Accessibility of Radiology Equipment for Patients with Mobility Disabilities

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Objective: The purpose was to evaluate accessibility of typical radiology platforms by participants with mobility disabilities. **Background:** These patients have difficulty using radiology equipment and have an increased risk of falling. **Methods:** This field study evaluated three common types of radiology platforms – X ray, computed tomography (CT) scan, and fluoroscopy – by 20 patients/participants with mobility impairments who used walking aids. The participants were required to get onto the equipment, simulate a typical radiological procedure, and get off. Each participant then watched a video of his or her own session and answered questions. Four researchers independently reviewed the videotapes and identified accessibility and safety barriers. **Results:** Overall, the CT scan platform was the easiest to use and the fluoroscopy platform the most difficult, primarily because of platform height differences. Sitting up on the X-ray table was rated as difficult by most participants, primarily because of a lack of handholds and the surface pad not being fixed in place. Maintaining a position on the fluoroscopy platform while it rotated from horizontal to vertical was difficult and frightening for most participants. **Conclusion:** Some radiology platforms are difficult to use and are perceived to be less safe for patients with mobility disabilities. The interaction of patient disability and equipment design can impose substantial physical demands on medical personnel. Recommendations for improved design are provided to enhance radiology platform accessibility and safety. **Application:** The findings may be applicable to the design of a wide range of medical patient platforms.

INTRODUCTION

For a variety of reasons, some individuals with disabilities do not receive adequate health care. This population may lack opportunities to fully engage in diagnostic and preventive health care activities and may have limited access to health care procedures (DeJong, 1997; Smith, 2008; West, Luck, & Capps, 2007). One of the factors contributing to the disparity of health care services for persons with disabilities may be the lack of accessible medical devices (Nosek, 2000). For example, inaccessible radiologic medical equipment makes it less likely that a woman with disabilities will receive breast screening (Nosek, 2000). Cheng et al. (2001) found that ambulatory patients had 3.2 times the odds of having a mammography exam when compared with their nonambulatory counterparts with multiple sclerosis.

Medical equipment may also pose an increased risk of fall injury for patients with mobility impairments (Nevitt, Cummings, Kidd, & Black, 1989; Tinetti, Speechley, & Ginter, 1988). It is estimated that at least 40% of accidents that occur in the hospital are related to falls (Groves, Lavori, & Rosenbaum, 1993). Risk factors associated with falling in the hospital include a history of falls, difficulty in transfers and ambulating, dizziness, lower limb weakness, delirium, visual impairment, medications, incontinence, and toileting frequency (Chu et al., 1999; Hendrich, Nyhuis, Kippenbrock, & Soja, 1995; Papaioannou et al., 2004; Stevenson, Mills, Welin, & Beal, 1998).

In a national survey, patients with disabilities reported difficulty using a range of medical equipment, particularly examination tables, radiology equipment, exercise and rehabilitation equipment, and weight scales (Jill M. Winters et al., 2007).

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They reported difficulty getting on and off medical platforms because the platforms were too high or had no handholds. They also reported difficulty changing positions on medical platforms or resting comfortably on platforms.

The purpose of this study was to evaluate the accessibility and safety of radiology platforms for patients with mobility disabilities. The study also identified specific barriers associated with equipment design features that may contribute to poor accessibility and decreased safety.

METHODS

This field study tested use of three common types of radiology platforms – for X ray, computed tomography (CT), and fluoroscopy – in a functioning radiology department by patients/participants with mobility impairments who used walking aids. This population was selected because these individuals are at higher risk of falling because of difficulties with balance and diminished protective reflexes (to either avoid or break a fall), and they may be more sensitive to inaccessible features of standard radiology equipment.

Participants and Tasks

The participants were age 21 years or older, used at least one mobility aid (e.g., walker, cane, crutches), and were able to walk for at least 10 feet (3.05 m) but no more than one-quarter mile (0.4 km) without having to stop to rest. Individuals were excluded if they weighed more than 250 pounds (93.25 kg; the limit of the equipment), were pregnant, or had a cognitive disability. Participants were recruited through community-based organizations. The study was approved by the human subjects committees at the University of California, San Francisco, and Marquette University.

