1-2015

Weight-Bearing Asymmetry in Individuals Post-Hip Fracture During the Sit to Stand Task

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Weight-bearing asymmetry in individuals post-hip fracture during the sit to stand task

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Keywords:
Hip fracture
Sit to stand
Kinetics
Ground reaction force

A B S T R A C T

Background: Individuals post hip fracture decrease force on the involved limb during sit to stand tasks, creating an asymmetry in vertical ground reaction force. Joint specific differences that underlie asymmetry of the vertical ground reaction force are unknown. The purpose of this study was to compare differences in vertical ground reaction force variables and joint kinetics at the hip and knee in participants post-hip fracture, who were recently discharged from homecare physical therapy to controls.
Methods: Forty-four community-dwelling older adults, 29 who had a hip fracture and 15 elderly control participant's completed the sit to stand task on an instrumented chair with 3 force plates. *T*-tests were used to compare clinical tests (Berg Balance Scale, activity balance confidence and gait speed, isokinetic knee strength) and vertical ground reaction force variables. Two-way analyses of variance compared vertical ground reaction force variables and kinetics at the hip and knee between hip fracture and elderly control groups. Pearson correlation coefficients were used to determine correlations between clinical and vertical ground reaction force variables.
Findings: Vertical ground reaction force variables were significantly lower on the involved side for the hip fracture group compared to the uninvolved side and controls. Lower involved side hip and knee moments and power contributed to lower involved side vertical ground reaction force. Vertical ground reaction force variables and strength had moderate to high correlations with clinical measures.
Interpretation: Uninvolved side knee moments and powers were the largest contributors to asymmetrical vertical ground reaction force in participants post-hip fracture. The association of vertical ground reaction force variables and clinical measures of function suggesting reducing vertical ground reaction force asymmetry may contribute to higher levels of function post-hip fracture. Functional and strength training should target the involved knee to reduce vertical ground reaction force asymmetry.

1. Introduction

Hip fracture is a significant public health concern because of its prevalence, financial costs, and serious medical consequences. The cost of hip fractures in the U.S. is over 8 billion dollars per year ((CDC), 2010; Brainsky et al., 1997; Etxebarria-Foronda and Mar, 2013; Hoerger et al., 1999; Ohsfeldt et al., 2006). While the incidence of hip fracture has decreased due to prevention because of the larger number of elders, the prevalence of hip fractures continues to increase (Adams et al., 2013; (CDC), 2010; Etxebarria-Foronda and Mar, 2013). Amplifying the impact of this increased prevalence, the functional loss associated with hip fracture is high with approximately 50% of community-dwelling elder's experiencing a long-term loss of function after a hip fracture. The loss in function after hip fracture occurs despite rehabilitation protocols directed to restore impairments and reduce functional limitations (Kammerlander et al., 2011; Kristensen, 2011).

Although multimodal rehabilitation programs focus on restoring pre-fracture function only 50% achieve pre-fracture status (Magaziner et al., 2003). The loss of physical function can be devastating to the patient even though independence, using compensatory strategies, is reached (Magaziner et al., 2003). Usual care post-hip fracture is multimodal including strength (unilateral and bilateral), balance, and functional training (Binder et al., 2003, 2004; Host et al., 2007; Magaziner et al., 2000b). Despite multimodal training approaches, significant functional deficits as compared to pre-fracture persist. (Orwig et al., 2011). This has led to clinical trials of higher intensity training in an attempt to improve function (Host et al., 2007) These studies show the potential for greater improvements in strength and function to restore individuals to pre-fracture levels of function (Binder et al., 2004; Host et al.,

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2007; Mangione et al., 2005). However, identifying key targets for training to enhance recovery to pre-fracture status remains a priority.

One of the more difficult functional tasks is the sit to stand task (STS), making it a good measure for determining outcomes after hip fracture. Compared to walking and stair climbing, the STS task is the most demanding, requiring higher hip and knee moments (Mak et al., 2003). As a result, high hip and knee joint moments during an STS task frequently require compensations (high seat height, arm rests, and greater uninvolved limb strength) post-hip fracture to maintain independence. For individuals who sustain a hip fracture, restoring STS independence is an important functional ability to return patients to community-dwelling status. To optimize usual care, clinicians often target hip and knee strength during multimodal treatment to maintain or restore STS ability (Mangione et al., 2005; Palombaro et al., 2006). Yet studies note persistently impaired involved side function during STS transfers despite multimodal treatment (Nightingale et al., 2010; Sherrington et al., 2004).

Fig. 1. Sit to stand starting position.

