Comparative Kinematic and Electromyographic Assessment of Clinician- and Device-Assisted Sit-to-Stand Transfers in Patients With Stroke

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Background. Workplace injuries from patient handling are prevalent. With the adoption of no-lift policies, sit-to-stand transfer devices have emerged as one tool to combat injuries. However, the therapeutic value associated with sit-to-stand transfers with the use of an assistive apparatus cannot be determined due to a lack of evidence-based data.

Objective. The aim of this study was to compare clinician-assisted, device-assisted, and the combination of clinician- and device-assisted sit-to-stand transfers in individuals who recently had a stroke.

Design. This cross-sectional, controlled laboratory study used a repeated-measures design.

Methods. The duration, joint kinematics, and muscle activity of 4 sit-to-stand transfer conditions were compared for 10 patients with stroke. Each patient performed 4 randomized sit-to-stand transfer conditions: clinician-assisted, device-assisted with no patient effort, device-assisted with the patient's best effort, and device- and clinician-assisted.

Results. Device-assisted transfers took nearly twice as long as clinician-assisted transfers. Hip and knee joint movement patterns were similar across all conditions. Forward trunk flexion was lacking and ankle motion was restrained during device-assisted transfers. Encouragement and guidance from the clinician during device-assisted transfers led to increased lower extremity muscle activation levels.

Limitations. One lifting device and one clinician were evaluated. Clinician effort could not be controlled.

Conclusions. Lack of forward trunk flexion and restrained ankle movement during device-assisted transfers may dissuade clinicians from selecting this device for use as a dedicated rehabilitation tool. However, with clinician encouragement, muscle activation increased, which suggests that it is possible to safely practice transfers while challenging key leg muscles essential for standing. Future sit-to-stand devices should promote safety for the patient and clinician and encourage a movement pattern that more closely mimics normal sit-to-stand biomechanics.

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Workplace injuries arising from manual patient handling during transfers are prevalent in health care and are a concern because of the risk of injury to both clinicians and patients.[1–7] Among nursing home employees, the incidence rate for back injuries that result in lost work days is more than twice the rate for construction workers and more than 3 times the rate for agriculture workers.[8–12] A large number of clinicians' work-related injuries result from lifting and transferring patients.[13] Therapists who perform 6 to 10 patient transfers a day are approximately 2.4 times more likely to incur lower back injuries compared with those who do not perform any patient transfers.[2] Although education in proper body mechanics to prevent or reduce the risk of back injuries often is incorporated into educational programs, training has not completely eliminated the problem.[14,15]

The nursing community has responded by implementing safe patient handling (SPH) techniques to reduce injuries caused by transferring patients. The Royal College of Nursing states that all manual lifting should be eliminated except in life-threatening situations.[16] To enact this policy, nurses have begun using SPH devices instead of manually moving patients. This no-lift policy has resulted in a significant decrease in work-related back injuries,[17] with SPH devices reducing chronic back pain among nurses by 23%.[18] Additionally, SPH techniques have reduced health care costs by decreasing the number of sick days and workers' compensation for work-related injuries. For instance, Siddharthan et al[19] reported a cost reduction of 74% in expenses associated with care provided to injured employees billed to workers' compensation, 50% in workers' compensation paid to individuals by facilities, and 95% in estimated cost of days on restricted duty.

One therapeutic tool that has emerged from the SPH movement is the sit-to-stand transfer device. Battery or pneumatically powered machines lift a patient from a seated to a standing position and, after relocation, return the individual to a seated position. These devices are intended for partially dependent patients who are able to bear some weight and are ideal for moving around in smaller, restricted areas. The basic design of the device includes a foot platform, sling or foldable seat that attaches to the lifting mechanism, and handles for the patient to grasp during the transfer.[20]

Although the nursing community has widely adopted sit-to-stand devices, many therapists have hesitated. Concerns have been expressed regarding the extent to which sit-to-stand devices permit practice of a "normal" sit-to-stand movement versus possibly promoting practice of abnormal movement patterns. Recently, a study compared the long-term effects on patient mobility for a group treated with the use of SPH principles and technologies (including sit-to-stand devices) versus a group not treated with the use of these approaches on an inpatient rehabilitation unit at a large hospital center.[21] The authors determined that patients in the SPH group achieved mobility outcomes similar to those rehabilitated without SPH.[21] Although these findings should help alleviate therapists' concerns that SPH programs, and specifically SPH devices, inhibit recovery and lead to equipment dependence, questions still exist regarding the task-specificity of training with the use of SPH devices.

Limited biomechanical data are available to guide decision making regarding the benefits and limitations of the use of sit-to-stand devices to facilitate patient transfers.[21–24] Burnfield et al[23] compared the kinematics and muscular demands of device-assisted transfers with transfers without a device in adults with no known disability to ascertain whether a sit-to-stand device simulated normal transfers and to explore movement-related constraints imposed by the device. Although the participants' movement patterns and muscular demand differed between the no-device and device-assisted transfers, verbal encouragement to exert their best effort within the device promoted a more similar movement profile at the hip, knee, and ankle as well as increased lower extremity muscular activation.[23]

To date, there have been no published reports comparing joint motion and muscle activity of clinician-assisted and device-assisted sit-to-stand transfers in patients with movement deficits. On the basis of our previous research with individuals without known disability,[23] it may be assumed that device-assisted movements would be less optimal than clinician-assisted movements. Arguably, it also is possible that clinician-assisted transfers may be less optimal because of the challenges that clinicians have when trying to safely move an individual with a variety of impairments (eg, weakness, sensory loss). These challenges

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- Video Abstract of the study's major findings, a demonstration of the four experimental conditions, and a brief discussion of safe patient handling in rehabilitation.

may prevent clinicians from assisting the individual in practicing consistent and correct movements. However, without evidence-based data, the therapeutic value and best practices associated with sit-to-stand transfers cannot be determined.

