) and surgical simulation. Various robotic systems used in different surgical fields are overviewed in *Table1*[11-24].

In general, presence of co-morbidities like hypertension, peripheral vascular diseases, diabetes, chronic pulmonary disease, arthritis and neurological conditions complicates the surgical treatments in elderly[25]. Robotic surgeries may be an alternative in such cases as they are minimally invasive, reduce the perioperative blood loss, need for blood transfusions, postoperative pain, complications, recovery time and hospital stay[26]. This was even reported in a recent meta-analysis where the clinical safety and efficacy of robotic right colectomy (RRC) was compared to conventional laparoscopy[27]. Similar results were revealed in some other studies[28-31]. Although they did not intend to evaluate the telerobotic surgeries in elderly, most of them incorporated subjects aged ≥55 years and considered robotics as a safe option for them. However, they suggested a few drawbacks like need for greater user training and practice, advanced medical equipment and elevated cost not covered under the national health insurance[32].

Social assistance

Patients with cognitive and social disorders (e.g., autism, stroke, brain injuries, dementia and Alzheimer's disease) often require lifelong multicentre therapy[7]. Their recovery is highly dependent on repeated practice. This requires continuous reinforcement and longer duration of cognitive therapies, which are tedious and expensive when provided by human therapists[7].

Dementia in elderly is a significant public health issue worldwide. A systematic review suggested that stimulation therapy was an effective tool for optimizing cognitive function in older adults with mild to moderate dementia[33]. It reduced depression and improved their quality of life[34,35]. However, the greatest challenge was in stimulating these olds to respond and participate in such activities[34,36]. Lack of manpower was another limitation to effective utilization of such programs. This may be overcome by Socially Assistive Robots (SAR), which have infused new hopes in management of these subjects[33,37]. They assist the users through social interactions, which influence the inherent human tendency to engage with lifelike social behavior[7]. They even monitor, motivate, encourage and sustain the user activities and enhance their performances.

Table 1. Telerobotic surgery

Surgical branch	Type of surgery	Robotic system used	Year of use	Current status
Neurosurgery	BRAIN SURGERY	-Industrial robot	1985	Discontinued
	-Brain biopsies	-Minerva robot[12]	1991	Discontinued
	-Deep brain stimulation	-Neuromate[13]	2014	FDA approved
	-Stereotactic electroencephalography	-Pathfinder robot[14]	2004	FDA approved
	-Transcranial magnetic stimulation			
	-Radiosurgery			
	-Neuroendoscopy			
	SPINAL SURGERY	-Renaissance[15]	2011	FDA approved
	-Deformity corrections,			
	-Biopsies			
	-Minimally invasive			
	-Surgeries			
	-Electrode placement procedures			
Orthopedics	-Bone resection	-Robodoc[11]	1998, 2009	FDA approved
	-Hip and knee replacements or resurfacing	-CASPAR[16]	1997	Discontinued
		-RIO robotic arm[17]	2008	FDA approved
Gynecology	-Laproscopy	-The Zeus system[10]	2001	Discontinued
		-da Vinci[10]	2000	FDA approved
		-Telelap ALF-X system[18]	2011	
Cardiology	-Mitral valve repair	-The Sensei X system[19]	2007	FDA approved
	-Atrial fibrillation surgery	-The Niobe[20]	2008	FDA approved
	-Coronary revascularization	-da Vinci[21]	2000	FDA approved
	-Left ventricular lead placement			
	-congenital heart disease			
Oncology	-Radiotherapy for tumours	-The CyberKnife[22]	1999	FDA approved
		-TrueBeam STx[23]	2000	FDA approved
Urology	-Radical prostatectomy	-da Vinci[24]	2000	FDA approved

The most widely studied SAR is the pet like robot or PARO[33,38,39,40]. It was designed by Shibata et al in 2003. Since then it has shown successful results in many countries including Japan[41-44]. In 2009, it was certified as a type of neurological therapeutic device by the FDA[45].

Physical rehabilitation and mobility assistance

Currently, rehabilitation of subjects with neuromuscular injuries, diseases or stroke is one of the most challenging tasks. The neuro-rehabilitation is often expensive, complicated and time consuming. Similarly, the prosthetic rehabilitation of subjects with reduced or lost function of limbs is difficult due to the enormous size of the prostheses and exoskeletons.

Neurological disorders like Parkinson's disease hamper the mobility and independence of the elderly. Some intelligent devices like wheelchairs, interactive walkers and self-stabilizing guide canes have been introduced to help them[46]. They not only make them self-reliant but also improve their quality of life indirectly by reducing social isolation and depression.

Incorporation of robots for rehabilitation and post-operative recovery can have several advantages like provision for untiring, consistent, lengthy and personalized therapy; objective quantification of recovery data; and implementation of therapeutic exercises not possible by a human therapist[47].

The robotic prostheses and exoskeletons provide greater dexterity, natural mobility and a sense of touch to missing or paralyzed limbs. In fact some of these are 'haptic devices' not required to be worn by the patient but can replicate its biological functions precisely[47]. Some of the common intelligent prostheses utilizing robotic systems are mentioned in *Table 2*[48-52].

The robotic exoskeletons have even been utilized for restoring the lost gait in subjects with Parkinson's disease[53]. They help in motor coordination through carefully directed repetitive movements. These exoskeletons are similar to the joint system of the human body. They utilize 'joint trajectories' of the entire gait cycle and offer a uniform stiff control along this trajectory[51]. Their beneficial role in electromechanical gait training was supported in a Cochrane review as well[54].

Other applications in health care

Besides the above applications, robots have been widely incorporated in the hospital set ups to assist the medical and paramedical staff. They help in lifting the patients, bedside rounds as well as medication management.

Table 2. Robotic systems used in healthcare

Robot support		**Robot**[reference]
Prostheses	Upper limbs	-MIT-MANUS[47]
		-PUMA (MIME)[47]
		-PHANTOM[47]
		-WAM[47]
	Lower limbs	-Lokomat[47]
		-Lokohelp
		-LOPES
Self-feeding		-Secom's My spoon[62]
		-KNRC[62]
Behavioral therapy		-PARO[33]
		-KASPAR[37]
		-MUU[37]
		-FACE [37]
Physical therapy		-NEUROBike[48]
Mobility assistance		-SmartCane[46]
		-GuideCane[46]
		-Smart Walkers[46]
		-JAIST active robotic walker[49]
		-Nav Chair[50]
		-Re-Walk[51]
		-RIBA[52]
		-HAWK
		-Topio Dio
		-Carnegie Mellon University's robotic walker

Robotic nurses

Robotic nurses like nursebot and Terapio may help in relieving the nurses from tasks like collecting patient data and vital signs. The 'Terapio' was developed from researchers at Toyohashi University of Technology, Japan[55]. It maintains electronic medical records, which reduces the time required for their retrieval. The patient records, history and medications are available instantly on the robot's display[55]. It even recognizes any allergies and potentially dangerous drug interactions for a patient. Besides, when not in use, the display can convey emotions to the subject by changing the shape of the eyes.