Persistent side-to-side asymmetry of the vertical ground reaction force (vGRF) during an STS task may be an important functional variable to target during rehabilitation (Houck et al., 2011; Kneiss et al., 2012). Elderly participants demonstrate side-to-side asymmetry of the vertical ground reaction force (vGRF) of less than 10% during an STS task (Houck et al., 2011; Kneiss et al., 2012). In contrast, studies of participants 4–12 months post-fracture demonstrate side-to-side asymmetries of 30% to 40%, typically favoring the uninjured side (Houck et al., 2011; Kneiss et al., 2012). It is unclear why multimodal treatment and/or natural recovery did not lead to symmetry of vGRF during an STS task (Houck et al., 2011). Interestingly, participant's post-hip fracture demonstrate the capacity to generate equivalent side-to-side vGRF during an STS task, however, persists in selecting an asymmetrical vGRF pattern (Kneiss et al., 2012). Although not directly tested, this finding suggests hip and knee strengthening may not remediate side-to-side vGRF asymmetries. Further, the correlation between vGRF and clinical variables in a small sample of participants showed that function (lower extremity measure $r = 0.6$ and gait speed $r = 0.6$) was associated with STS task (Houck et al., 2011). These findings suggest more studies of vGRF symmetry during an STS task in participants post-hip fracture are warranted.

To date, studies of vGRF are limited by a small sample ($n = 14$ hip fracture participants), data collected over a wide range of time points, and no joint specific kinetic data (Houck et al., 2011; Kneiss et al., 2012). Larger samples of community-dwelling individuals post-hip fracture that are likely to benefit from higher intensity rehabilitation approaches are desirable to capture the variability of patient responses (Houck et al., 2011; Kneiss et al., 2012). Collecting data at discharge from rehabilitation has the advantage of documenting the current success of rehabilitation in re-establishing movement patterns like symmetrical vGRF. It is currently unclear if current rehabilitation approaches are successful at restoring vGRF symmetry post-hip fracture. Another criticism of current studies is the lack of joint specific kinetic data. Joint specific kinetic data (i.e., joint moments and powers) from the hip and knee could assist therapists understanding of muscle function responsible for a lower vGRF of the involved limb. Although clinical correlations with vGRF were explored in a previous study (Houck et al., 2011), the spectrum of clinical variables (strength, balance, and function) explored was limited. Including vGRF data from larger samples of hip fracture participants, joint kinetic movement patterns, and correlations with a wider set of clinical variables may inform a targeted approach to restore vGRF symmetry during an STS task post-hip fracture.

The three aims of this study were: (1) to determine differences in vGRF variables between the involved and the uninvolved limbs in participants post-hip fracture compared to controls; (2) to determine differences in hip and knee joint kinetics between the involved and the uninvolved limbs in participants post-hip fracture compared to controls; and (3) to examine the correlations between vGRF variables and specific clinical variables.

For aim one, the hypothesis was that the rate and magnitude of the involved side STS vGRF variables would be significantly lower compared to the uninvolved side and controls. For aim two, the hypothesis was that a combination of lower involved side hip and knee moments and powers results in lower vGRF (involved side). This hypothesis is consistent with lower contributions of the involved side hip and knee extensor muscles, explaining the lower involved side vGRF. A parallel hypothesis was that a combination of higher uninvolved side hip and knee powers would be associated with higher uninvolved side vGRF. For aim three, it was hypothesized that clinical variables of balance and function would be strongly correlated ($r > 0.7$) to vGRF variables.

2. Methods

2.1. Participants

A convenience sample of 44 participants, who were community-dwelling elderly, participated in the study. Twenty-nine participants had recovered from a hip fracture and 15 were elderly controls with no history of a hip fracture. Post-hip fracture participants were recruited from a local hospital and home care agency and were on average approximately 2.60 (0.9) months post-hip fracture. Also, participants were recently discharged from home care physical therapy (within 2 weeks of discharge). Sample descriptive and clinical data are shown in Table 1. Participants in the hip fracture group were included if they had a unilateral hip fracture, were functionally independent, and were discharged from physical therapy care. Participants in both groups

Table 1
Baseline and clinical variables for each group.

Variable	Hip fracture, n = 29	Controls, n = 15	*p*-value
Age	80.4 (7.3)	73.1 (4.9)	<0.01*
Weight (kg)	63.8 (12.5)	70.2 (11.2)	0.12
Height (m)	1.6 (0.1)	1.7(0.1)	0.46
Gender	22 F/7 M	11 F/4 M	–
Time since fracture (months)	2.6 (0.9)	n/a	–
Time (weeks) since discharge from home care physical therapy	1.7 (0.4)	n/a	–
Type of fracture	13T/16FN	n/a	–
Comorbidities	1.2 (0.6)	1.1 (0.6)	0.35
Knee extension strength ratio involved/uninvolved	0.8 (0.1)	1.0 (0.3)	<0.01*
BBS	43.7 (6.0)	55.2 (1.6)	<0.01*
ABC	69.2 (19.0)	91.0 (9.4)	<0.01*
LEM	80.6 (11.0)	88.5 (11.9)	0.03*
GS (m/s)	0.9 (0.3)	1.7 (0.3)	<0.01*
STS time (s)	1.1 (0.4)	0.7 (0.2)	<0.01*

The *p*-values represent comparisons between hip fracture and control groups using independent-sample *t*-tests.
T—trochanteric, FN—femoral Neck, BBS—Berg Balance Scale, ABC—Activities Balance Confidence Scale, LEM—lower extremity measure, GS—gait speed, STS—sit to stand.
* Denotes a significant difference ($p < 0.05$) between hip fracture and control groups.

were excluded based on known neurologic diagnosis, documented osteoarthritis of the hip or knee (e.g., taking medications for joint pain or radiographic evidence of osteoarthritis), severe visual impairments, vestibular disorders, or peripheral neuropathy. Participants were given a variety of clinical tests to describe specific sample characteristics (Table 1). Recruitment and study procedures were approved by Institutional Review Board at the University of Rochester Medical Center (RSRB00027531).