Thus, the purpose of this study was to compare the movement patterns and muscular demands during clinician-assisted transfers with 3 forms of device-assisted sit-to-stand transfers in individuals who recently had a stroke (see also a video abstract for this study, available at ptjournal.apta.org). We specifically evaluated device usage in survivors of stroke because cerebrovascular accidents are a leading cause of disability in the United States. More than 795,000 individuals have a stroke each year,[25] and approximately two thirds of those who survive require rehabilitation to improve independence.[26]

On the basis of our previous research,[23] clinical observations, and the study aims, we hypothesized that (1) device-assisted transfers would result in slower movements than clinician-assisted transfers, (2) sagittal-plane motions of the trunk (flexion) and ankle (dorsiflexion) would be limited during device-assisted transfers compared with when only the clinician facilitated the transfer, and (3) clinician guidance (physical or verbal) during transfers would facilitate greater lower extremity muscle activation compared with not encouraging patient engagement. The knowledge gained from this study may be used to evaluate the potential therapeutic uses of the sit-to-stand transfer device in rehabilitation.

Method

Participants

Participants included were adults with hemiparesis caused by ischemic or intracerebral hemorrhage (time since stroke onset ≤1 month; use of a mechanical lift for transfers; a Functional Independence Measure [FIM] transfer score of ≤3; and in stable cardiovascular condition [ie, class B according to the American College of Sports Medicine]). Participants were excluded if they had bilateral, cerebellar, or brain-stem cerebrovascular accidents; were unable to understand simple commands because of language or cognitive deficits; did not transfer independently before their stroke or had orthopedic limitations (eg, severe lower extremity contractures, recent fracture[s] or severe osteoporosis that would interfere with their ability to transfer); or had any other significant neuromuscular condition beyond a stroke (eg, Parkinson disease).

During the study time frame, a total of 66 patients were admitted to Madonna Rehabilitation Hospital's inpatient stroke service. Three patients were deemed ineligible because they had a bilateral stroke and 15 because they lacked unilateral weakness. The remaining 48 patients were screened and contacted for study inclusion. Thirty-eight patients were excluded because they had a cerebellar or brain-stem stroke, were unable to understand simple commands, did not transfer independently before their stroke, had orthopedic limitations that would interfere with their ability to transfer, had another significant neuromuscular condition, or refused to participate.

Ten adults (3 women, 7 men) with hemiparesis secondary to a unilateral cortical stroke that occurred within 1 month were included in this study. All participants used a mechanical lift for transfers and required moderate to total assistance to transfer. With an average FIM total score of

The Bottom Line

What do we already know about this topic?

Although sit-to-stand (STS) transfer devices have been widely adopted by rehabilitation nurses to reduce work-related musculoskeletal disorders, physical therapists have hesitated to adopt these devices due to concerns about their therapeutic value.

What new information does this study offer?

This study compared clinician-assisted, device-assisted, and the combination of clinician- and device-assisted STS transfers in people poststroke. Hip and knee joint movement patterns were similar across conditions. During device-assisted transfers, forward trunk flexion was lacking and ankle motion was restrained. Clinician encouragement and guidance during device-assisted transfers led to increased lower extremity muscle activation.

If you're a patient, what might these findings mean for you?

If encouraging greater activation of the vastii muscles is an important therapeutic goal, then device-assisted transfers—where the patient exerts his or her best effort and the clinician provides guidance—may provide a means of challenging the knee extensors.

Table 1.
Selected Clinical and Anthropometric Characteristics of the Study Participants at the Time of Admission

Characteristic	Values
Age, (y)	69 (12.5)[a]
Height, (cm)	171 (9.61)[a]
Weight, (kg)	94 (21.1)[a]
Sex	7 male/3 female
Paretic side	7 left/3 right
Days poststroke	14.4 (13.4)[a]
Functional Independence Measure total score[c]	42.6 (10.0)[a]
Motor subscale total score[d]	21.2 (5.3)[a]
Transfers: bed, chair, wheelchair score	1 (0)[b]
Transfers: toilet transfer score	1 (0)[b]
Transfers: tub, shower score	1 (2)[b]
Locomotion: walk/wheelchair score	1 (3)[b]
Locomotion: stairs score	1 (0)[b]

[a] Mean (SD).
[b] Median (range).
[c] Ranges from 18 (total dependence) to 126 (total independence).
[d] Ranges from 13 (total dependence) to 91 (total independence).

42.6 and an average motor subscale total of 21.2, a majority of the participants were considered completely dependent at admission (Tab. 1).

