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Katie Pei-Hsuan Wu

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Jyh-Yuh Ke

See next page for additional authors

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Katie Pei-Hsuan Wu, Yu-Cheng Pei, Mei-Yun Liaw, Wei-Hsien Hong, Jyh-Yuh Ke, and Alice M.K. Wong

Original Article

Temporal and Kinetic Characteristics of Different Sit-to-Stand Movement Strategies in Females with Osteoporotic Vertebral Compression Fractures

Katie Pei-Hsuan Wu,[1] Yu-Cheng Pei,[1] Mei-Yun Liaw,[1] Wei-Hsien Hong,[2] Jyh-Yuh Ke,[1] Alice M.K. Wong[1,3]

[1]Department of Physical Medicine and Rehabilitation, Chang Gung Memorial Hospital, Taoyuan;
[2]School of Sports Medicine, China Medical University, Taichung;
[3]Graduate Institute of Rehabilitation Science, Chang Gung University, Taoyuan.

The purpose of this investigation was to objectively identify the temporal and kinetic features of the three different sit-to-stand (STS) strategies in patients with osteoporotic vertebral compression fractures for possible future reference. Fourteen female patients, aged 68.2±7.8 years, with osteoporotic vertebral compression fractures were included. Subjects sat on a height adjustable, armless, backless chair with their feet on force plates to perform STS using simple, flexion, and extension strategies. Temporal and kinetic features, including STS duration, horizontal and vertical momentums, and maximal left–right vertical force differences (Max-LR-VF-Diff) were measured. The flexion strategy allowed for the longest overall STS duration. The flexion strategy's peak horizontal and vertical momentums during STS were 44% and 24% smaller in magnitude, respectively, than in the simple strategy. The extension strategy had a smaller Max-LR-VF-Diff between both feet than the simple strategy. We found that the flexion strategy gave a slower STS movement, which may have a role in simplifying the neuromuscular demand for motor control and trunk stability. The extension strategy seemed to offer a more symmetric STS pattern by reducing left–right weight distribution difference, and its clinical relevance warranted further investigation. (Tw J Phys Med Rehabil 2006; 34(3): 129 - 139)

Key words: osteoporosis, vertebral compression fractures, kinetics, sit-to-stand

INTRODUCTION

Sit-to-stand (STS) movement serves a fundamental activity and is a mechanically demanding functional task in daily activity.[1] The ability to go from a sitting position to a standing position is an important skill. Clinically, the elderly and patients with musculoskeletal system disorders, such as osteoporotic vertebral compression fractures, usually complain of STS difficulties. Chamberlain and

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Address correspondence to: Dr. Alice M.K. Wong, Department of Physical Medicine and Rehabilitation, Chang Gung Memorial Hospital, No. 5, Fu-Shin Street, Kweishan, Taoyuan 333, Taiwan.
Tel：(03) 3281200 ext 3846 e-mail：walice@adm.cgmh.org.tw

Munton[2,3] reported that 42 to 43% of the elderly subjects they surveyed had difficulty in getting up from a chair. The causes that patient with vertebral compression fractures have difficulty getting up included: significant loss of bone mass, reduced range or quality movement in joint, increased thoracic kyphosis and altered position of center of gravity.[4] The ease of rising from a chair was the primary concern of these subjects when selecting a chair.

Previous works used parameters to delineate STS movements, such as duration of STS phases, momentum,[5,6] and symmetry of left and right vertical ground reaction forces. [7] Also, an analysis of STS transfer using a biomechanical approach provides information about how to maintain the body's center of mass within a base of support throughout the STS process.[6,8] Typically, rising requires changes in the centre of the mass of the human body and an impulse-momentum relationship has to be established. Propulsion is thus generated by creating a forward momentum in the horizontal direction. The propulsive impulse must then be reversed or falling forward will tend to occur and thus phase I is potentially the most dangerous part of any STS activity.[8,9] Subsequently, a vertical ground reaction force acts as the propulsive impulse to elevate the body’s center of mass during STS. According to this concept, horizontal and vertical momentums can be applied to delineate the integrated effects of acceleration and deceleration of STS movement.