2.2. Clinical variables: functional and balance assessment

Validated tests used to document function and balance recovery in participants with hip fracture included performance-based measures (Gait Speed,(Binder et al., 2004; Mangione et al., 2005; Sherrington and Lord, 1997; Suetta et al., 2004), Berg Balance Scale (Hall et al., 2000; Kulmala et al., 2007; Tinetti et al., 1997; Whitehead et al., 2003), self-report measures (lower extremity measure (Jaglal et al., 2000)), and Activities Balance Confidence Scale (Kulmala et al., 2007)). Gait speed is commonly used to document outcomes in elderly participants after hip fracture (Binder et al., 2004; Mangione et al., 2005; Sherrington and Lord, 1997; Suetta et al., 2004). The time participants took to walk a 6-meter distance as fast as they could, continuing at least 2 complete steps before stopping, was clocked with a stopwatch. The time was then divided by 6 m to obtain gait speed (m/s) (Fransen and Edmonds, 1999; Fransen et al., 1997; Potter et al., 1995). The Berg Balance Scale is used frequently to identify risk of falling (scores below a cut off of 42 are considered positive for risk of falling) and balance in elderly participants, including those post-hip fracture (Berg et al., 1992; Hall et al., 2000; Kulmala et al., 2007; Tinetti et al., 1997; Whitehead et al., 2003). The lower extremity measure is a validated self-report scale for assessment of functional mobility in participants post-hip fracture (Jaglal et al., 2000). Scores of 75–85 indicate moderate limitations in functional mobility and scores above 85 indicate normal functional ability (Jaglal et al., 2000). The Activities Balance Confidence scale is a validated self-report scale for assessment of balance confidence in participants post-hip fracture (Kulmala et al., 2007). Higher scores indicate greater confidence in balance and scores below 67% indicate risk of falling.

2.3. Knee extension strength

The Biodex Multi-joint System 4 Pro Isokinetic dynamometer™ was used to determine unilateral knee extension strength. Study participants were positioned in a chair with their hips and knees at 90° flexion. Participants were asked to kick their leg out against a resisted pad (located at the distal tibia) as hard and as fast as they could. The process was repeated for both the right and left sides. Peak values for a total of 3 trials were determined at a rate of 60° per second, and the average peak score was recorded. Knee extension strength of the involved and uninvolved sides were determined using average peak values.

2.4. STS chair

A custom built chair with an adjustable seat height (5 cm increments from 45 cm to 60 cm) was used and adjusted to approximate a 90/90 hip/knee flexion angle when the participant was seated. Participants were seated on the front half of the instrumented chair with mid-length of the thighs aligned with the edge of the chair and ankles placed in 15° of dorsiflexion. Participants were instructed to stand up "as quickly as possible." One practice trial was performed before recording data from 3 STS. No participant reported pain during any of the testing sessions.

Vertical ground reaction force variables taken under each foot were used to determine magnitude and rate for the involved, uninvolved, and bilateral limbs.

Three force plates (2 Model # 92868, and 1 Model # 9865C Kistler, Instrument Corp., Amherst, NY) integrated into a custom built chair were used to capture vGRF. Two force plates were flush with the floor to record vGRF under each foot ($vGRF_{involved}$ and $vGRF_{uninvolved}$). A force plate mounted on the seat recorded vGRF ($vGRF_{seat}$) under the buttock. During each data collection, the vGRF of each force plate was recorded at a sampling rate of 1000 Hz using Motion Monitor Software (Innsport Training, Inc., Chicago, IL).

2.5. Phases of sit to stand task

As used in previous studies (Etnyre and Thomas, 2007; Lindemann et al., 2003, 2007), two phases of the STS task were identified from the sum of $vGRF_{involved}$ and $vGRF_{uninvolved}$ ($vGRF_{bilateral}$) (Fig. 2). The preparation phase was considered to begin when there was a 5 N decrease in $vGRF_{bilateral}$. This brief unweighting of the limbs is a countermovement that precedes the rapid loading of the limbs. The end of the preparation phase occurred at seat off, marked as the instant when $vGRF_{seat}$ was below 5 N. The rising phase began at seat off and ended when $vGRF_{bilateral}$ equaled body weight, subsequent to the first peak of $vGRF_{bilateral}$ (Fig. 2). The STS time was measured from the beginning of the preparatory phase to the end of the rising phase.