Clinician

The same licensed physical therapist (36 years old) provided assistance for all participants. The physical therapist was trained in the neurodevelopmental treatment approach for treating adults with hemiplegia and had 10 years of experience working in an inpatient acute rehabilitation stroke program. The physical therapist positioned herself along the patient's more affected side and provided hands-on facilitation and verbal cueing to promote a more natural sit-to-stand movement pattern, improved postural control, and muscle activation. For manual transfers that posed patient safety concerns, a trained rehabilitation associate (28 years old) provided assistance to the nonaffected side while the physical therapist provided primary assistance to the affected side.

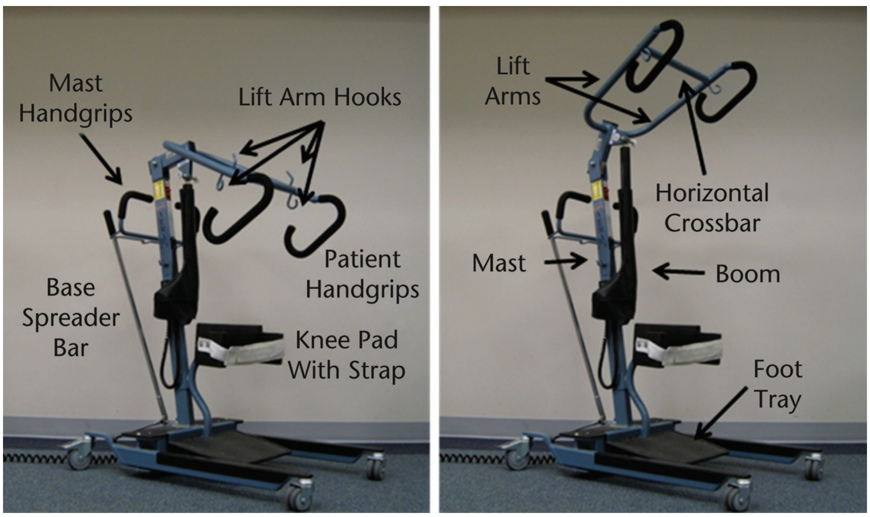

Figure 1.
VERA-LIFT sit-to-stand device.

Sit-to-Stand Device

A VERA-LIFT sit-to-stand device (model V350, Vancare Inc, Aurora, Nebraska) was used for all transfers (Fig. 1). According to the manufacturer, the lift has a heavy-duty frame for patients weighing up to 158.76 kg (350 lb) and swiveling hand grips for client comfort and security. A handheld electronic switch raised and lowered a 54-cm-long boom. A double–strap, contoured back belt secured the client to the boom's 4-point attachment arm with the use of the lift arm hooks. The back belt was wide enough to fit from the top of the buttocks to approximately 5 cm below the lower edge of the client's shoulder blades. A height-adjustable, nonslip foot tray (43 × 32 cm) was located approximately 11 cm above floor level and tilted approximately 8 degrees upward (heel to toe). A dense foam knee pad (approximately 46 × 16 cm) with a Velcro (Velcro USA Inc, Manchester, New Hampshire) safety strap prevented accidental stepping off and knee collapse during transfers. This device was used because it was the primary sit-to-stand tool used at Madonna Rehabilitation Hospital during the study period.

Instrumentation

Three-dimensional joint kinematics were recorded (60 Hz) with the use of the Qualisys Motion Capture System (Qualisys AB, Gothenburg, Sweden), including 12 Oqus Series-3 cameras, retroreflective markers (12.5-mm diameter), and 12 marker clusters. The capture volume was maximized and marker loss was minimized by positioning 4 tripod cameras around the participant and

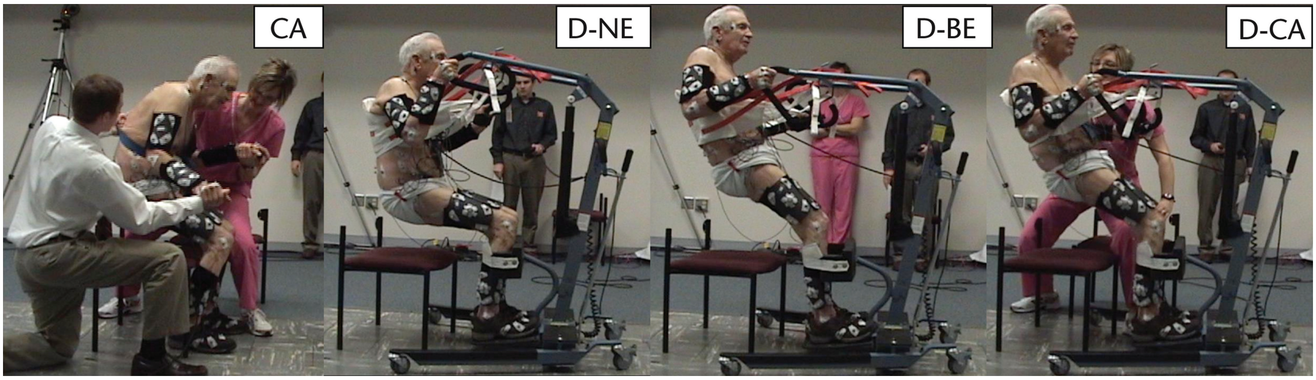

Figure 2.
Sit-to-stand transfer conditions: CA=clinician-assisted, D-NE=device-assisted with no patient effort, D-BE=device-assisted with patient's best effort, D-CA=device-assisted with verbal and physical guidance from the clinician.

the sit-to-stand device. Surface electromyography (EMG) signals were collected through the use of the MA-300-10 EMG system and MA-311 preamplified surface electrodes (Motion Lab Systems Inc, Baton Rouge, Louisiana). The EMG signals were low-pass filtered (500 Hz) and digitally recorded (1,200 Hz).