Another robot for Interactive Body Assistance or RIBA, helps in gently lifting the patients into or out of bed or wheelchair, or moves them from a sitting position to standing[52].

A new robot, the Veebot, helps in drawing blood and inserting intravenous injections[52,56]. It utilizes an infrared light to locate the vein and an ultrasound to analyse the blood flow for efficient withdrawal. It takes a minute for Veebot to perform this task with about 83% accuracy[56].

The HOSPI-R, (from Panasonic) is a delivery robot, which can transport samples and drugs. It navigates with the help of sensors and can climb the elevators. It can deviate from its path when encountered by an obstacle[57]. Some other examples of robotic nurses include, the 'Dr Robot', by InTouch; Robotic Nursing Assistant or RONA, by Hstar technologies[58]. They all help in lifting and moving patients, transporting supplies and in providing two-way communication[59].

Robotic telerounds

The most important aspect of in-patient care in hospitals is the bedside rounds conducted by the physicians[60]. These are essential for ensuring optimum recovery of the patient as determined by the subjective (e.g. history and physical examination) and objective (e.g. vital signs and laboratory values) clinical signs.

Lately, videoconferencing (telerounding) has been introduced as an adjunct to regular bedside rounds[60]. Although, it has shown positive outcomes, the only concern is that remote presence of physician during the postoperative period could delay the identification of the complications and reduce patient's satisfaction. This issue was addressed in a study on 270 patients (mean age 53.5 years) at three academic institutions[60]. The patient's randomly received traditional bedside rounds or robotic telerounds. The robot used was a 60-inch-tall wheel-driven device[60]. The physician connected remotely to the robot via a base station. The study did not report any differences in morbidity rates, length of stay and patient satisfaction between the two groups. The robotic telerounds matched the performance of standard bedside rounds. There were no missed or increased postoperative complications. However, the authors cautioned that this system was not evaluated on patients with slow recovery or where patients demanded physical presence of the physician[60]. Hence, it could not be considered as an absolute replacement for bedside rounds. However, such a system if in practice could reduce the physician workload.

Daily needs and medication management

As already stated, the increasing prevalence of disability or chronic illness in elderly often reduces their ability to perform one or more daily self-care tasks. The routine activities of an individual may be subdivided into three classes namely: self-maintenance, instrumental and enhanced activities[61]. Even though the robotic assistance is available for all these categories, they are not equally accepted by the seniors. This was revealed in a recent work on 21 independently living old Americans (aged 65-93 years) who were questioned about their preferences and attitudes towards robotic assistance for 121 daily tasks. They were shown a video of a personal robot-2 (PR-2) performing various errands[61]. The study reported that although the elderly preferred robotic assistance for tasks related to instrumental and enhanced activities of daily living they were reluctant in accepting the machines for self-maintaining daily needs like grooming[61]. Besides, robots have been developed which help in feeding individuals with reduced mobility of upper limbs[62]. They wait for the user's instructions for food selection, pick up the bite size food and bring it gently to the mouth. Amongst the various types in this category, the Korean National Rehabilitation Center (KNRC) and Secom's My spoon have been widely investigated in their ability to feed different types of foods. A recent study showed assuring results with the KNRC self- feeding robot. The users were highly satisfied with its performance specifically when they ate Korean food, including the sticky rice[62]. The My Spoon self-feeding robot is also very popular.

ROBOTICS IN GERIATRIC HEALTHCARE

As stated earlier, the older adults usually require health and social support services to attain an optimum level of physical, psychological and social functioning. Currently, the elderly prefer to be independent but are often hampered due to their physical or cognitive disabilities. A recent study on Japanese elderly (aged≥ 65 years) showed that out of 1550 olds, 311 had some form of disability (prevalence 20.1%)[63]. The prevalence increased with age and doubled with every 5-year increment in age. It was highest in women aged ≥85 years. Among the various causes for functional disability, dementia accounted for 23.5%, stroke for 24.7%, orthopaedic disease for 12.9%, and other disease for 38.9% of cases in men; in women, the respective values were 35.8%, 9.3%, 31.0%, and 23.9%. Regarding age, dementia was the most frequent cause of disability in subjects aged 75 years or older, whereas stroke was most common in subjects aged 65 to 74 years[63].

Similarly, the disability index is also increasing globally and aging is one of the causes[4]. The elderly need external care to overcome their disabilities. But currently it is extremely difficult and expensive to achieve this due to the reduced workforce[64]. At this point SAR's may be helpful in promoting ageing-in-place and facilitating independent living in one's own home as long as possible. The following section deals with the scientific evidence on the role of SAR's in geriatric healthcare specifically in relation to social support and activities of daily needs.

Methodology

A systematic search of Pubmed, Google Scholar and IEEE libraries was performed for records through January 2011 to April 2016 to identify studies, which aimed to assess the effects of assistive robots on elderly health. A combination of the following keywords- assistive robots, robotics, elderly, geriatrics, healthcare, PARO and social robots were used to search these databases. This ensured that all the studies reporting applications of assistive robots in elderly healthcare were included. The search was restricted to publications in English language only. All the researchers independently screened the initial set of results. The inclusion criteria were studies reporting applications of robots in older adults aged ≥55 years.

The first step of data collection resulted in 410 studies. In the second step, after excluding the systematic reviews, overviews, non-human experiments or studies involving younger subjects, 59 studies were selected. Lastly 28 studies were included after a thorough discussion between the researchers.

Results

There were 28 citations, 16 on social support and 12 reporting the role of SAR's in assisting elderly with activities of daily need. For each study, their aim, salient features, type of robot, country, whether the study was on independent or institutionalized elderly, their results and conclusions were recorded. Further, whether the robotic therapy had a positive, negative or neutral outcome was also noted. Some of these studies utilized questionnaires before and after contact with the robot to evaluate its effectiveness[65,66,67]. The results from these studies may be grouped under two categories:

Enhancing social interactions

About 16 studies evaluated the role of SAR's on either the companionship, loneliness, mood, cognitive activity or speech of the elderly (*Appendix A*)[65,68-82]. They utilized the robots like PARO, Matilda, Giraff and Brian 2.1 in their research, which was mainly on institutionalized elderly. They reported positive outcomes on social interaction, communication and mood of the subjects before and after treatment with SAR's,

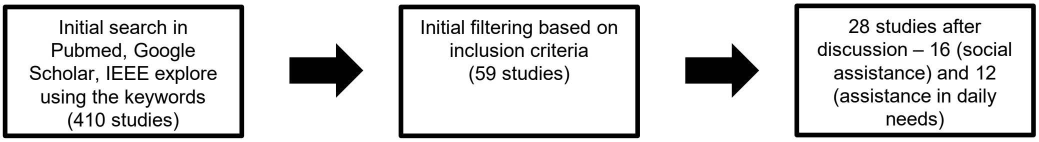

Figure 1. Methodology for selecting studies for systematic review on role of assistive social robots in supporting the social wellbeing and activities of daily needs of older adults

specifically the PARO[68-70,72]. The communication between the residents was primarily about the robot. One study reported improvement in the blood pressure of the residents following PARO therapy[71].