2.6. Ground reaction force variables

Unilateral and bilateral vGRF variables were identified as previously described: $vGRF_{bilateral}$, $vGRF_{involved}$ ($RFD_{involved}$) and $vGRF_{uninvolved}$ ($RFD_{uninvolved}$) (Lindemann et al., 2007). The difference in contribution of each foot during the rising phase was captured using a symmetry measure, where the area (AREA) between the $vGRF_{involved}$ and the $vGRF_{uninvolved}$ was calculated over the rising phase (Fig. 3). A lower AREA suggests higher symmetry or relatively equal vGRF under both limbs, and higher AREA suggests lower symmetry or greater reliance on one foot. Test–re-test reliability has been determined in a previous study (Houck et al., 2011).

2.7. Lower extremity kinetic model

Kinematic and kinetic data were captured and applied to a 7-segment model of lower extremity. Each segment of the model was tracked using infrared emitting diodes (IRED) using the Optotrak Motion Analysis System (Model 3020 Northern Digital Inc, Waterloo, Ontario) at a sampling rate of 60 Hz. The accuracy of tracking an IRED is ± 0.1 mm when the cameras are set to record an area of 2.25 m^2 at a distance of 2 m. A digital video camera (model DCR-TRV240, Sony), recorded at a rate of

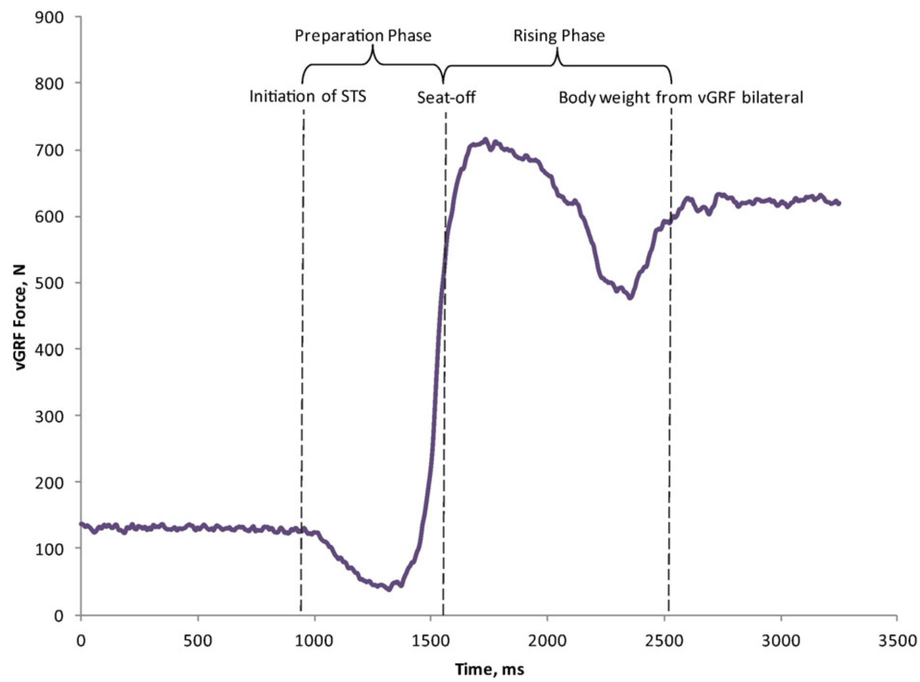

Fig. 2. The summed vertical ground reaction forces under the right and left lower extremity ($vGRF_{bilateral}$) are shown. Task initiation and the end of the rising phase were determined from $vGRF_{bilateral}$. Seat off, which determines the transition point between the preparation and rising phases, was determined from the seat force plate. STS, sit to stand.

30 frames/second, was used to acquire frontal plane video of participants during the STS task.

The 7 segment model included the right and left foot, right and left shank, right and left thigh and sacrum. The sacrum was tracked by mounting a lightweight orthoplast platform, with 3 IREDs positioned in a triangle, over the skin of the sacrum using a double-sided tape. Joint centers were established for the hip using an optimization approach (Piazza et al., 2004). *n* is the average of the medial and lateral condyles for the knee, and medial and lateral malleoli for the ankle. Synchronized force (Fx, Fy, and Fz) and position data (x, y, z) were filtered at a cut off frequency of 60 and 6 Hz, respectively, using a fourth-order Butterworth low-pass zero phase lag filter. Segment inertial properties were combined with filtered vGRF and position data to calculate joint moments and powers using Innovative Sports Training Software, Chicago, IL (Dempster et al., 1959). Net joint moments were determined using local coordinates of the distal segment. This method of calculating net joint moments determines the agonist contribution for that time point. Joint power was calculated by combining information from joint angles and joint moments (joint power = joint moment × joint angular velocity).