Procedure

This cross-sectional, repeated-measures study was conducted from October to December 2009 in the Institute for Rehabilitation Science and Engineering at Madonna Rehabilitation Hospital. After written informed consent was obtained, bipolar EMG electrodes were taped over the muscle bellies of the affected leg's gluteus maximus, lateral hamstring, vastus lateralis, tibialis anterior, and gastrocnemius muscles following standard procedure.[27] After the electrodes were attached to the participant, three 5-second maximum voluntary contractions (MVCs) were recorded for each muscle through the use of standardized muscle testing positions if the participant exhibited selective control or mass patterns if selective control was lacking.[28] Placement of the electrodes and MVCs were validated by inspecting a real-time display of the EMG signals arising from specific resisted movements (WinDaq Pro v2.72 software with DI-720 A/D Board, DATAQ Instruments Inc, Akron, Ohio). Next, a 5-second resting trial was recorded to determine the baseline noise for the EMG data. The MVC and resting data were used for subsequent EMG signal processing.

To determine sagittal-plane trunk, pelvis, and affected-side lower extremity kinematics, reflective markers were placed bilaterally over the acromial processes, iliac crests, posterior superior iliac spines (PSISs), anterior superior iliac spines, lower extremity greater trochanter, medial and lateral femoral condyles, medial and lateral malleoli, posterior heels, medial first metatarsals, distal second and third metatarsal heads, distal lateral fifth metatarsal heads, and lateral borders of the midfoot.[29] Twelve tracking marker clusters were secured on the trunk, thighs, and shanks.[30] After marker placement, a static calibration trial was recorded for subsequent kinematic data processing.

Each participant practiced the sit-to-stand movement from a 45.7-cm-high (18-in-high), armless, and backless chair several times with the clinician's assistance until both the participant and clinician were comfortable with the transfer. The participant then performed each of the following movements, in a randomized order (Fig. 2):

1. **Clinician-assisted sit-to-stand movement with no device assistance (CA).** Instruction: "We would like you to allow [the clinician] to lift you into a standing position. Please assist as best you can and follow any instructions that she gives you during the movement."

2. **Device-assisted sit-to-stand movement using no effort (D-NE).** Instruction: "We would like you to let the device lift your entire body weight. Try to not provide any effort in assisting the device. Lean back into the device so that it can support your whole body weight."

3. **Device-assisted sit-to-stand movement exerting best effort (D-BE).** Instruction: "We would like you to stand up with the device. Use your legs to assist the device as you stand. Please do not use your arms to lift your body."

4. **Device- and clinician-assisted sit-to-stand movement (D-CA).** Instruction: "We would like you to stand up as best you can with the device. [The clinician] will provide you with guidance as you stand. Please do not use your arms to lift your body."

Device-assisted transfers (D-NE, D-BE, and D-CA) were completed in accordance with the VERA-LIFT operating manual as well as published guidelines.[31–33] For clinician-assisted transfers (CA and D-CA), the clinician-assisted the participant by guiding the movement through tactile and verbal feedback to promote a sit-to-stand pattern that the clinician believed would lead to client independence. Participants were provided with a rest period between trials until they indicated readiness to perform the next activity.

Data Analysis

All participants completed at least 1 trial for each condition and, if endurance permitted, 2 consecutive trials of the same condition. Data from either the single trial or the average of the 2 trials were used to analyze each transfer condition. Although other methods have been used to define the movement cycle (MC),[34] left PSIS marker data were used to define the duration of the MC. *Onset*, or zero percent of the movement cycle (0% MC), was defined as the frame at which the left PSIS marker's location increased vertically (z-direction) >3 standard deviations from the average of the first 100 frames before motion initiation. *Cessation* (100% MC) was defined as the frame at which the marker reached the maximum most anterior (x-direction) position. The time required to complete the transfer was calculated as the duration from onset to cessation averaged across trials and participants for each condition.

Motion data were processed with Visual3D software (CA-Motion Inc, Germantown, Maryland) to produce 3-dimensional trajectories for each marker. These data were filtered with a 6-Hz Butterworth low-pass digital filter. The position and orientation of the trunk, pelvis, thigh, shank, and foot segments in the laboratory coordinate system were obtained, and Visual3D algorithms were used to determine trunk, pelvis, and lower extremity joint angles for each percentage of the movement cycle. Sagittal-plane trunk, pelvis, and thigh orientations were expressed relative to vertical, whereas hip, knee, and ankle joint angles were generated by their relative segments. Separate time-normalized, ensemble-averaged joint angle plots were created for each participant and condition. Within these ensemble plots the start, end, and peak joint angle values were identified. Four group ensemble-averaged profiles (CA, D-NE, D-BE, and D-CA) were created for each joint angle.