Twenty patients/participants, 15 women and 5 men, participated in the study. The participants' mean age was 61.5 ± 11.9 years (range: 42–86 years), and each used at least one type of mobility aid for walking: one or two canes (9), cane or walker (4), crutches (3), walker (2), crutches or walker (1), or trekking poles (1). In addition, some individuals reported they used a wheelchair (3), scooter (4), or both (1) to travel long distances or on bad days. The participants reported mobility impairments attributable to arthritis (16), back or spine condition (14), and/or paralysis (13). The causes of the impairments were multiple sclerosis (9), degenerative spine disease (4), cerebral palsy (4), spinal cord injury (1), traumatic brain injury (1), stroke (1), polio (1), and/or lower extremity trauma (1).

The X-ray platform (Diagnost TH2, Philips Medical Systems, Andover, MA) and CT scan machine (Lightspeed, General Electric Healthcare, Waukesha, WI) were adjustable in height. Two substantially similar fluoroscopy machines were used in the study (Legacy and Advantx, General Electric Healthcare, Waukesha, WI). Both fluoroscopy machines had short, cylindrical handles that could be attached to the longitudinal edges of and extended perpendicular to the platform to serve as patient handholds. An auxiliary steel step unit (38 cm wide, 28 cm deep, 23 cm high) with a tubular handrail was available for use with the fluoroscopy machines.

A typical patient procedure was simulated on each type of equipment; no X rays or scans were actually taken. On the X-ray machine, the technologists simulated a knee scan, which required participants to lie on their backs for one scan and turn onto their left sides for a second scan. On the CT machine, they simulated a chest scan, for which participants were asked to lie on their backs and put their hands over their heads. On the fluoroscopy machine, they simulated a throat scan. This test required participants to lie on their backs, maintain the position while the platform was rotated to vertical, and then pretend to drink from a cup. The participants then stepped down off the footboard and sat down, then stepped back up onto the footboard and maintained their position while the platform was rotated to horizontal. Most participants used the equipment in this order. For 4 participants, the CT scan room was unavailable after the X-ray room and participants used the fluoroscopy machine before the CT scan.

Each participant performed one trial on each machine. Cameras, a microphone, and computer equipment were set up in one of the radiology rooms. After each participant came in and used that machine, he or she went into another room with a researcher to review the video and answer questions. The video, audio, and computer gear were then moved to a different room with the next piece of radiology equipment, and the process was repeated. An experienced radiology technologist was involved in each trial; a total of 11 technologists participated in the study. (Two technologists participated in one trial, when they determined that the participant needed extra assistance.)

Data Collection

The equipment use trials were captured on digital video using a Mobile Usability Lab (MU-Lab) consisting of three cameras, a room microphone, and a laptop computer on which all data were recorded (Jack M. Winters et al., 2007). Following each trial, a researcher who was not present at the trial reviewed the videotape with the participant, who described his or her experiences during the session. The participant then answered a standard set of questions about the equipment's usability and safety. The interview sessions were recorded on videotape with audio for later transcription. Four of the questions were general, and four were specific to subtasks associated with patient use of radiology platforms (Figure 1).

Data Analysis

Researchers reviewed the videotapes of the equipment use trials and used Multimedia Video Task Analysis (MVTA) software (Yen & Radwin, 2007) to mark and annotate safety and accessibility barriers (Table 1). The barriers were based on major categories of interactions between humans and devices, including classic distinctions made by the movement science research community among posture, movement, and manipulation by human operators (Jack M. Winters & Woo, 1990). Each observer marked the beginning and end of each barrier incident and labeled it with a marker that reflected its severity as mild, moderate, or extreme. Prior to conducting an MVTA, each researcher read a transcript of the participant's