3. Data analysis

The three trials of data were averaged prior to hypothesis testing. The average of three STS trials normalized to body mass were used for all vGRF variables. Hip joint moment and power data were normalized

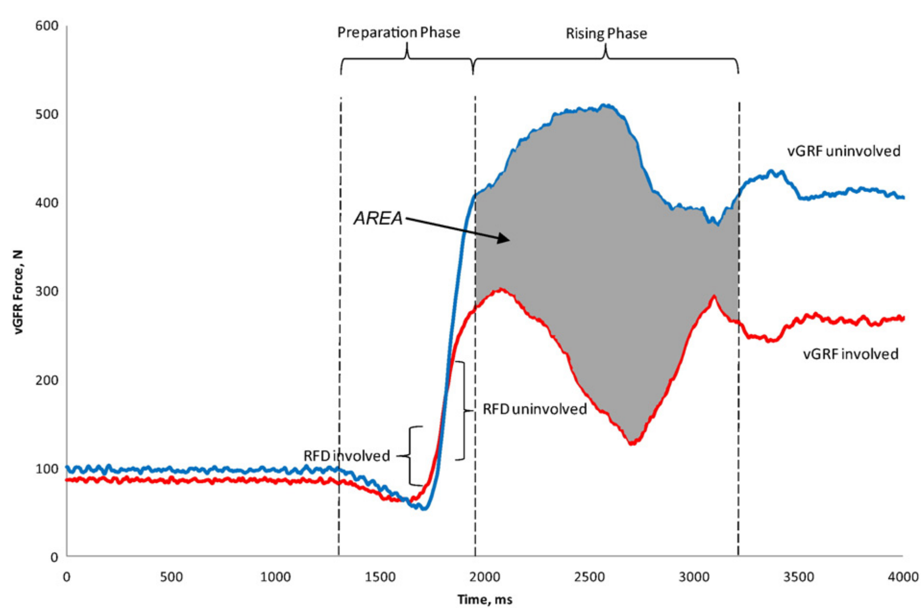

Fig. 3. The unilateral measures of vertical ground reaction forces for the involved and uninvolved side were determined from 2 force plates located under each foot. The rate of force development (RFD) during the preparation phase was calculated as the slope from 25% to 50% of the force value at seat off.

to body mass and ensemble averaged across an STS trial (101 points per trial from the beginning of the preparation phase to the end of the rising phase). The peak knee and hip joint moments and powers of the ensemble patterns were averaged for statistical analysis. For data from control participants, the right side was considered the involved side and the left side the uninvolved side.

Statistical analysis included descriptive statistics (means, confidence intervals) for each variable to determine normality of distribution using PAWS™ version 18. Analyses included *t*-tests to compare AREA, descriptive data, and clinical data (Table 1). For the first and second purpose, mixed 2-way ANOVAs were used to compare unilateral vGRF variables (RFD, vGRFpeak) and peak hip and knee moments/powers (Tables 2 and 3). For 2-way ANOVAs, the fixed factor was group (hip fracture, Control) and the repeated factor was side (involved, uninvolved). The dependent variables included RFD, vGRFpeak, peak hip moment, peak hip power, peak knee moment, and peak knee power. If significant interaction effects were demonstrated, main effects were ignored. Significant effects were then evaluated using pair-wise comparisons. Since age was significantly different between the hip fracture and the control groups (Table 1), age was used as a covariate for all analyses. A priori effect size was calculated using vGRF variables (*d*-statistic 1.2, 80% power) to be 1.1 (0.6). The PAWS™ version 18 software was used to perform all analyses. For the third purpose, Pearson correlation coefficients were examined between vGRF variables and clinical variables (Table 4).

4. Results

4.1. Ground reaction force variables

Vertical GRF variables were significantly different between groups and side. There was a significant interaction effect of group and side for RFD (Table 2). Pair-wise comparisons indicated that hip fracture $RFD_{involved}$ was significantly lower than hip fracture uninvolved side ($p < 0.01$) and Control involved side ($p < 0.01$) (Table 2). Further, Control involved side compared to the Control uninvolved side was not significantly different ($p = 0.14$). Similarly, there was a significant interaction effect of group and side for $vGRF_{peak}$ (Table 2). Pair-wise comparisons indicated that the hip fracture involved side $vGRF_{peak}$ was significantly lower than hip fracture uninvolved side ($p < 0.01$) and Control involved side ($p < 0.01$). Further, the Control involved side compared to the Control uninvolved side was not significantly different ($p = 0.46$). A one-way ANOVA indicated AREA was significantly higher for the hip fracture group compared to Control group ($p < 0.01$; hip fracture = 1.7 (0.8), Control = 0.7 (0.3)).

4.2. Lower extremity kinetic variables

Peak hip moments and power were significantly lower for the hip fracture group compared to controls (Table 3). There was a significant interaction effect of group and side for peak hip moments. Pair-wise comparisons indicated that hip fracture involved side peak hip moment was significantly lower than hip fracture uninvolved side ($p < 0.01$) and Control involved side ($p < 0.01$) (Table 3). The peak hip moments for Control involved side compared to Control uninvolved side were not significantly different ($p = 0.21$). There was a main effect for group ($p < 0.01$) where average peak hip power was lower for the HF group compared to controls (Table 3); however, the interaction effect between group and side was not significant ($p = 0.07$).