The Visual3D software also filtered, integrated, normalized, and determined the peak and mean EMG activity for each muscle. Specifically, after adjustment for direct current bias and baseline noise, the EMG data were digitally filtered (60-Hz notch; Butterworth 10-Hz high-pass and 350-Hz low-pass filters), full-wave rectified, and integrated over 0.01-second intervals. Processed EMG signals were normalized and expressed as a percentage of the maximum recorded within a 0.05-second moving window average of either the MVC or any of the sit-to-stand transfer trials. Because the signals were normalized to any maximum muscle contraction that occurred during testing, EMG data were expressed as a percentage of maximum voluntary contraction (% MVC).

All statistical analyses were carried out with the use of SigmaPlot Software (version 11, Systat Software Inc, Chicago, Illinois), with significance set at the $P<.05$ level. Descriptive statistics were performed to describe all key variables. Assumptions of normality were examined with the use of the Shapiro-Wilk test. Twenty-nine separate, parametric 1-way analyses of variance (ANOVAs) with repeated measures were performed to determine the differences in transfer time, joint kinematics (start, peak, end), and muscle activity (peak, mean) across the 4 sit-to-stand conditions. If assumptions of normality were violated, the Friedman ANOVA on ranks (nonparametric) was performed. Post hoc Tukey tests were performed for significant between-conditions effects.

Role of the Funding Source

This research was supported, in part, by the Undergraduate Creative Activities and Research Experiences Program, Agricultural Research Division grants from the University of Nebraska–Lincoln, and the Donald and Pearl Winkler for Stroke Research Institute Endowment.

Results

All participants were able to perform 2 consecutive trials of each testing condition, except for 1 participant who completed only 1 trial of the D-NE and D-BE conditions because of fatigue. The time required to complete a sit-to-stand transfer was approximately twofold longer during device-assisted transfers (D-NE=9.1±0.8 seconds; D-BE=8.7±0.4 seconds; D-CA=8.5±0.4 seconds) versus clinician-assisted transfers (CA=4.6±1.7 seconds; $F_{3,39}$=45.3, $P<.001$).

Kinematics

The mean ensemble joint angle graphs are provided in Figure 3, and a comparison of the mean start, peak, and end joint angles is presented in Table 2. The 21-degree excursion of trunk flexion documented during CA resulted in significantly greater forward trunk lean at the 3 epochs evaluated (ie, start, peak, and end of transfer) compared with the distinctly extended posture maintained throughout the device-assisted conditions ($P<.001$). The pelvis displayed a wave of increasing anterior tilt during CA, contrasting notably with the relatively gradual transition from posterior to anterior tilt during the device-assisted conditions. This contrasting motion pattern resulted in significantly greater anterior tilt at the beginning (P=.009) and at the peak of motion (P<.001) for CA compared with the 3 device-assisted conditions.

At the hip (expressed as thigh versus pelvis), all 4 conditions started in approximately 90 degrees of flexion and then gradually increased an additional 3 to 11 degrees during the first third of the movement cycle as the proximal pelvis tilted anteriorly. Hip extension characterized the latter two thirds of the transfer across all conditions. At the end of the transfer, participants remained in greater hip flexion during D-NE compared with D-CA (36° versus 23°; P=.026).

The thigh (expressed relative to vertical) remained relatively stationary in the sagittal plane at the start of motion, as evidenced by the plateau in motion that occurred during the first 10% of the movement cycle. Start and peak thigh flexion angles were 12 to 15 degrees greater during the device-assisted conditions compared with CA (P<.001). At the end of the transfer, the thigh was 8 to 9 degrees more flexed during D-NE compared with all other conditions (P<.001), which contributed to the increased hip flexion also recorded for this condition at the end of the transfer.

The 94-degree start position in the knee for CA was 6 to 7 degrees less than the device-assisted conditions (P=.005). Peak knee flexion closely approximated the start position (both in amplitude and timing), with CA postured in notably less flexion than D-NE and D-CA (P=.019). After an initial plateau across all conditions, the knee gradually extended during the remainder of the transfer. Although none of the conditions ended in full extension (ie, 0° flexion), the final position of D-NE was more flexed than the final position for the remaining 2 device-assisted conditions (22° versus 13°; P=.004).