Supporting daily activities
About 12 studies reporting the role of assistive robots in elderly with disability were reviewed (*Appendix B*)[83-94]. The robots included in these studies were HOBBIT, PARO, iRobi, Charlie, Guide robot, Cafero touchscreen robot, Brian 2.1 as well as robotic smart walkers and medicine dispensers. The subjects mainly suffered from conditions like stroke, dementia or ageing only, which hampered their ability to perform routine activities. Most of these studies revealed positive effects of robotic therapy specifically in relation to medication administration and lifting objects[83,84,87,88]. However, few studies even reported reluctance of subjects in accepting the services from these robots[86,89,91].

Although these studies revealed a positive impact of robotics in elderly care, their results cannot be generalized as they lacked uniformity in study design. The majority of these studies involved institutionalized elderly and their sample size was small. Moreover, their response in home environment cannot be evaluated, although one study reported a positive outcome at home[83].

In order to further strengthen the evidence on the positive aspects of robotics for geriatric healthcare, there is a need for further well-designed multicentre controlled trials involving elderly in real home environments. Besides, there are some other challenges related to the widespread adoption of robots in geriatric healthcare, which are discussed in the following section.

Challenges in geriatric healthcare

Designing robots for elderly care is challenging, as there is a complete change of scenarios i.e. from laboratories and industrial settings to the real environment where they have to interact with the users. The factors governing the acceptance of robots may be classified into two categories namely, human and robot related factors. While the former includes age, gender, prior experience with technology and robots, level of education and staff role, the latter is mainly related to the robots' appearance i.e. whether it is human like or machine like and the degree of adaptability of the robot to users' needs. Furthermore, human robot interaction (HRI) is currently the most important feature of socially assistive robots determining their acceptance in real environments. It consists of three phases namely, understanding the psychology of HRI, algorithms for affective computing for driving the HRI such as gaze tracking or face tracking and lastly the software engineering and programming language technologies for implementing the HRI design. For instance, males have more positive attitude towards robots as compared to the females.

Robots are expected to maintain an appropriate spatial distance to people and respect their personal and social spaces[95]. In order to engage in social interactions, the robot needs to be aware of human presence, detect the willingness of humans to interact, and determine and learn appropriate personal space ranges for various users. They should be able to learn from us or teach us, as well as to communicate and understand us.

Another important challenge is to build inherently safe robots that are easy to operate and affordable to a large segment of the population, as well as endorsed by education, health care, and elder care experts[95]. The ultimate goal of this technology is the creation of systems capable of helping people recover, train and learn.

CONCLUSION

Robots are an integral part of healthcare systems worldwide. Various studies have reported positive reactions of elderly to assistive social robots. However, this area of research is still in its infancy but time is not far when they would be widely used in hospitals, schools and homes to monitor, encourage and assist the olds across the globe.

References

1. Deloitte. 2014 Global health care outlook shared challenges, shared opportunities. 2014; https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Life-Sciences-Health-Care/dttl-lshc-2014-global-health-care-sector-report.pdf ; retrieved October 12, 2015
2. Council on Scientific Affairs. American medical association white paper on elderly health. Report of the council on scientific affairs. Archives of Internal Medicine 1990;150(12):2459-2472; doi:10.1001/archinte.1990.00390230019004
3. Fried LP, Ferrucci L, Darer J, Williamson JD, Anderson G. Untangling the concepts of disability, frailty, and comorbidity: implications for improved targeting and care. Journals of Gerontology. Series A 2004;59(3):255-263; doi:10.1093/ ultic/59.3.M255
4. Disability and Health. World health organization. 2015; www.who.int/mediacentre/factsheets/fs352/en/; retrieved May 9, 2016
5. Kumar V, Bekey G, Zheng Y. Industrial, Personal, and Service Robots. In: Bekey G, Ambrose R, Kumar V, Lavery S, Sanderson A, Wilcox B, Yuh J, Zheng Y, editors. Robotics: State of the art and future challenges, 1st edition. London: Imperial