Peak knee moments and powers were significantly lower for the hip fracture involved side compared to Control (Table 3). There was a significant interaction effect of group and side for peak knee moments. Pair-wise comparisons indicated that hip fracture involved side peak knee moment was significantly lower than the hip fracture uninvolved side ($p < 0.01$) and the Control involved side ($p < 0.01$) (Table 3). Similarly, there was a significant interaction effect of group and side for peak knee powers. Pair-wise comparisons indicated that the hip fracture involved side peak knee power was significantly lower than the hip fracture uninvolved side ($p < 0.01$) and Control involved side ($p < 0.01$) (Table 3). In addition, the hip fracture uninvolved side was significantly lower than the Control involved side ($p = 0.02$).

A post hoc analysis evaluating the influence of sit to stand time was also completed because there was a significant difference in sit to stand time between the hip fracture and Control group. All the analyses were repeated with sit to stand time as a covariate. There were no changes in significance for any of the dependent variables.

4.3. Correlations between ground reaction force variables and clinical data

The vGRF variables and strength were correlated with clinical measures of function (Table 4). Strong correlations ($r > 0.70$) were determined when examining $RFD_{involved}$ and Berg Balance Scale ($r = .80$), $RFD_{involved}$ and gait speed ($r = 0.81$), and $vGRF_{peakinvolved}$ and gait speed ($r = 0.72$). Additionally moderate to weak ($r < 0.70$) significant correlations were determined for the remainder of the vGRF and clinical variables (Table 4). The vGRF variables that were not significantly correlated included $RFD_{uninvolved}$ and Activities Balance Confidence Scale, $RFD_{uninvolved}$ and lower extremity measure, and $vGRFpeak_{uninvolved}$ and lower extremity measure. Some of the vGRF variables were correlated with isokinetic strength; however, *r*-values were less than 0.70 (Table 4).

5. Discussion

The new findings of this study indicate that individuals post-hip fracture recently discharged from usual care used significantly less vGRF on the involved side compared to the uninvolved side during the STS task. Although hip fracture participants were independent at

Table 2
Means for RFD and vGRFpeak for the hip fracture and control groups during sit to stand.

Group	Involved	Uninvolved	Group main effect	Side interaction effect
RFD, (N/s)/kg				
Hip fracture	17.5 (8.5)	30.3 (12.4)	$p < 0.01$**	$p < 0.01$*
Controls	39.0 (8.7)	42.2 (12.0)	$p < 0.01$**	$p = 0.14$
vGRFpeak, N/kg				
Hip fracture	4.5 (0.7)	6.2 (0.7)	$p < 0.01$**	$p < .01$*
Controls	6.0 (0.7)	6.5 (0.7)	$p < 0.01$**	$p = 0.21$

Data are adjusted for age. Standard deviations are denoted in parenthesis where applicable.
* Denotes a significant interaction between hip fracture and Control, $p < 0.05$.
** Denotes a significant main effect, $p < 0.05$.

Table 3
Means for peak hip and knee moments/powers for HF and control groups during sit to stand.

Group	Involved	Uninvolved	Group main effect	Side interaction effect
Hip moment, (nm)/kg				
Hip fracture	0.5 (0.2)	0.7 (0.2)	$p = 0.01$**	$p < 0.01$*
Controls	0.8 (0.3)	0.8 (0.3)	$p = 0.01$**	$p = 0.21$
Hip power, W/kg				
Hip fracture	0.6 (0.3)	0.7 (0.3)	$p < 0.01$	$p = 0.07$
Controls	1.5 (0.4)	1.4 (0.5)	$p < 0.01$**	$p = 0.26$
Knee moment, (nm)/kg				
Hip fracture	0.6 (0.1)	1.0 (0.2)	$p < 0.01$**	$p < 0.01$*
Controls	1.0 (0.2)	1.0 (0.2)	$p < 0.01$**	$p = 0.56$
Knee power, W/kg				
Hip fracture	0.8 (0.3)	1.2 (0.5)	$p = 0.02$**	$p < 0.01$*
Controls	2.0 (0.8)	1.9 (0.8)	$p = 0.02$**	$p = 0.28$

Data are adjusted for age. Standard deviations are denoted in parenthesis where applicable.
* Denotes a significant interaction between hip fracture and Control, $p < 0.05$.
** Denotes a significant main effect, $p < 0.05$.

Table 4
Correlations (p-values) of vertical ground reaction force variables and validated scales $n = 29$.

Variables	Berg Balance Scale	Activity balance confidence	Lower extremity measure	Gait speed
RFD involved, (N/s)/kg	0.80* ($p < 0.01$)	0.49* (<0.01)	0.40* (0.01)	0.81* ($p < 0.01$)
RFD uninvolved, (N/s)/kg	0.52* ($p < 0.01$)	0.19 (0.22)	0.19 (0.21)	0.53* ($p < 0.01$)
1st peak vGRF uninvolved, N/kg	0.43* (<0.01)	0.31* (0.04)	0.20 (0.20)	0.33* (0.03)
1st peak vGRF involved, N/kg	0.61* ($p < 0.01$)	0.52* ($p < 0.01$)	0.45* (<0.01)	0.72* ($p < 0.01$)
Area, (N*s)/kg	−0.53* ($p < 0.01$)	−0.50* ($p < 0.01$)	−0.42* (<0.01)	−0.67* ($p < 0.01$)
Strength involved, N/kg	0.67* ($p < 0.01$)	0.55* ($p < 0.01$)	0.48* (<0.01)	0.74* ($p < 0.01$)
Strength uninvolved, N/kg	0.53* ($p < 0.01$)	0.52* ($p < 0.01$)	0.47* (<0.01)	0.65* ($p < 0.01$)