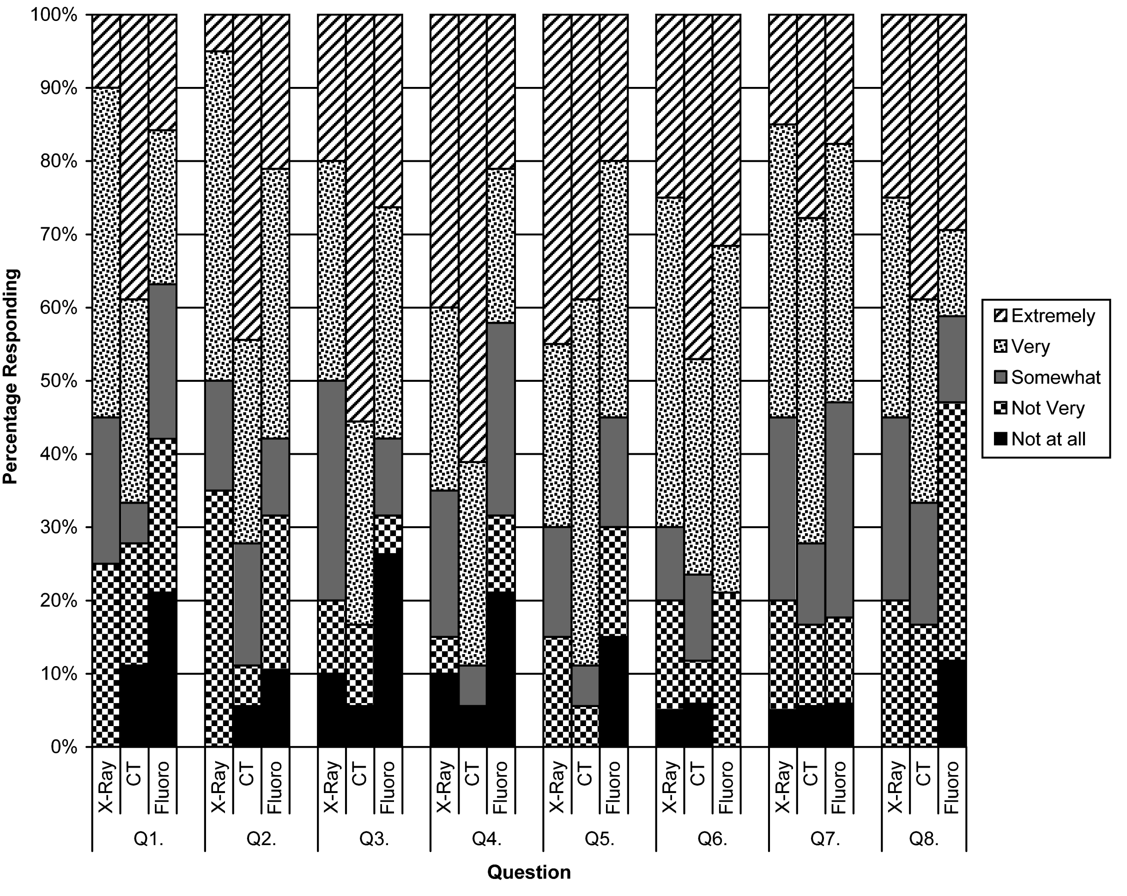

Figure 1. Posttest interview responses from participants across all equipment (CT = computed tomography, Fluoro = fluoroscopy). Key to questions: Q1. Were the postures you used comfortable? Q2. Was the amount of strength needed okay? Q3. Was the amount of fatigue you had okay? Q4. Did you feel safe? Q5. How easy was it for you to get up onto the platform? Q6. How easy was it for you to lie down on the platform? Q7. How easy was it for you to sit up on the platform? Q8. How easy was it for you to get down off the platform?

TABLE 1: Definitions and Descriptions of Accessibility and Safety Barriers Used in MVTA

#	Name of Barrier	Description of Barrier
1	Orienting/positioning body or device barrier	Involves *dynamic* support needs, such as at setup/beginning and end of device use (e.g., transferring, body balance or stability, physical obstruction, movement requirements, reaching, strength requirements).
2	Body support barrier	Involves *static* support needs for body or extremities (e.g., seat, back, leg, arm, head support), without which there is loss of stability or fatigue.
3	Physical interaction/ manipulation/operation of controls barrier	Involves physical interactions with controls (e.g., switches, levers), reaching, handling, strength, dexterity, motor control, physical obstructions to hands (or other appropriate body part), and so on during device use.
4	Sensory barrier with communication or display	Involves device exceeding sensory capabilities for vision, hearing, touch, and so on (e.g., sight lines, letter size, sound volume, ambient noise, tactile features).
5	Cognitive barrier	Involves misunderstanding device, misinterpreting visual cues, memory demands, cuing, language.
6	Use error	Involves misuse from manufacturer's intended manner of use.
7	Unsafe activity	Involves activity that may put patient or other person at risk of injury.
8	External barrier with device use	Involves entities that impede patient's use of device; may be architectural elements, auxiliary furniture or equipment, or other people.
9	Unable to use assistive technology effectively with device	Involves device impeding or not supporting effective use of personal assistive technology or technologies (e.g., wheelchair, leg brace, glasses, hearing aid).
10	Assistance from another person required with device	Involves patient's use of tools/objects or another person to compensate for a possibly inadequate device design; the compensatory assistance must be directly related to intended use of device by the patient; does not include "air spotting" or "comfort touches."