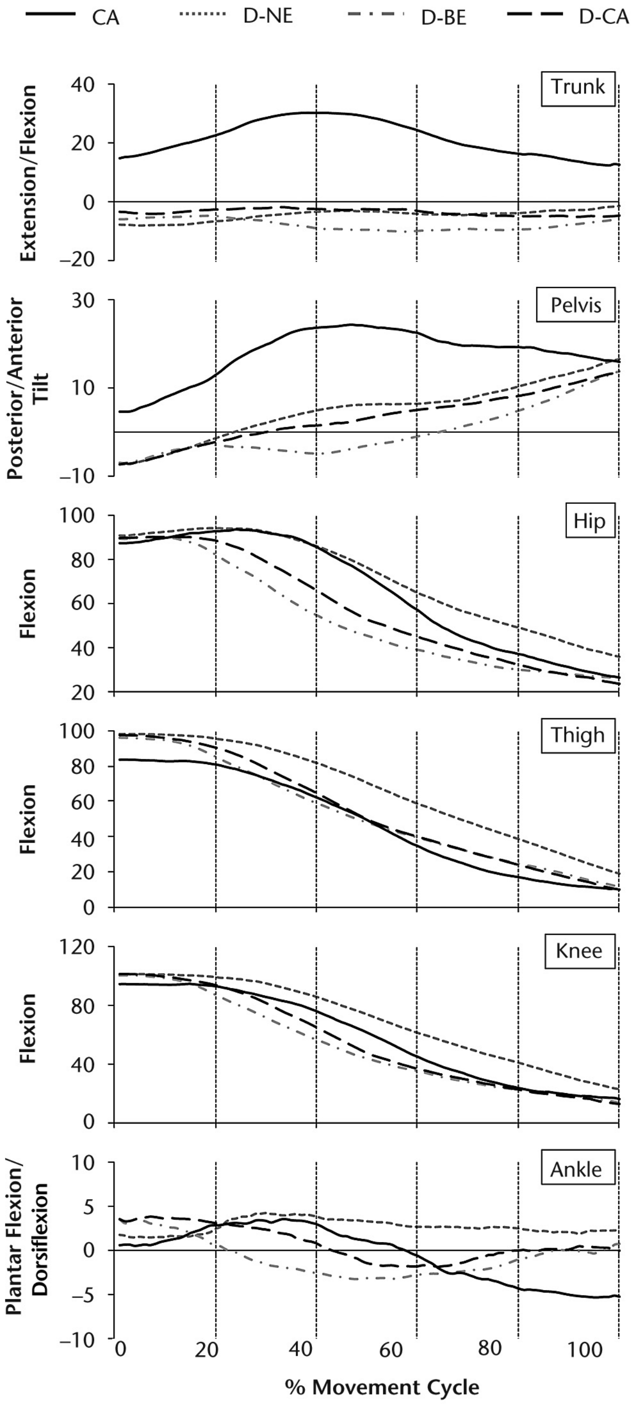

Figure 3.
Ensemble-averaged (n=10) sagittal-plane mean joint angles (degrees) of the trunk, pelvis, hip, thigh, knee, and ankle recorded during sit-to-stand transfers with clinician-assisted (CA, solid line), device-assisted with no patient effort (D-NE, dotted line), device-assisted with patient's best effort (D-BE, dash-dotted line), and device-assisted with verbal and physical guidance from the clinician (D-CA, dashed line) conditions.

Table 2.
Comparison of Mean (SD) Start, Peak, and End Joint Angles (°) During Sit-to-Stand Transfers[a]

Joint	Phase	CA	D-NE	D-BE	D-CA	Statistical Significance	Results
Trunk	Start	15 (8)	−8 (9)	−6 (9)	−4 (9)	$F_{3,39}$=43.45, P<.001	CA > ALL
	Peak	33 (8)	2 (9)	−1 (8)	2 (8)	$F_{3,39}$=100.2, P<.001	CA > ALL
	End	12 (12)	−2 (8)	−6 (7)	−5 (6)	$F_{3,39}$=16.72, P<.001	CA > ALL
Pelvis	Start	4 (12)	−7 (7)	−7 (7)	−8 (10)	χ^2 (3, n=40)=11.52, P=.009	CA > ALL
	Peak	29 (8)	17 (7)	14 (7)	14 (9)	$F_{3,39}$=27.98, P<.001	CA > ALL
	End	16 (8)	17 (7)	14 (7)	13 (9)	No significant difference	
Hip	Start	87 (15)	91 (11)	89 (12)	90 (13)	No significant difference	
	Peak	98 (11)	96 (11)	92 (13)	95 (14)	No significant difference	
	End	26 (13)	36 (13)	25 (10)	23 (10)	χ^2 (3, n=40)=9.24, P=.026	D-NE > D-CA
Thigh	Start	83 (9)	98 (9)	96 (9)	97 (9)	$F_{3,39}$=130.4, P<.001	ALL > CA
	Peak	84 (9)	98 (9)	96 (9)	97 (9)	$F_{3,39}$=105.1, P<.001	ALL > CA
	End	10 (9)	19 (10)	11 (10)	10 (9)	$F_{3,39}$=13.04, P<.001	D-NE > ALL
Knee	Start	94 (14)	101 (14)	100 (14)	101 (13)	$F_{3,39}$=5.35, P=.005	ALL > CA
	Peak	95 (13)	102 (14)	100 (14)	101 (13)	$F_{3,39}$=3.93, P=.019	D-NE, D-CA > CA
	End	16 (10)	22 (12)	13 (13)	13 (11)	$F_{3,39}$=5.56, P=.004	D-NE > D-BE, D-CA
Ankle	Start	1 (8)	2 (6)	3 (8)	3 (6)	No significant difference	
	Peak	6 (7)	6 (6)	5 (7)	6 (6)	No significant difference	
	End	−5 (5)	2 (6)	1 (9)	0 (8)	$F_{3,39}$=7.01, P<.001	ALL > CA

[a] CA=clinician-assisted, D-NE=device-assisted with no patient effort, D-BE=device-assisted with patient's best effort, D-CA=device-assisted with verbal and physical guidance from the clinician, ALL=other 3 conditions, F test statistic from the parametric analysis of variance tests, chi-square test statistic from nonparametric Friedman analysis of variance on ranks tests.