College Press, 2008; pp 55-62

6. Broekens J, Heerink M, Rosendal H. Assistive social robots in elderly care: a review. Gerontechnology 2009;8(2):94-103; doi:10.4017/gt.2009.08.02.002.00
7. Mataric M, Okamura AM, Christensen H, editors. A Research Roadmap for Medical and Healthcare Robotics. Arlington; 2008; http://bdml.stanford.edu/twiki/pub/Haptics/HapticsLiterature/CCC-medical-healthcare-v7; retrieved October 12, 2015
8. Cleary K, Melzer A, Watson V, Kronreif G, Stoianovici D. Interventional robotic systems: Applications and technology state-of-the-art. Minimally Invasive Therapy and Allied Technologies 2006;15(2):101-113; doi:10.1080/13645700600674179
9. Menciassi A, Quirini M, Dario P. Microrobotics for future gastrointestinal endoscopy. Minimally Invasive Therapy and Allied Technologies 2007;16(2):91-100; doi:10.1080/13645700701266982
10. Schreuder HW, Verheijen RH. Robotic surgery. BJOG : An international journal of Obstetrics and Gynaecology 2009;116(2):198-213; doi:10.1111/j.1471-0528.2008.02038.x
11. Spencer EH. The ROBODOC clinical trial: a robotic assistant for total hip arthroplasty. Orthopedic Nursing 1996;15(1):9-14
12. Glauser D, Fankhauser H, Epitaux M, Hefti JL, Jaccottet A. Neurosurgical robot Minerva: first results and current developments. Journal of Image Guided Surgery 1995;1(5):266-272
13. Kajita Y, Nakatsubo D, Kataoka H, Nagai T, Nakura T, Wakabayashi T. Installation of a Neuromate Robot for Stereotactic Surgery: Efforts to Conform to Japanese Specifications and an Approach for Clinical Use-Technical Notes. Neurologia Medico Chirurgica (Tokyo) 2015;55(12):907-914; doi:10.2176/nmc.tn.2015-0043
14. Eljamel MS. Robotic neurological surgery applications: accuracy and consistency or pure fantasy? Stereotactic and Functional Neurosurgery 2009;87(2):88-93; doi:10.1159/000202974
15. Kuo KL, Su YF, Wu CH, Tsai CY, Chang CH, Lin CL,Tsai TH . Assessing the Intraoperative Accuracy of Pedicle Screw Placement by Using a Bone-Mounted Miniature Robot System through Secondary Registration. PLoS One 2016;11(4); doi:10.1371/journal.pone.0153235 (online)
16. Siebert W, Mai S, Kober R, Heeckt PF. Technique and first clinical results of robot-assisted total knee replacement. The Knee 2002;9(3):173-180
17. Sugano N. Computer-Assisted Orthopaedic Surgery and Robotic Surgery in Total Hip Arthroplasty. Clinics in Orthopedic Surgery 2013;5(1):1-9; doi:10.4055/cios.2013.5.1.1
18. Gueli Alletti S, Rossitto C, Fanfani F, Fagotti A, Costantini B, Gidaro S, Monterossi G, Selvaggi L, Scambia G. Telelap Alf-X-Assisted Laparoscopy for Ovarian Cyst Enucleation: Report of the First 10 Cases. Journal of Minimally Invasive Gynecology 2015;22(6):1079-1083; doi:10.1016/j.jmig.2015.05.007
19. Ruiter QM de, Moll FL, Herwaarden JA van. Current state in tracking and robotic navigation systems for application in endovascular aortic aneurysm repair. Journal of Vascular Surgery 2015;61(1):256-264; doi:10.1016/j.jvs.2014.08.069
20. Carpi F, Pappone C. Stereotaxis Niobe magnetic navigation system for endocardial catheter ablation and gastrointestinal capsule endoscopy. Expert Review of Medical Devices 2009;6(5):487-498; doi:10.1586/erd.09.32
21. Yoo JS, Kim JB, Jung SH, Kim DH, Choo SJ, Chung CH, Lee JW. Mitral durability after robotic mitral valve repair: analysis of 200 consecutive mitral regurgitation repairs. The Journal of Thoracic and Cardiovascular Surgery 2014;148(6):2773-2779; doi:10.1016/j.jtcvs.2014.07.054
22. Zhang H, Zhao G, Djajaputra D, Xie Y. Determination of acquisition frequency for intrafractional motion of pancreas in CyberKnife radiotherapy. The Scientific World Journal 2014; doi:10.1155/2014/408019 (online)
23. Kielar KN, Mok E, Hsu A, Wang L, Luxton G. Verification of dosimetric accuracy on the TrueBeam STx: rounded leaf effect of the high definition MLC. Medical Physics 2012;39(10):6360-6371; doi:10.1118/1.4752444
24. Wexner SD, Bergamaschi R, Lacy A, Udo J, Brölmann H, Kennedy RH, John H. The current status of robotic pelvic surgery: results of a multinational interdisciplinary consensus conference. Surgical Endoscopy 2009;23(2):438-443; doi:10.1007/s00464-008-0202-8
25. Vasdev N, Poon AS, Gowrie-Mohan S, Lane T, Boustead G, Hanbury D, Adshead JM. The physiologic and anesthetic considerations in elderly patients undergoing robotic renal surgery. Reviews in Urology 2014;16(1):1-9
26. Chiu LH, Chen CH, Tu PC, Chang CW, Yen YK, Liu WM. Comparison of robotic surgery and laparoscopy to perform total hysterectomy with pelvic adhesions or large uterus. Journal of Minimal Access Surgery 2015;11(1): 87-93; doi:10.4103/0972-9941.147718
27. Xu H, Li J, Sun Y, Li Z, Zhen Y, Wang B, Xu Z. Robotic versus laparoscopic right colectomy: a meta-analysis. World Journal of Surgical Oncology 2014; doi:10.1186/1477-7819-12-274 (online)
28. Nakamura H, Suda T, Ikeda N, Okada M, Date H, Oda M, Iwasaki A. Initial results of robot-assisted thoracoscopic surgery in Japan. General Thoracic and Cardiovascular Surgery 2014;62(12):720-725; doi:10.1007/s11748-014-0441-7
29. Breitenstein S, Nocito A, Puhan M, Held U, Weber M, Clavien PA. Robotic-assisted versus laparoscopic cholecystectomy: outcome and cost analyses of a case-matched control study. Annals of Surgery 2008;247(6):987-993; doi:10.1097/SLA.0b013e318172501f
30. Hoog DE de, Heemskerk J, Nieman FH, Gemert WG van, Baeten CG, Bouvy ND. Recurrence and functional results after open versus conventional laparoscopic versus robot-assisted laparoscopic rectopexy for rectal prolapse: a case-control

study. International Journal of Colorectal Disease 2009;24(10):1201-1206; doi:10.1007/s00384-009-0766-3