Note. MVTA = Multimedia Video Task Analysis.

posttest video review comments. Four researchers reviewed all the videos, then met and developed a consensus of barrier events in each video.

Barriers identified from the videos for each of the three types of equipment were determined to be present if marked as moderate or extreme or absent if marked as mild or not marked. The barriers were then compared using Cochran's Q test for repeated measures of dichotomous outcomes (Neter, Wasserman, & Kutner, 1985). Significant differences ($p < .05$) were followed up at a 5% procedure-wise error rate using Bonferroni techniques appropriate for Cochran's Q test.

RESULTS

Researcher-Identified Accessibility and Safety Barriers

The researcher-identified accessibility and safety barriers for the four subtasks common to the three types of radiology equipment are presented in Figure 2. The barriers were related to physical orientation or positioning (Barrier 1), body support (Barrier 2), cognitive demands (Barrier 5), use error (Barrier 6), unsafe activity (Barrier 7), external elements (Barrier 8), and assistance from another person (Barrier 10). Assistance received (Barrier 10) was judged to indicate that the participant would have had greater difficulty or would not have been able to perform the task without assistance.

For the subtask of getting onto the equipment, most participants did not have much difficulty with the X-ray and CT scan platforms but did have difficulty with the fluoroscopy machine. Two technologists each used the auxiliary step for fluoroscopy with 2 participants. While getting on, participants experienced significantly more Barrier 1 (physical orientation/positioning) events on the fluoroscopy platform than on the other two machines (Cochran $Q = 20.17$, $p < .001$; see Table 2). Two participants who used wheelchairs had difficulty getting onto the CT scan platform: One of them received assistance, but the other participant

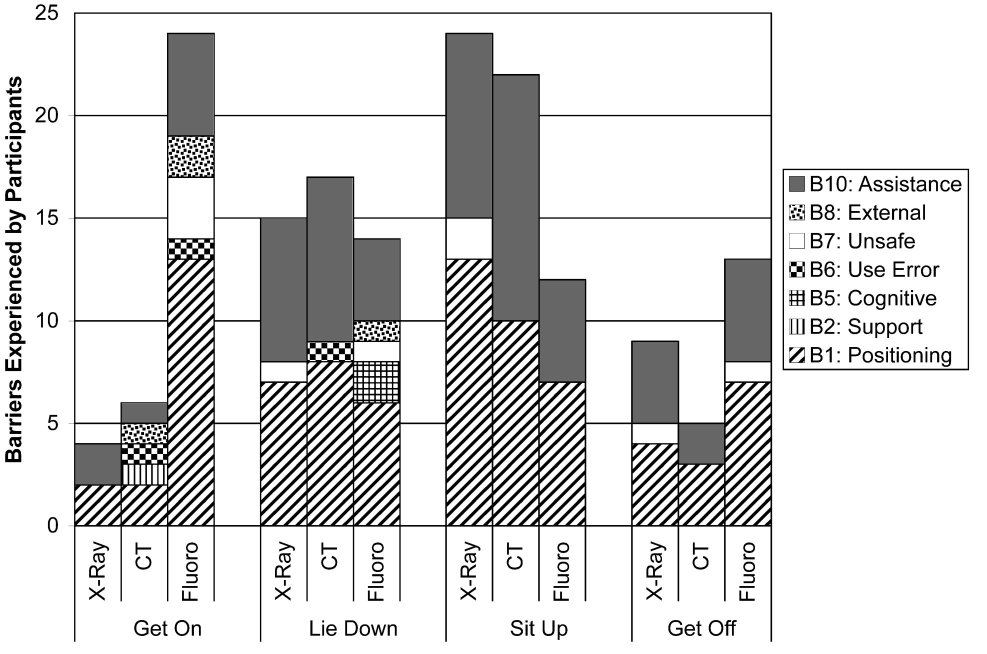

Figure 2. Observed barrier counts by subtasks and radiology platforms (CT = computed tomography, Fluoro = fluoroscopy). See Table 1 for details on Barriers 1 through 10.