RFD = rate of force development, Area = magnitude of the difference between $vGRF_{involved}$ and $vGRF_{uninvolved}$.
* Correlation is significant at $p < 0.05$.

home (i.e., community dwelling), it is likely, during STS transitions, they complete the STS task with considerable side-to-side asymmetry. Unique to this study, hip and knee kinetic variables were evaluated to determine whether isolated hip kinetic variables or both hip and knee kinetic variables combined were driving the lower involved side vGRF during the STS task. The lower involved side vGRF during STS tasks was the result of lower involved side hip and knee kinetics. To compensate for lower involved side vGRF, hip fracture participants succeeded in rising by (1) decreasing their overall STS times (i.e., speed) and (2) adopting higher uninvolved side knee moments and powers with less of a change in uninvolved side hip moments and powers. Clinical variables were significantly associated with vGRF variables underscoring the potential importance of improving vGRF symmetry between the involved and the uninvolved sides (Table 4).

Characteristics of the sample at discharge from rehabilitation suggest hip fracture participants that are community-dwelling continue to experience mild to moderate balance and functional deficits. Common clinical cut points for the Berg Balance Scale, Activities Balance Confidence Scale, and lower extremity measure are 42/56, 67%, and 85%, respectively (Berg et al., 1992; Jaglal et al., 2000; Whitehead et al., 2003). Mean scores for Berg Balance Scale of the hip fracture group were 43/56 and for the Activities Balance Confidence Scale 69%, which are both just above classification for fall risk. Similarly, the self-rated function score (lower extremity measure) suggests on average participants post-hip fracture are having minimal difficulty with functional tasks (lower extremity measure = 80.5) (Table 1). The Control participants, on the other hand, were not classified at falls risk and reported no functional difficulties. Hip fracture participants had lower strength and moved slower (i.e., lower STS times and gait speed) compared to controls. Despite these clinical deficits, it is common to discharge individuals post-hip fracture when they are identified as independent in their home. This often includes compensatory strategies such as lower vGRF of the involved side and higher vGRF of the uninvolved side (Host et al., 2007; Kammerlander et al., 2011; Magaziner et al., 2000a).

The involved limb vGRF was markedly lower for hip fracture compared to Control participants. In this study, RFD for hip fracture involved side was 58% of the RFD uninvolved side. Similarly, the involved side $vGRF_{peak}$ was 72.6% of the uninvolved side. In contrast, side-to-side differences for the Controls were less than 10% for both the RFD and $vGRF_{peak}$. The markedly lower vGRF rate and magnitude for the hip fracture group suggest a significant asymmetrical lower limb loading during STS. The hip fracture group showed an AREA measure 2.5 times greater than Controls, indicating a marked reliance on the uninvolved limb during the rising phase. In a previous study that included a smaller sample of hip fracture participants ($n = 14$) that were 2-12 months post-hip fracture, the side-to-side differences in the vGRF were similar (Kneiss et al., 2012). As in the previous study, current studies of hip fracture participants suggest that alterations in involved and uninvolved side vGRF are typical and present at the completion of rehabilitation.

The hip and knee kinetic variables associated with the involved limb suggested overall decreased STS performance. Hip and knee joint powers of the hip fracture group were less than half of the values of the Control group (Table 3). This is consistent with a significantly lower sit to stand time of hip fracture participants compared to Control participants. Since joint power is partially determined by joint angular velocity, the speed of the STS task influences joint powers independent of which group participants were in. When sit to stand time was entered as a covariate in the analyses, no changes in the significance of the results were found. This suggests that although sit to stand time does influence kinetic variables, the patterns displayed by the hip fracture group were not solely due to speed of rising. However, to understand the importance of specific joint contributions to a lower vGRF of the involved limb, side-to-side differences are considered more relevant.

Lower hip and knee kinetic variables of the involved side suggest a global decrease in muscle output of the involved limb. Significant interactions for all kinetic variables except for hip joint power resulted from lower involved side kinetic variables. The hip fracture group involved side hip moment and power, which were 70.1% and 83.5%, respectively, of the uninvolved side. Similar values for the Control group suggested side-to-side differences at the hip were on average 6%. Knee moments and powers of the hip fracture group show even larger side-to-side effects. The hip fracture group involved side knee moment and power, which were 62.9% and 61.9%, respectively, of the uninvolved side. Similar values for the Control group suggested that side-to-side differences at the knee were on average <4%. Therefore, while hip power data suggest no significant interaction effect (discussed more below), the data overall confirm that the lower vGRF of the involved side is a result of decreased contributions from the involved side hip and knee.