Table 3.
Comparison of Mean (SD) Peak and Mean (% MVC) Muscle Activity During Sit-to-Stand Transfers[a]

Muscle	Variable	CA	D-NE	D-BE	D-CA	Statistical Significance	Results
Gluteus maximus	Peak	18 (35)	9 (26)	14 (29)	19 (34)	No significant difference	
	Mean	4 (9)	2 (5)	4 (8)	6 (9)	No significant difference	
Lateral hamstring	Peak	20 (22)	8 (12)	32 (37)	19 (28)	$F_{3,39}$=3.06, P=.045	D-BE > D-NE
	Mean	8 (10)	2 (3)	11 (14)	9 (14)	No significant difference	
Vastus lateralis	Peak	39 (37)	26 (33)	63 (42)	61 (36)	$F_{3,39}$=4.21, P=.014	D-BE, D-CA > D-NE
	Mean	17 (17)	11 (14)	21 (15)	22 (14)	No significant difference	
Gastrocnemius	Peak	43 (31)	12 (20)	19 (23)	24 (27)	$F_{3,39}$=4.07, P=.016	CA > D-NE
	Mean	15 (8)	5 (7)	7 (7)	10 (9)	$F_{3,39}$=5.60, P=.004	CA > D-BE, D-NE
Tibialis anterior	Peak	35 (41)	6 (17)	26 (40)	28 (41)	$F_{3,39}$=2.98, P=.049	CA > D-NE
	Mean	14 (16)	2 (6)	12 (19)	12 (18)	No significant difference	

[a] MVC=maximum voluntary contraction, CA=clinician-assisted, D-NE=device-assisted with no patient effort, D-BE=device-assisted with patient's best effort, D-CA=device-assisted with verbal and physical guidance from the clinician, F test statistic from the parametric analysis of variance tests.

Start and peak ankle dorsiflexion angles did not vary significantly across conditions. However, the end position of 5 degrees of plantar flexion for CA did differ significantly from the relatively neutral position of the ankle during the device-assisted conditions (P<.001). The total arc of motion of the ankle during CA (11°) was distinctly larger than the 4 to 6 degrees documented during the device-assisted conditions.

Electromyography

As expected, D-NE consistently demonstrated the lowest muscular activation levels across conditions; however, these differences achieved statistical significance for only 5 of the 10 comparisons (Tab. 3). Two knee stabilizers (lateral hamstring and vastus lateralis muscles) displayed greater peak EMG activation during D-BE compared with D-NE (P=.045 and P=.014, respectively). The D-CA condition also resulted in greater peak vastus lateralis muscle EMG activity compared with D-NE (P=.014). Distally, the gastrocnemius and tibialis anterior muscles displayed greater peak EMG activation during CA compared with D-NE (P=.016 and P=.049, respectively). The CA condition also resulted in greater mean gastrocnemius activation compared with D-BE and D-NE (P=.004).

Discussion

After a stroke, profound weakness and instability frequently make it difficult for patients to move independently between surfaces. As a result, relearning to safely transfer is often a central goal of many inpatient stroke rehabilitation programs. Whereas current practice paradigms emphasize the importance of mass repetition for learning, the repetitive lifting associated with patient transfers unfortunately increases a clinician's risk for work-related musculoskeletal disorders.[2] Mechanical lift devices offer a promising means for reducing injuries arising from transfers, yet widespread use in the rehabilitation setting remains limited, given therapists' concerns that these devices may not promote therapeutically meaningful practice. Consequently, the current study compared the movement patterns and muscular demands during clinician-assisted transfers with 3 forms of device-assisted sit-to-stand transfers (no effort, best effort, and clinician-guided).

As hypothesized, device-assisted transfers were twofold longer in duration than clinician-assisted transfers despite device setup and patient preparation times not being included. If time efficiency is the sole determining factor, clinicians might opt to perform transfers without the lifting device. However, the long-term concern would be clinician injuries. An alternative approach would be to capitalize on this temporal difference to promote muscle endurance by encouraging patients to exert their best effort during slow device-assisted transfers (with or without clinician assistance). Further research is needed to better understand potential implications of slow movement training within the context of task-specific training principles for neuroplastic reorganization and muscle fiber recruitment (ie, slow versus fast twitch). Additionally, sit-to-stand device manufacturers might consider incorporating alternative lift speeds.

Consistent with our second hypothesis, trunk flexion and ankle dorsiflexion were limited during device-assisted transfers compared with CA. The 33-degree peak forward trunk flexion during CA closely approximated the 36-degree peak flexion angle recorded in adults without known pathology previously documented during unassisted sit-to-stand transfers from a similar height chair.[23] Probable causes for the limited forward trunk flexion during the device-assisted conditions in the current study were multifold. First, a horizontal crossbar on the lift blocked forward trunk lean to approximately 20 degrees because any further forward flexion might have resulted in the client's head contacting the metal bar. Next, the back belt or sling that wrapped posteriorly around the trunk provided elevation and forward translation of the trunk. If a client leaned forward, the back belt would have become slack, thus lessening support for lifting the head, arms, and trunk. Additionally, the design of the back belt did not incorporate a mechanism to limit excess forward trunk flexion. It is possible that if clients with weak trunk extensors flexed forward, they may collapse forward, potentially resulting in injury.

The final flexed posture of the trunk during CA contrasted notably with the trunk extension at the end of device-assisted transfers and with the approximately 2-degree extension previously documented for normal sit-to-stand transfers in young adults without known disability.[23] The differences may have reflected the final support points available for maintaining stability at the end of the transfer. Specifically, at the end of CA, participants sometimes leaned forward onto the clinician, who provided a countersupport to prevent forward collapse of the trunk, whereas the inherent design of the device (ie, lift crossbar and flexible back belt) prevented forward trunk flexion during device-assisted transfers. Despite our clinician's best effort, the difference in the end posture of the trunk during CA compared with normal sit-to-stand transfers reflects the struggle clinicians often face when balancing safety, stability, and promotion of "optimal" movements in patients with profound weakness and balance deficits.