TABLE 2: Cochran's *Q* Statistic on Homogeneity of Presence of Barriers 1 and 10

	Get On			Lie Down			Sit Up			Get Off		
	X-ray	CT	Fluo.	X-ray	CT	Fluo.	X-ray	CT	Fluo.	X-ray	CT	Fluo.
Barrier 1	2	2	13	7	8	6	12	10	7	4	3	7
Cochran's *Q*		20.17*			0.75			3.80			3.71	
Critical value		5.99			5.99			5.99			5.99	
df		2										
p value		.00004										
Critical difference		6.77										
	X-ray	CT	Fluo.	X-ray	CT	Fluo.	X-ray	CT	Fluo.	X-ray	CT	Fluo.
Barrier 10	2	1	5	7	8	5	8	12	5	4	2	5
Cochran's *Q*		4.33			1.40			7.40*			2.33	
Critical value		5.99			5.99			5.99			5.99	
df								2				
p value								.025				
Critical difference								6.18				

Note. CT = computed tomography, Fluo. = fluoroscopy.
*Statistically significant at the alpha = .05 level.

got out of the wheelchair about a meter away from the platform and then held on to the wheelchair's arm for support, which was not stable, while transferring to the platform.

Most participants (13 of 20) had at least moderate difficulty getting onto the fluoroscopy platform (Barrier 1); 5 participants had extreme difficulty, including 2 of the 4 people who used the auxiliary step (with the same technologist) either instead of (3) or in addition to (1) the platform's pull-out step. While attempting to step up onto the fluoroscopy platform step, 1 participant grasped the handle on the X-ray plate because she thought it was a handhold; when she applied weight to it, the plate slid out of her hand, forcing her to step back to regain her balance (Barrier 6). In addition, actions of the technologist interfered with movement strategies used by 2 participants while getting themselves onto the fluoroscopy platform (Barrier 8).

Barriers associated with the subtask of lying down on the platform were very similar across the three types of equipment. To lift the legs onto the platform, 1 participant needed assistance for X ray, 2 participants needed this help for the CT platform, and 3 participants needed it for fluoroscopy. The cognitive barrier (Barrier 5) associated with the fluoroscopy table was related to the technologist not explaining to participants why they needed to lie down with their feet against the footboard. The footboard became the standing surface when the platform rotated from horizontal to vertical. Four participants (attended by 2 different technologists) did not maneuver themselves into this position at first and slid down the platform while it was rotating. The unsafe activity (Barrier 7) for the X-ray table related to the cushion on its surface. The cushion was not fixed in place and slid under most of the participants while they moved to lie down. The unsafe activity for the fluoroscopy platform was related to the location of the scanning unit, on which 1 participant nearly hit her head.

The subtask of sitting up on the equipment was relatively demanding. Most participants (15 of 20) had at least moderate difficulty sitting up on the X-ray table (Barrier 1), and 2 of them had extreme difficulty. Half of the participants (10 of 20) had at least moderate difficulty sitting up on the CT scan platform; 4 participants had extreme difficulty and received extreme assistance (Barrier 10). Barrier 10 events associated with sitting up were significantly more common on the CT scan machine than on fluoroscopy (Cochran $Q = 7.40$, $p = .02$; see Table 2). Two incidents of unsafe activity (Barrier 7) were observed on the X-ray table. One participant rolled from his side onto his back while sitting up, and a portion of his buttocks briefly extended beyond the side of the table. Another participant struck her leg against the table as she moved to sit up, causing her distress.

Getting off the equipment was difficult for some participants. Four participants had difficulty with the task (Barrier 1) on X ray, 3 participants had difficulty on CT scan, and 7 participants had difficulty on fluoroscopy. One incident of unsafe activity (Barrier 7) was observed on the X-ray table, when the tabletop slid sideways a few centimeters when the participant leaned against it while standing up. One unsafe activity was observed on the fluoroscopy machine, when the auxiliary step wobbled when the participant grasped it while getting off.