As elderly patients with osteoporotic vertebral compression fractures frequently have STS difficulties, clinicians and therapists may need to introduce strategies to overcome these difficulties in addition to targeting on muscle strengthening and posture adjustment. In this work, three STS strategies are presented: the simple, flexion, and extension strategies. The simple strategy means rising in a natural way as in daily living. The flexion strategy, which is commonly used in a rehabilitation setting for stroke patients with increased extensor tone in the trunk or patients with knee extensor weakness, utilizes an extensive trunk flexion to manipulate the center of gravity (COG) before seat off. The extension strategy, a reverse of the flexion strategy, places an emphasis on the initial posture of STS, beginning with an extended trunk and neck posture before initiating the trunk flexion motion. As body equilibrium in STS controlled during weight transfer is mainly programmed before seat off,[10] the adjustment of the initial posture or motor control pattern before seat off would seem to be an effective intervention to modify the whole sequence of STS movement. However, no study, insofar as we could determine, has attempted to identify the effects of the three different STS strategies on STS kinetics.

Therefore, the purpose of this investigation was to objectively identify the effects of the three different STS strategies on the temporal and kinetic characteristics of STS in patients with osteoporotic vertebral compression fractures.

MATERIALS AND METHODS

Subjects

Fourteen women were recruited, aged between 50 and 81 years. Their mean age was 68.2±7.8 years, and mean height and weight were 149.1±6.8 cm and 53.4±6.8 kg, respectively. All had documented severe osteoporosis and vertebral compression fractures. The World Health Organization has defined osteoporosis as bone mineral density 2.5 standard deviations below the peak mean bone mass of young normal adults. [11] Vertebral compression fractures were defined as a 25% reduction in vertebral body anterior height relative to posterior height, biconcave changes, or a reduction in height by more than 25% compared with a normal adjacent vertebral body. The types and distribution of compression fracture were presented (Figure 1). During the experiment, no patient wore a brace or had received a surgery. However, patients may have received medication, physical therapy or used spinal orthosis after their diagnosis of compression fracture.

The mean bone mineral density of our subjects was −3.6±1.0 grades, and their mean kyphotic angle measured by Cobb’s angle was 47.1±19.8 degrees. Subjects with neuromuscular disease, uncorrected visual deficits, a manual muscle testing of lower limbs of less than 4, joint contracture in the lower limbs, leg discrepancies, acute lower back pain and scoliosis were excluded. All subjects were able to perform STS independently and signed informed consent forms before participating in the study.

Instrumentation

An height adjustable, armless, backless chair was used to fulfill the initial STS posture required herein (Figure 2). Three AMTI force plates (Advanced Biomechanical Technology, Newton, MA, US), one under each foot and one under the sitting chair, were used to measure the ground reaction forces at a frequency of 960 Hz.

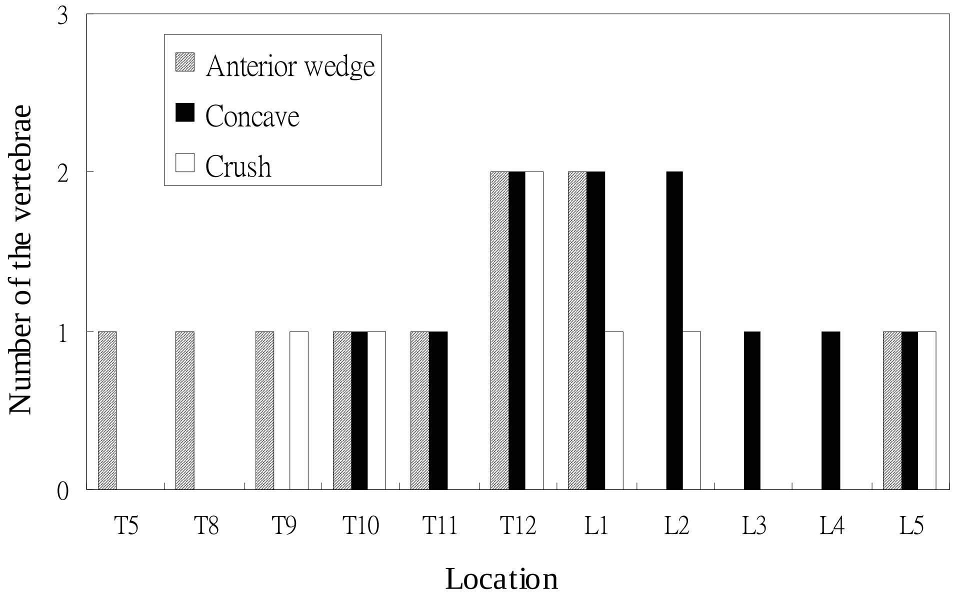


Figure 1. Diagrammatic representation of the distribution and types of the osteoporotic vertebral compression fractures (n=14)