31. Sarlos D, Kots L, Stevanovic N, Schaer G. Robotic hysterectomy versus conventional laparoscopic hysterectomy: outcome and cost analyses of a matched case-control study. European Journal of Obstetrics, Gynaecology, and Reproductive Biology 2010;150(1):92-96; doi:10.1016/j.ejogrb.2010.02.012
32. Nishimura K. Current status of robotic surgery in Japan. Korean Journal of Urology 2015;56(3):170-178; doi:10.4111/kju.2015.56.3.170
33. Yuill N, Hollis V. A systematic review of cognitive stimulation therapy for older adults with mild to moderate dementia: an occupational therapy perspective. Occupational Therapy International 2011;18(4):163-186; doi:10.1002/oti.315
34. Yu R, Hui E, Lee J, Poon D, Ng A, Sit K, Ip K, Yeung F, Wong M, Shibata T, Woo J. Use of a Therapeutic, Socially Assistive Pet Robot (PARO) in improving mood and stimulating social interaction and communication for people with dementia: study protocol for a randomized controlled trial. JMIR Research Protocols 2015;4(2); doi:10.2196/resprot.4189 (online)
35. Leung P, Orrell M, Orgeta V. Social support group interventions in people with dementia and mild cognitive impairment: a systematic review of the literature. International Journal of Geriatric Psychiatry 2015;30(1):1-9; doi:10.1002/gps.4166
36. Kwok T, Ho D, Chan G, Ip I, Wong B, Ho F. Evaluation of day care services for demented clients in Hong Kong. Asian Journal of Gerontology and Geriatrics 2014;9(1); http://ajgg.org/AJGG/V9N1/2013-163-OA.pdf; retrieved December 30, 2015
37. Scassellati B, Admoni H, Matarić M. Robots for use in autism research. Annual Review of Biomedical Engeenering 2012;14:275-294; doi:10.1146/annurev-bioeng-071811-150036
38. Flandorfer P. Population ageing and socially assistive robots for elderly persons: the importance of socio demographic factors for user acceptance. International Journal of Population Research 2012; doi:10.1155/2012/829835 (online)
39. Shibata T, Mitsui T, Wada K, Touda A, Kumasaka T, Tagami K, Taniel K. Mental commit robot and its application to therapy of children. In: Proceedings of the IEEE/ASME International Conference on Advanced Intelligent Mechatronics 2001; pp 1053-1058; doi:10.1109/AIM.2001.936838
40. Takayanagi K, Kirita T, Shibata T. Comparison of verbal and emotional responses of elderly people with mild/moderate dementia and those with severe dementia in responses to seal robot, PARO. Frontiers in Aging Neuroscience 2014; doi:10.3389/fnagi.2014.00257 (online)
41. Hansen ST, Andersen HJ, Bak T. Practical evaluation of robots for elderly in Denmark – an overview. In: Proceedings of the 5th ACM/IEEE International Conference on Human-Robot Interaction (HRI) 2010; pp 149-150; doi:10.1109/HRI.2010.5453220
42. Roger K, Guse L, Mordoch E, Osterreicher A. Social commitment robots and dementia. Canadian Journal on Aging 2012;31(1):87-94; doi:10.1017/S0714980811000663
43. Marti P, Bacigalupo M, Giusti L, Mennecozzi C, Shibata T. Socially assistive robotics in the treatment of behavioural and psychological symptoms of dementia. In: Proceedings of the first IEEE/RAS-EMBS International Conference on Biomedical Robotics and Biomechatronics 2006; pp 483-488; doi:10.1109/BIOROB.2006.1639135
44. Kidd CD, Taggart W, Turkle S. A sociable robot to encourage social interaction among the elderly. In: Proceedings IEEE International Conference on Robotics and Automation 2006; pp 3972-3976; doi:10.1109/ROBOT.2006.1642311
45. Shibata T. Therapeutic seal robot as biofeedback medical device: qualitative and quantitative evaluations of robot therapy in dementia care. In: Proceedings of the IEEE 2012; pp 2527-2538; doi:10.1109/JPROC.2012.2200559
46. Martins MM, Santos CP, Frizera-Neto A, Ceres R. Assistive mobility devices focusing on Smart Walkers: Classification and review. Robotics and Autonomous Systems 2012;60(4):548-562; doi:10.1016/j.robot.2011.11.015
47. Dellon B, Matsuoka Y. Prosthetics, exoskeletons, and rehabilitation (Grand Challenges of robotics). IEEE Robotics and Automation Magazine 2007;14(1); doi:10.1109/mra.2007.339622 (online)
48. Monaco V, Galardi G, Coscia M, Martelli D, Micera S. Design and evaluation of NEUROBike: a neurorehabilitative platform for bedridden post-stroke patients. IEEE Transactions on Neural Systems and Rehabilitation Engineering 2012;20(6):845-852; doi:10.1109/TNSRE.2012.2212914
49. Lee G, Ohnuma T, Chong NY. Design and control of JAIST active robotic walker. Intelligent Service Robotics 2010;3(3):125-135; doi:10.1007/s11370-010-0064-5
50. Simpson RC,Levine SP. Automatic adaptation in the NavChair Assistive Wheelchair Navigation System. IEEE Transactions on Rehabilitation Engineering 1999;7(4):452-463
51. Sale P, Franceschini M, Waldner A, Hesse S. Use of the robot assisted gait therapy in rehabilitation of patients with stroke and spinal cord injury. European Journal of Physical and Rehabilitation Medicine 2012;48(1):111-121
52. Jeelani S, Dany A, Anand B, Vandana S, Maheswaran T, Rajkumar E. Robotics and medicine: A scientific rainbow in hospital. Journal of Pharmacy and Bioallied Sciences 2015;7(Suppl2):S381-383; doi:10.4103/0975-7406.163460
53. Sale P, De Pandis MF, Le Pera D, Sova I, Cimolin V, Ancillao A, Albertini G, Galli M, Stocchi F, Franceschini M. Robot-assisted walking training for individuals with Parkinson's disease: a pilot randomized controlled trial. BMC Neurology 2013;13; doi:10.1186/1471-2377-13-50 (online)
54. Mehrholz J, Werner C, Kugler J, Pohl M. Electromechanical-assisted training for walking after