Participants' Posttest Interview Responses

The participants' posttest interview responses indicate differences in usability and safety concerns across the three types of equipment (Figure 1). On the general questions (Q1–Q4), the largest difference between platforms was on feeling safe (Q4), with CT scan ranking the most safe, followed by X ray, then fluoroscopy. For fatigue (Q3) and strength required (Q2), the CT scan received the best rating, and there was little difference between X ray and fluoroscopy. There was relatively little difference between platforms on comfort ratings (Q1).

Across the 4 targeted questions (Q5–Q8), there were minor differences between platforms. For getting onto the platform (Q5), CT was the easiest, followed by X ray, then fluoroscopy ($p = .04$; Friedman test). There was relatively little difference between platforms for lying down (Q6) or sitting up (Q7). For getting off the platforms (Q8), fluoroscopy was reported to be the most difficult.

Being on the fluoroscopy table while it rotated was difficult for participants. The table had auxiliary cylindrical handles that could be attached to the sides of the platform. The technologists were instructed to use the handles, but they were actually used for only 8 of the 19 trials. (One participant was prevented from using the fluoroscopy machine by the technologist, who judged the task as too demanding for the participant's capabilities.) During the video review of the platform being rotated between horizontal and vertical, 11 of the 19 participants volunteered that they felt physically insecure or were afraid they might fall, 12 wanted something more secure to hold on to, and 4 wished they had been strapped to the platform. One participant commented about the fluoroscopy platform's rotation to vertical: "Very extremely uncomfortable; extremely dangerous. I had a fear of falling the whole time. I was holding on for dear life."

DISCUSSION

Usability evaluations are an important part of the equipment design process (Welch, 1998). Previous usability studies of medical equipment have primarily focused on evaluation from the perspective of a medical professional. For example, patient transfer devices have been evaluated for their impact on nurses using the devices by expert appraisal and user trials (Le Bon & Forrester, 1997) and by biomechanical analysis and perceived stress ratings (Garg, Owen, Beller, & Banaag, 1991; Ulin et al., 1997). Evaluating use of equipment by people with disabilities has generally involved subjective evaluations (e.g., Lenker, Scherer, Fuhrer, Jutai, & DeRuyter, 2005; Manzke, Egan, Felix, & Krueger, 1998). This study evaluated accessibility and safety of medical equipment from the perspective of medical patients and collected a combination of video-based observer data and subjective data to identify equipment features that presented barriers to use.

The goal of this project was to study use of radiology platforms by patients with mobility disabilities and to identify design features of the equipment that interfered with safe use. Several problems were found and associated with specific equipment features.

The only machine that was observed to be difficult for participants to get onto was the fluoroscopy platform. For those participants having the most difficulty, the primary obstacles were the high height of the platform and the small surface area of the pull-out or auxiliary step.

For those participants having the most difficulty lying down and getting into position on the X-ray table, the primary obstacle was identified as the surface pad, which was not fixed in place and tended to slide around when the participants moved. Some technologists took advantage of this feature by pulling on or pushing the pad to position participants rather than using the table's controls to move the tabletop laterally. On the fluoroscopy platform, the need for participants to get into position with their feet against the footboard complicated the task of lying down. The movable pad on the X-ray table also made the task of sitting up more difficult. The fact that fewer participants received assistance with sitting up on the fluoroscopy platform might have been attributable to its greater height, which could have made it more difficult for the technologists to provide this assistance.

Standing up from the CT scan machine seemed to be easier than from the X-ray table, possibly because the CT machine's lowest height was 5 cm higher (57 vs. 52 cm). Higher seat heights can be easier to stand up from (Bahrami, Riener, Jabedar-Maralani, & Schmidt, 2000; Janssen, Bussmann, & Stam, 2002). The greater difficulty associated with getting down from the fluoroscopy platform was most likely attributable to its extreme height of 86 or 90 cm. In addition, the pull-out step was not centered along the platform and extended only 21 to 23 cm beyond its edge, which made it difficult for participants to locate while on top.

Maintaining a position on the fluoroscopy platform while it rotated from horizontal to vertical was the most difficult and frightening task for participants. Although 8 participants were provided with simple cylindrical handholds, the handles were short (approximately 12 cm), far apart (75 cm), and not carefully located by the technologists. Insufficient or missing handholds seemed to be the most critical problem.