At the ankle, the foot tray of the device and knee pad limited ankle dorsiflexion to a 6-degree arc, which was considerably smaller than the 11-degree range observed in CA. The combination of the distal stability created by the knee pad and the foot tray constrained the anterior translation of the proximal tibias normally present during the sit-to-stand transition.

Encouraging effort (either through physical cueing/assistance or verbal encouragement) resulted in greater activation of the muscles studied compared with when participants were told to "let the device lift your entire body weight," although these differences were not always statistically significant. The increased activity documented in the gastrocnemius and tibialis anterior during CA helped stabilize the ankle through a larger arc of motion compared with conditions in which the lower leg was tethered to the device. It is interesting to note that the normalized peak activity of the tibialis anterior muscle during CA (35% MVC) was less compared with the peak tibialis anterior muscle demands previously documented when individuals without disability stood from a chair of similar height (85% MVC).[23] Although comparing the muscle activity of individuals without disability with patients soon after stroke should be done cautiously, the nearly twofold difference in amplitude suggests muscle activation pattern differences. Normally, the tibialis anterior muscle helps advance the tibia and ultimately the mass of the head, arms, and trunk as a person transitions from a seated to standing position.

During CA, it is possible that the clinician facilitated this forward advancement, diminishing the need for the tibialis anterior muscle activity in participants recovering from a stroke. Given that peak ankle dorsiflexion was less during CA in individuals after stroke than in normal sit-to-stand transfers (6° versus 27°, respectively),[23] it also is possible that the clinician purposefully blocked forward collapse of the tibia and thus the need for tibialis anterior muscle activity to draw the ankle forward. Normalized peak gastrocnemius muscle activity was actually greater during CA in individuals after stroke compared with normative control individuals performing an unassisted sit-to-stand transfer (43% versus 17% MVC),[23] despite the finding that they remained in relatively less dorsiflexion throughout the transfer. It is conceivable that the sustained forward trunk lean during CA resulted in an increased external dorsiflexion torque at the ankle that necessitated greater activity of the plantar flexors to help maintain stability. Future research incorporating kinetics may help elucidate the impact of abnormal proximal postures on distal muscle demands. Additionally, studies exploring the impact of calf strap tightness on ankle motion and muscle activation patterns could help guide clinicians in optimizing therapeutic use of the device.

With encouragement and guidance from the clinician, participants exerted higher activation of the vastus lateralis muscle during D-BE and D-CA compared with D-NE. If encouraging greater activation of the vastii is an important therapeutic goal for those performing device-assisted transfers, then D-BE or D-CA may provide a means of challenging the knee extensors. Further work assessing different facilitation techniques as well as quantifying the forces imparted by clinicians onto participants is needed to refine cueing approaches during device-assisted transfers.

In summary, helping patients relearn to transfer is a central goal addressed by many therapists during physical rehabilitation. The elevated risk of back injury in therapists performing more than 6 to 10 transfers per day[2] highlights the need to explore alternative strategies to help patients relearn to transfer. A conflict exists between the need for mass repetition during practice to improve learning and the need to prevent overuse injuries in therapists. Simply telling clinicians to use "good mechanics" is not an adequate safeguard from injury. Although device-assisted transfers do not fully mimic previously documented normative kinematic and muscle demands of sit-to-stand transfers, they do provide a means for diminishing the physical demands placed on the clinician. After positioning the patient in the device, the clinician can simply push a button, and the device will elevate the patient to a standing position. Encouraging greater patient engagement either by verbal cueing to give one's "best effort" or physical cueing to better align the "nose over the toes" positively affected muscle effort. It is worth noting that transfers facilitated solely by the clinician did not fully mimic normal sit-to-stand movement patterns and muscle demands. Although variability might be expected across clinicians, it is improbable that a clinician can independently facilitate a completely normal movement pattern in a person with profound weakness, movement deficits, or sensory loss.

Given a goal of promoting optimal patient rehabilitation outcomes, while minimizing injuries and costs associated with the use of multiple clinicians to facilitate a transfer, the time has come for therapists to consider shifting their paradigm to more fully embrace functionally meaningful training technology. Undoubtedly, a dedicated consortium of clinicians, researchers, manufacturers, and patients could design a sit-to-stand device that addresses patient and clinician needs. It is recommended that future sit-to-stand devices redesign the horizontal crossbar and back belt to accommodate safe forward trunk lean, modify the foot tray and knee pad to allow for more ankle and shank range of motion, include lift speed adjustability, and incorporate biofeedback of the amount and symmetry of patient effort. In light of the current emphasis within the inpatient rehabilitation setting to more rapidly discharge clients,[35] it is of paramount importance that we address this need sooner rather than later.

A key limitation in this study was that only one kind of lifting device was tested. Lifting devices with different designs may lead to alternative patient kinematics and muscle activation patterns. Finally, while providing a strong starting foundation, the specific techniques that the single clinician applied to transfer individuals during the early stages of stroke recovery may limit generalizability to other sit-to-stand device users.

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