stroke. The Cochrane Database of Systematic Reviews 2007;4; doi:10.1002/14651858.CD006185 (online)
55. Kremen R. Nursing robot designed to assist on hospital rounds. Robot Magazine 2015; www.botmag.com/nursing-robot-designed-to-assist-on-hospital-rounds/; retrieved December 20, 2015
56. Perry TS. Profile: Veebot- making a robot that can draw blood faster and more safely than a human can. IEEE Spectrum 2013; http://spectrum ieee.org/robotics/medical-robots/profile-veebot; retrieved December 22, 2015
57. Falconer J. HOSPI-R drug delivery robot frees nurses to do more important work. Gizmag 2013; http://www.gizmag.com/panasonic-hospi-r-delivery-robot/29565/; retrieved December 25, 2015
58. Mahoney DF. The aging nurse workforce and technology. Gerontechnology 2011;10(1):13-25; doi:10.4017/gt.2011.10.01.003.00
59. Cousein E, Mareville J, Lerooy A, Caillau A, Labreuche J, Dambre D, Odou P, Bonte JP, Puisieux F, Decaudin B, Coupé P. Effect of automated drug distribution systems on medication error rates in a short-stay geriatric unit. Journal of Evaluation in Clinical Practice 2014;20(5):678-684; doi:10.1111/jep.12202
60. Ellison LM, Nguyen M, Fabrizio MD, Soh A, Permpongkosol S, Kavoussi LR. Postoperative robotic telerounding: a multicentre randomized assessment of patient outcomes and satisfaction. Archives of Surgery 2007;142(12):1177-1181; doi:10.1001/archsurg.142.12.1177
61. Smarr CA, Mitzner TL, Beer JM, Prakash A, Chen TL, Kemp CC, Rogers WA. Domestic Robots for Older Adults: Attitudes, Preferences, and Potential. International Journal of Social Robotics 2014;6(2):229-247; doi:10.1007/s12369-013-0220-0
62. Buckwalter KC, Wakefield BJ, Hanna B, Lehmann J. New technology for medication adherence: electronically managed medication dispensing system. Journal of Gerontological Nursing 2004;30(7):5-8; doi:10.3928/0098-9134-20040701-04
63. Yoshida D, Ninomiya T, Doi Y, Hata J, Fukuhara M, Ikeda F, Mukai N, Kiyohara Y. Prevalence and causes of functional disability in an elderly general population of Japanese: the Hisayama study. Journal of Epidemiology 2012;22(3):222-229; doi:10.2188/jea.JE20110083
64. Patel S, Park H, Bonato P, Chan L, Rodgers M. A review of wearable sensors and systems with application in rehabilitation. Journal of NeuroEngineering and Rehabilitation 2012; 9; doi:10.1186/1743-0003-9-21 (online)
65. Thodberg K, Sørensen LU, Videbech PB, Poulsen PH, Houbak B, Damgaard V, Keseler I, Edwards D, Christensen JW. Behavioral Responses of Nursing Home Residents to Visits From a Person with a Dog, a Robot Seal or a Toy Cat. Anthrozoös 2016; 29; doi:10.1080/08927936.2015.1089011 (online)
66. Louie WYG, McColl D, Nejat G. Playing a memory game with a socially assistive robot: A case study at a long-term care facility. In: Proceedings of the IEEE RO-MAN: The 21st IEEE International Symposium on Robot and Human Interactive Communication 2012; pp 345-350; doi:10.1109/ROMAN.2012.6343777
67. McGlynn SA, Kemple SC, Mitzner TL, King CH, Rogers WA. Understanding older adults' perceptions of usefulness for the PARO robot. In: Proceedings of the Human factors and ergonomics society annual meeting 2014; pp 1914-1918; doi:10.1177/1541931214581400
68. Valentí Soler M, Agüera-Ortiz L, Olazarán Rodríguez J, Mendoza Rebolledo C, Pérez Muñoz A, Rodríguez Pérez I, Osa Ruiz E, Barrios Sánchez A,Herrero Cano V, Carrasco Chillón L, Felipe Ruiz S, López Alvarez J, León Salas B, Cañas Plaza JM, Martín Rico F, Abella Dago G, Martínez Martín P. Social robots in advanced dementia. Frontiers in Aging Neuroscience 2015;7; doi:10.3389/fnagi.2015.00133 (online)
69. Robinson H, Broadbent E, MacDonald B. Group sessions with PARO in a nursing home: Structure, observations and interviews. Australasian Journal of Ageing 2015;34(2); doi:10.1111/ajag.12199 (online)
70. Sung HC, Chang SM, Chin MY, Lee WL. Robot-assisted therapy for improving social interactions and activity participation among institutionalized older adults: a pilot study. Asia Pacific Psychiatry 2015;7(1):1-6; doi:10.1111/appy.12131
71. Robinson H, MacDonald B, Broadbent E. Physiological effects of a companion robot on blood pressure of older people in residential care facility: a pilot study. Australasian Journal of Ageing 2015; 34(1):27-32; doi:10.1111/ajag.12099
72. Bemelmans R , Gelderblom GJ, Jonker P, Witte L de. Effectiveness of robot PARO in intramural psychogeriatric care: a multicentre quasi-experimental study. Journal of the American Medical Directors Association 2015;16(11):946-950; doi:10.1016/j.jamda.2015.05.007
73. Yu R, Woo J, Hui E, Lee J, Point D, Ip K, Yeung F. Feasibility and effect of a therapeutic robot PARO on moods and social interaction in older adults with declining cognitive function. Gerontechnology 2014;13(2):317; doi:10.4017/gt.2014.13.02.149.00
74. Wada K, Takasawa Y, Shibata T. Robot Therapy at Facilities for the Elderly in Kanagawa Prefecture – a Report on the Experimental Result of the First Month. In: Proceedings of the 23rd IEEE International Symposium on Robot and Human Interactive Communication 2014; pp 193-198; doi:10.1109/ROMAN.2014.6926252
75. Chang WL, Šabanovic S, Huber L. Observational study of naturalistic interactions with the socially assistive robot PARO in a nursing home. In: Proceedings of the 23rd IEEE International Symposium on Robot and Human Interactive Communication 2014; pp 294-299; doi:10.1109/ROMAN.2014.6926268
76. Šabanović S, Bennett CC, Chang WL, Huber L. PARO robot affects diverse interaction modalities in group sensory therapy for older adults with

dementia. In: Proceedings of the IEEE International Conference on Rehabilitation Robotics (ICORR) 2013; pp 1-6; doi:10.1109/ICORR.2013.6650427

77. Khosla R, Chu MT. Embodying Care in Matilda: An affective communication robot for emotional wellbeing of older people in Australian residential care facilities. ACM Transactions on Management Information Systems 2013;4; doi:10.1145/2544104 (online)
78. Robinson H, Macdonald B, Kerse N, Broadbent E. The psychosocial effects of a companion robot: a randomized controlled trial. Journal of the American Medical Directors Association 2013;14(9):661-667; doi:10.1016/j.jamda.2013.02.007
79. Chang WL, Šabanovic S, Huber L. Use of seal-like robot PARO in sensory group therapy for older adults with dementia. In: Proceedings of 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI) 2013; pp 101-102; doi:10.1109/HRI.2013.6483521
80. Tiberio L, Cesta A, Cortellessa G, Padua L, Pellegrino AR. Assessing affective response of older users to a telepresence robot using a combination of psychophysiological measures. In: Proceedings of IEEE RO-MAN: The 21st IEEE International Symposium on Robot and Human Interactive Communication 2012; pp 833-838; doi:10.1109/ROMAN.2012.6343855
81. Jayawardena C, Kuo I, Datta C, Stafford RQ, Broadbent E, MacDonald BA. Design, implementation and field tests of a socially assistive robot for the elderly: HealthBot version 2. In: Proceedings of 4th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob) 2012; pp 1837-1842; doi:10.1109/BioRob.2012.6290890
82. Louie WYG, McColl D, Nejat G. Playing a memory game with a socially assistive robot: A case study at a long-term care facility. In: Proceedings of IEEE RO-MAN: The 21st IEEE International Symposium on Robot and Human Interactive Communication 2012; pp 345-350; doi:10.1109/ROMAN.2012.6343777
83. Pripfl J, Körtner T, Klein DB, Hebesberger D, Weninger M, Gisinger C, Frennert S, Eftring H, Antona M, Adami I, Weiss A, Bajones M, Vincze M. Results of a Real World Trial with a Mobile Social Service Robot for Older Adults. In: Proceedings of the 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI) 2016; pp 497-498; doi:10.1109/HRI.2016.7451824
84. Ahn HS, Datta C, Kuo IH, Stafford R, Kerse N, Peri K, Broadbent E, MacDonald BA. Entertainment services of a healthcare robot system for older people in private and public spaces. In: Proceedings of the 6th International Conference on Automation, Robotics and Applications (ICARA) 2015; pp 217-222; doi:10.1109/ICARA.2015.7081150
85. Broadbent E, Orejana JR, Ahn HS, Xie J, Rouse P , MacDonald BA. The cost-effectiveness of a robot measuring vital signs in a rural medical practice. In: Proceedings of the 24th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN) 2015; pp 577-581; doi:10.1109/ROMAN.2015.7333668
86. Shin J, Itten D, Rusakov A, Meyer B. SmartWalker: Towards an Intelligent Robotic Walker for the Elderly. In: Proceedings of International Conference on Intelligent Environments (IE) 2015; pp 9-16; doi:10.1109/IE.2015.10
87. Chelvam YK, Zamin N. M3DITRACK3R: A design of an automated patient tracking and medicine dispensing mobile robot for senior citizens. In: Proceedings of the International Conference on Computer, Communications, and Control Technology (I4CT) 2014; pp 36-41; doi:10.1109/I4CT.2014.6914141
88. McColl D, Nejat G. Meal-time with a socially assistive robot and older adults at a long-term care facility. Journal of Human-Robot Interaction 2013;2(1):152-171; doi:10.5898/JHRI.2.1.McColl
89. McGlynn SA, Kemple SC, Mitzner TL, King CH, Rogers WA. Understanding older adults' perceptions of usefulness for the PARO robot. In: Proceedings of the Human factors and ergonomics society annual meeting 2014; pp 1914-1918; doi:10.1177/1541931214581400
90. Kawamoto H, Kamibayashi K, Nakata Y, Yamawaki K, Ariyasu R, Sankai Y, Sakane M, Eguchi K, Ochiai N. Pilot study of locomotion improvement using hybrid assistive limb in chronic stroke patients. BMC Neurology 2013;13; doi:10.1186/1471237713141 (online)
91. Prakash A, Beer JM, Deyle T, Smarr CA, Chen TL, Mitzner TL, Kemp CC, Rogers WA. Older adults' medication management in the home: How can robots help? In: Proceedings of the 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI) 2013; pp 283-290; doi:10.1109/HRI.2013.6483600
92. Begum M, Wang R, Hug R, Mihailidis A. Performance of daily activities by older adults with dementia: the role of an assistive robot. In: Proceedings of the IEEE International Conference on Rehabilitation Robotics 2013; pp 1–8; doi:10.1109/ICORR.2013.6650405
93. Sale P, De Pandis MF, Le Pera D, Sova I, Cimolin V, Ancillao A, Albertini G, Galli M, Stocchi F, Franceschini M. Robot-assisted walking training for individuals with Parkinson's disease: a pilot randomized controlled trial. BMC Neurology 2013;13; doi:10.1186/1471-2377-13-50 (online)
94. King CH, Chen TL, Fan Z, Glass JD, Kemp CC. Dusty: an assistive mobile manipulator that retrieves dropped objects for people with motor impairments. Disability and Rehabilitation: Assistive Technology 2012;7; doi:10.3109/17483107.2011.615374 (online)
95. Tapus A, Mataric MJ, Scassellati B. Socially assistive robotics (Grand Challenges of Robotics). IEEE Robotics & Automation Magazine 2007;14; doi:10.1109/MRA.2007.339605 (online)