The posttest review of the video data with participants proved particularly useful. Participants explained their actions and thoughts during each trial, which might not be obvious to observers. For example, a stroke-survivor participant who lay down on the X-ray table and ended up at an angle with her head hanging off the side commented, "And then she [the technologist] helped me stretch out. It wasn't that hard." One interpretation of this comment might be that the participant was not very talkative, but another might be that in the context of the participant's life, this experience was not extreme.

At the other end of the spectrum, another participant stood without moving on the footboard of the fluoroscopy platform while the technologist walked across the room to retrieve the participant's forearm crutches. During the video review the participant commented, "At the end, I was almost vertical and he had his hand against me. Then he had to leave me alone to get the crutches. So here I am in a potentially vulnerable position to fall. . . . I didn't feel I could move because I had no sense of how much step space I had. I had to stay frozen. . . . Each time, on each of the three sequences [machines], they brought the crutches backwards to me, and I had to switch them around to the correct way." The participant's description makes it clear that this individual had insufficient support to maintain this position and was, in fact, at risk (and afraid) of falling while standing still and while manipulating the crutches.

The role of the radiology technologists must be recognized. In some instances, technologists were observed to compensate for equipment shortcomings, such as serving as a missing side rail by standing alongside the platforms as patients maneuvered or serving as a pull-up assist when patients struggled to sit up. In other instances, staff members did not use auxiliary equipment available, such as offering a stepstool or attaching handholds to the fluoroscopy platform. Some technologists even interfered with movements of patients by attempting to stabilize or move their arms or legs in ways that were counter to the participants' movement strategies.

A limitation of the study was that the participants were younger than the overall population that uses walking aids. The 1994 National Health Interview Survey found that 61.5% of individuals who use a mobility aid (cane, crutches, walker, wheelchair, and/or scooter) are age 65 or older (Russell, Hendershot, LeClere, Howie, & Adler, 1997), but only 35.0% of the study population were of this age. Therefore, the problems identified here may be more prevalent and serious than the data suggest.

There are additional reasons that the problems identified most likely provide a conservative estimate of the overall problem. People with disabilities are overrepresented among health care consumers (Rice & LaPlante, 1992). Disability increases with age (U.S. Department of Commerce, 2006), and visits to health care providers increase with severity of disability (LaPlante, 1993). Importantly, both the incidence of falls and the severity of complications increase with age, increased disability, and functional impairment (de Rekeneire et al., 2003; Gassmann, Rupprecht, & Freiberger, 2008; Kannus et al., 1999). Furthermore, as the average age of the American population increases and demands on health care services increase (including demands on diagnostic facilities because of anticipated increases in age-related falls and injuries), these issues will become even more pressing.

Recommendations

The results of this study suggest a number of design recommendations to make radiology equipment more accessible and safer for patients with mobility disabilities.

- The pad on top of a platform should be fixed in place.
- The platform should have clearly marked handholds along the edges that patients can use as they position or reposition themselves.
- Platforms should be height adjustable and set to the patient's midthigh level for easy entry and exit.
- Side handles should be provided for platforms that rotate to a vertical position.
- Strapping to secure patients against the platform should be available on platforms that rotate to a vertical position.
- A step with railings on both sides should be provided, and two steps should be provided for platforms that are taller than 75 cm. The top step should be large enough to allow patients to turn around easily.
- A handhold should be available to assist patients to sit up from a supine position.
- Platforms should be designed to minimize the ability of patients to commit use errors (e.g., accidental removal of X-ray plates or activation of switches).

In addition to improving accessibility and safety for patients with mobility disabilities, these design changes would benefit nondisabled patients, as well. Accommodating the needs of people with disabilities can also make devices easier to use for people without disabilities, an approach known as universal or inclusive design (Ostroff, 1998; Story, 2007).

Furthermore, medical personnel can make equipment easier and safer to use or more difficult and dangerous to use. Additional training may be helpful.

- Medical personnel should be trained on the capabilities of their equipment and auxiliary equipment that may be available to make patients safer or more comfortable.
- Medical personnel should be trained on the characteristics and needs of patients with disabilities and on ways in which individual patients' needs may be accommodated.

These recommendations are likely to make radiology equipment more accessible for patients with mobility disabilities (and for patients without disabilities) and to reduce physical demands on health care providers who assist patients with transfers. Future research will explore the effects of implementing these recommendations in laboratory or clinical settings. Some of the findings may be generalizable to other medical platforms that support patients, such as surgical and examination tables.

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