An unexpected finding in this study was lower knee rather than hip moments, and powers were the largest contributor to lower involved side vGRF. Hip fracture participants used higher uninvolved side knee kinetics (i.e., moments and powers) and only marginally higher uninvolved side hip kinetics (i.e., moments and powers) to complete the STS task. Since hip moments are consistent with nearly equivalent uninvolved side hip moments between the Control and the hip fracture participants, it is interesting to speculate that a larger sample may have led to a significant interaction effect of hip power ($p = 0.07$). A post hoc power calculation suggests a sample of approximately 80 hip fracture participants would have resulted in a significant difference between the involved and the uninvolved sides of hip power. Nevertheless, knee kinetics are markedly distinct and suggest a strong reliance on the uninvolved side knee extensors to complete the STS task.

Significant correlations of vGRF variables with clinical measures suggest vGRF variables are associated with balance, function, and strength (Table 4). Balance as defined by the Berg Balance Scale was correlated to all vGRF variables. The strongest correlation was with $RFD_{involved}$ and Berg Balance Scale ($r = 0.80$). The $vGRFpeak_{uninvolved}$ demonstrated a moderate correlation with balance ($r = 0.61$), and other vGRF variables showed lower r-values. Taken together, a moderate to strong association is possible between vGRF involved side force rate, peaks, and balance. Similarly, associations of vGRF variables and gait speed were also observed, where $RFD_{involved}$ was strongly correlated with gait speed ($r = 0.81$). The same r-values were lower for balance and gait speed with vGRF of the uninvolved side. This raises the possibility that clinically it may be more important to improve (i.e., increase) involved side vGRF variables, as opposed to decrease uninvolved side vGRF variables to improve symmetry. The Activities Balance Confidence Scale and Lower Extremity Measure, although correlated with some vGRF variables, had smaller r-values, suggesting that altering the vGRF variables may have less impact on these clinical measures.

Strength was associated with clinical measures and vGRF variables (Table 4). Involved side strength was highly correlated with gait speed ($r = 0.74$) and moderately correlated to other clinical variables (Table 4). Moderate correlations between $RFD_{involved}$ and involved side strength ($r = 0.48$) and $vGRFpeak_{uninvolved}$ and uninvolved/involved side strength (involved $r = 0.54$ and uninvolved $r = 0.56$) suggest that strength is associated with vGRF variables. However, the correlations were lower than 0.56. Studies in post-hip fracture where increases in strength are associated with increases in balance and function were found (Binder et al., 2003; Host et al., 2007; Mangione et al., 2001). Data from this study suggest that vGRF variables are moderately correlated to strength during an STS.

Rehabilitation post-hip fracture may utilize this study to improve vGRF symmetry. It is unknown why individuals post-hip fracture chose a joint specific strategy utilizing uninvolved knee extensors. Yet to decrease reliance on the uninvolved side knee extensors, increased use of the involved side hip extensors and knee extensors may be necessary. Also, interesting to consider is the lack of higher hip joint extensor power on the uninvolved side. The less marked differences of the hip joint powers compared to knee powers may indicate significant trunk compensations, which this study did not evaluate, and are important to improve vGRF symmetry. The moderate correlations of isokinetic strength and vGRF suggest that task-specific training, not only strengthening, is likely important. The specific strategies likely to result in vGRF symmetry during an STS task have yet to be determined. However, this study suggests that movement control strategies emphasizing decreased reliance on the uninvolved knee extensors and increased reliance on the involved side hip and knee may improve vGRF symmetry post-hip fracture. Studies that focused on improving symmetrical power output when non-weight bearing also reported increases in functional status and decreases in falls post-hip fracture (Portegijs et al., 2008; Puthoff et al., 2007; Skelton et al., 1994).

A limitation to this study is the cross-sectional study design. Longitudinal studies could identify changes over time associated with asymmetrical weight bearing. It is unknown if asymmetrical movement strategies existed prior to hip fracture, and how long they persist after hip fracture. One study noted asymmetrical movement strategies up to 12 months post-fracture (Houck et al., 2011). It is also worthy to note that participants in this study were excluded for diagnoses of stroke, joint replacement, or osteoarthritis, which may contribute to asymmetrical movement strategies. An additional limitation was that the Control group was similar to the hip fracture group except for age, which was entered as a covariate for all analyses. However, the covariate analysis may not fully account for age if the relationship between asymmetry and age is non-linear. Another covariate not included was type of fracture due to the small sample size. Differences in rehabilitation strategies associated with type of fracture may be an important factor not considered in this study. The marked difference in STS time confounds the differences in rate dependent variables (i.e., RFD, joint powers), which is why the discussion primarily focused on side-to-side comparisons.

This study demonstrated significantly lower involved side vGRF variables in a group of community-dwelling participants post-hip fracture. The examined joint kinetic data suggested specific explanations for lower vGRF in hip fracture participants. Notably, there was a significant reliance on the uninvolved side knee extensors and less contribution of the involved side hip extensors and knee extensors. Surprisingly, knee kinetic variables suggested a stronger influence of knee extensors than hip extensors. Future studies should examine interventions to increase symmetry by including knee dominant rehabilitative strategies.

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