Appendix A: Studies evaluating the efficacy of socially assistive robots in geriatric healthcare; CI=Cognitive Impairment;

Robot reference	**Study design**	**Location**	**Country**	**n, age range**
PARO[65]	Randomized controlled trial	Nursing home	Denmark	n=100, 68-90 yrs
PARO, Humanoid robot (NAO)[68]	Pilot observational study	Nursing home, day care centers	Spain	Phase 1: n=101, 68-87 yrs Phase 2: n=110, 69-87 yrs
PARO[69]	Observational study	Nursing home	New Zealand	Residents: n=16 Staff: n=21
PARO[70]	Pilot observational study	Institution	Taiwan	9 males, 3 females, 77.3±6.7 yrs
PARO[71]	Observational study	Residential care facility	New Zealand	14 patients, 7 controls, 71-95 yrs
PARO[72]	Multicenter quasi-experimental time series	Small-scale psychogeriatric care units: 8-10 persons	Netherlands	n=91
PARO[73]	Observational/interventional study	Community dwelling elderly, MMSE 9-24	Hong Kong	n=11, 73-88 yrs
PARO[74]	Experimental study	Nursing care facility	Japan	n=64, 86.5±6.7 yrs
PARO[75]	Observational field study	Nursing home	USA	Not disclosed
PARO[76]	Observational study	Nursing home	USA	n=10

MCI=Mild Cognitive Impairment; NPI=Neuropsychiatric Inventory Irritability

Aim and salient features	**Results & conclusions**	**Evaluation**
-Immediate behavioral responses to bi-weekly visits from person with dog, PARO, or soft toy cat -Interactive behavior with the visitor & animal (real or artificial)	-Order of interaction: physical contact, eye contact, verbal communication: dog=PARO >toy cat -Higher CI, more interaction with animal, less with human	Positive
NURSING HOME: 3 parallel therapeutic arms (dementia severity): Phase 1: control, PARO & NAO Phase 2: control, PARO & dog DAY CARE CENTER: Phase 1: NAO Phase 2: PARO	NURSING HOME: Phase 1: Robot groups: improvement apathy, no difference in cognition Phase 2 : PARO group: improvement quality of life DAY CARE CENTER: Phase 1: NPI score improved Phase 2: no change in follow-up	Positive
-Social catalyst -Open-ended questions at end of the study	-Regarded an agent & artificial object -Emotional impact on residents -Psychosocial benefits	Positive
-Therapy, social interactions, activity participation	-4 wks: improved communication, interaction skills, activity engagement -Suitable for routine activity program -Improved social health in residential care	Positive
-Blood pressure (before, during, after) & heart rate	-Physiological effects on cardiovascular measures, similar with live animals. -Changed systolic & diastolic blood pressure, heart rate -Decreased systolic & diastolic blood pressure from baseline -Withdrawal: Increased diastolic blood pressure	Positive
-Psychogeriatric care -Short term effects & role in facilitating daily care activities by care providers	-A tool for care staff, not replacement -Daily care: improved mood and quality of care and life	Positive
-Benefits in CI -9 subjects in group based intervention, 2 individual based -participation time 17-30min	-Focused on PARO for the entire session -Facial expressions: neutral (91%), smile (34%), laugh (17%) -All participants gently stroked or held PARO -91% talked to PARO -Promoted conversation between participants & improved moods	Positive
-Management dementia & reducing care burden -Caregivers: 2 hrs training -Group & individual therapy for 2-5 months	-43 Subjects: liked PARO -25 Subjects: improved condition -4 Subjects: close relations after 1 week -Reducing anxiety, irritation, aggression, depression, maintained for one month	Positive
-3 Month development & maintenance of interaction, real-world setting -2-3 times/wk for 13 wks, total 35 sessions -Naturally occurring interactions of residents, staff and visitors	-Interactions required mediation of staff or family -Interacted in diverse ways based on user's needs -There is a need to explore new methodologies in studying HRI	Positive
-Multi-sensory behavioral therapy for varying CI levels -Interactions residents, PARO & therapist for 7 weekly therapy sessions	-Direct and indirect effects led to increased participation -Increased indirect engagement: looking at and talking to others interacting with PARO, interest in primary interactors & other people -Improve interpretive flexibility of robot to adapt to varying CI levels	Positive

Appendix A (continued)

Matilda [77]	Observational study	Residential care facilities	Australia	n=70, 71-98 yrs
PARO[78]	Randomized controlled trial	Residential care	New Zealand	n=40
PARO[79]	Observational study	Nursing home	USA	n=10, ≥65 yrs
Giraff[80]	Experimental observational study	Residential care	Italy	Control group (MMSE=30): n=9, 65-75 yrs MCI group (MMSE-25-30): n=8, 65-79 yrs
Health bot[81]	Parallel study design	Retirement village	New Zealand	n=67, 65-88yrs
Brian 2.1[82]	Observational study	Long term care center	Canada	n=22, 57-100 yrs

Appendix A (continued)

-Emotional well-being: 5 constructs (positive engagement, acceptability, personalization of care, encouragement for healthy living, usefulness)	-Strongly liked: 72-83% in group activities -83% comfortable, 62% positive response to communication -Positive impact on diet: 1 female, on mental activity: 5 persons	Positive
-Psychosocial effects in rest home/hospital setting -Residents randomized to intervention group (PARO) & control group (normal activities) -1 Hour, twice a week for 12 wks -Social behavior as a group with and without PARO	-Reduced loneliness & positive impact on social environment -Addressed unmet needs not satisfied by resident animal	Positive
-Small MCI groups (4-7 persons) -Therapists showing PARO weekly	-Increased activity & interaction among residents -Helped interaction with staff; calmed & reduced anxiety -Most appropriate for one-to-one interaction	Positive
-Psychophysiological response for MCI -Repeated interactions -Assessment of anxiety, robotic interaction & influence on heart rate	-MI group: tolerated Giraff, no adverse effects on cardiovascular response -Further investigations warranted	Positive
-Study 1: public spaces -Study 2: private spaces -Study 3: falls monitoring, wandering & activity monitoring -Robot interaction: synthesized speech, touch screen; providing services & collecting data	-High overall rating by all subjects; interaction enjoyed, future interaction requested	Positive
-Use & acceptability of expressive human-like robot -Completed questionnaire post interaction	-Enjoying interaction with robot, liking emotions & social attributes. -Easy to use, regardless of computer experience.	Positive

Appendix B. Efficacy of robots for assistance in daily activities in geriatric healthcare; ALS=Amyotrophic Lateral Sclerosis

Robot reference	**Activity**	**Study design**	**Country**	**Location**	**n, age range**
HOBBIT[83]	Lifting objects	Observational study	Austria, Greece, Sweden	Private homes of single-livers	n=18, 75-89 yrs
iRobi, PARO, Charlie, Guide robot, Friend robot[84]	Entertainment	Long term observational study	New Zealand	Retirement village	Not disclosed
Cafero touchscreen robot[85]	Routine vital signs investigation	Observational study	New Zealand	Rural clinic	Physician appointment: n=29; Nurse appointment: n=19, 24-89 yrs
Smart Walker[86]	Navigation	Experimental study	Switzerland	Retirement homes	Residents: n= 23; ≥80 yrs Staff: n=8,
M3DITRACK3R[87]	Medication dispensing	Observational study	Malaysia	Residential home	n=7
Brian 2.1[88]	Meal time interaction	Observational study	Canada	Elder care facility	n=8, 83-92 yrs
PARO[89]	Daily activities	Observational study	USA	From Human Factors and Aging Laboratory database	n=30, 67-80 yrs
Hybrid Assistive Limb (HAL)[90]	Locomotion & gait training	Pilot clinical trial	Japan	Not disclosed	n=16, 61±15 yrs
Willow garage's personal robot 2 (PR2)[91]	Medication Management	Observational	USA	Independent living	n=12, 68-79 yrs
Prototype 'Ed' on Robot Create platform[92]	Activities of daily needs	Observational study	Canada	Old age homes	n=5, 59-90 yrs
G-EO[93]	Gait training	Pilot randomized controlled observing trial	Italy	Not disclosed	n=20, Parkinson patients, cognitively intact, gait problems, 18-90 yrs
Dusty[94]	Lifting objects	Experimental study	USA	Emory ALS Center	n=20, 38-77 yrs

Aim and salient features	Results & conclusions	Evaluation
-Efficacy in 371 days trials in domestic environments, real world conditions, qualitative interviews & questionnaire	-High appreciation of picking up & transporting objects, emergency recognition, fitness program & ability to remind users -Independent living not supported -Safety perception not increased, despite emergency function	Positive
-Efficacy of 3 Healthbots: service robot platform, software system with service modules, medical server -3 Entertainment services: music videos, quotes & pictures; usage history analyzed	-Entertainment in private spaces > public places -Both places: music video services mostly used	Positive
-Feasibility, cost effectiveness of measuring routine vital signs -Consultation times before and after deploying the robot	-Consultation lengths 18% reduced -Benefit-Cost ratio: 2.3	Positive
-Appropriateness & usefulness of walker & gesture-based interface -Device assisted user intelligently, enabling free navigation	>50% user preferred traditional walkers -Robot too big, too heavy, unfamiliar technology	Negative
-Efficacy of automated medicine dispensing system	-Helped reminding independent elderly & caretaker, dispensed right amount of medicine -Tracked time, type, dosage	Positive
-Two occasions/patient in one wk, engagement & compliance at one-on-one meal-eating sessions -Reactions, acceptance, & attitudes towards the robot	-High rates of engagement & compliance -Participants enjoyed interaction	Positive
-Perceived usefulness, factors for health: questionnaires & interview before and after interaction	-Neutral on perceived usefulness, but wanted to own it	Neutral
-Feasibility of locomotor training in chronic stroke patients, differences between 2 subgroups -Stroke 47.1±37.6 months ago, 1st stroke >6 months ago -16 training sessions, 2 days/wk, 90 min/session, 20-30min with HAL	-Improved: gait speed, cadence, number of steps/10m, Burg balance scale score, TUG test score -HAL training feasible; effectiveness to be demonstrated	Positive
-Attitudes toward a mobile manipulator to support medication management -3 Specific goals: attitude towards robot, specifying implications for design, factors affecting attitudes	-Robot assistance accepted -Preferred robot over humans as reminders, but humans over robots for selecting medication -Factors: perception of one's own ability, robot reliability	Positive/ negative
-Dementia feasibility & usability in performing daily living tasks	-Step by step guidance valuable for assistance	Positive
-Feasibility, effectiveness, efficacy of robot-assisted walking & treadmill training: each 40min, 5x/wk for 4 wks	-Training: feasible, acceptable, safe, all sessions completed -Improved gait index, gait speed, step length, stride length	Positive
-Tasks for ALS subjects -Subjects teleoperated with joystick to move robot around an obstacle, pick up & deliver objects	-Tasks completed: 61.4± 20.5s -Overall satisfaction: 6.8±0.6 on 7-points Likert scale -Preference over own hands, family members, teachers -14 subjects preferred Dusty over current method	Positive