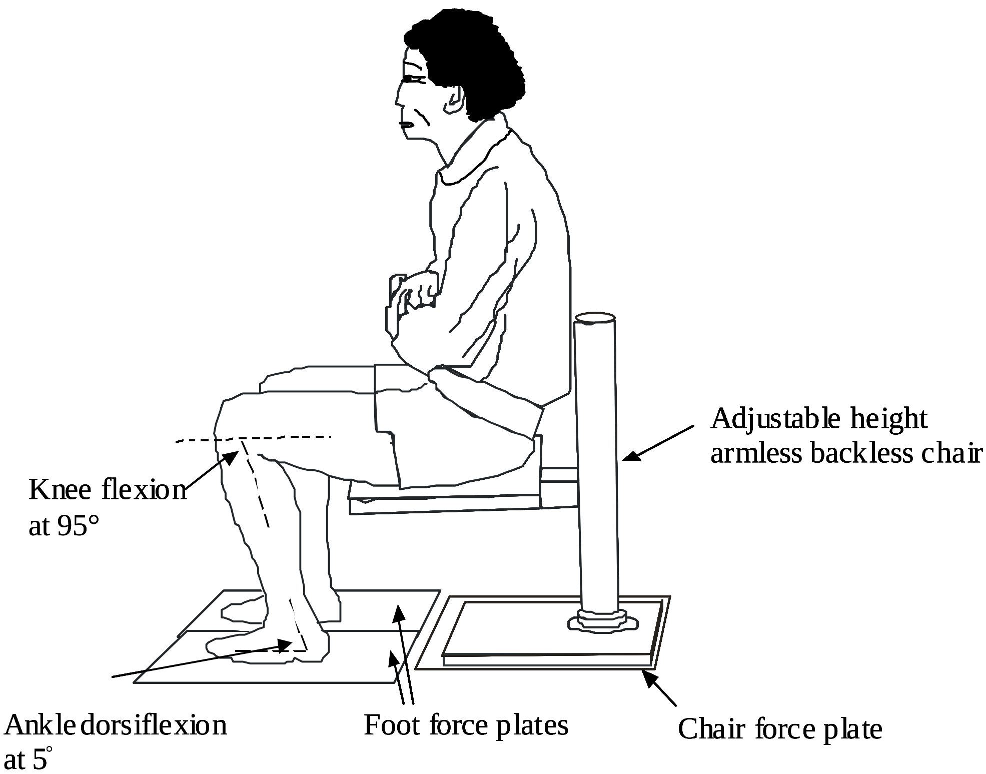


Figure 2. Diagrammatic representation of initial posture, force plates, and chair design.

Test procedures

A questionnaire collecting demographic data and history of incidental falls for the past six months were completed before each test. The history of incidental fall included a 'yes or no' question regarding performing the STS. The information about falls was gathered by asking the patients themselves, their family or caregivers. Subjects were then seated upon a height adjustable, armless, backless chair and the chair height was adjusted so that the subject's thighs were horizontal, the knees resting at a 95° flexion angle, and the ankle at a 5° dorsiflexion angle. Three kinds of STS strategies were introduced to the subject as follows:

(1) The simple strategy: rising in a natural way. Subjects were instructed to perform STS by the same method as they do in daily life.
(2) The flexion strategy: using an extensive trunk flexion to guide the floor projection point of the COG (an imaginary point) between both feet before leaving the chair. During the initial phase of STS (before seat off), subjects were instructed to make use of the extensive trunk flexion to shift the COG towards the anterior. Except for the requirement of the movement before seat off, other parts of STS movement were not restricted.
(3) The extension strategy: emphasizing the initial posture of STS that began with an extended trunk and neck posture before initiating the trunk flexion motion. Except for the requirement of initial posture, other parts of STS were not restricted.

These strategies were demonstrated and manually guided by a trained physician who was familiar with the design and context of this study. To ensure sufficient practice and adherence to correct patterns, these strategies were practiced repeatedly until the physician qualified the subject before entering the test. STS was performed at a self-paced comfortable speed and subjects were asked to cross their arms in front of the chest to avoid interference from upper limb motions. During testing, three trials were performed for each strategy. Subjects received an assessment of the visual analogue scale (VAS) of STS strenuosity after completing each strategy to subjectively quantify how strenuous the STS movement was. The scale designed herein consisted of a 10 cm horizontal line, where the left endpoint represents 'absolutely not strenuous' and the right endpoint represents 'the greatest strain imaginable'. Subjects were asked to select a point on the line to delineate their strenuosity with each strategy. In addition, the movement of each test was monitored by the physician; if there was any deviance from the required pattern, the patient was guided again and the test was redone until the movement conformed to the requirements.

Data analysis

A LabView (National Instruments, Austin, TX, US) based program was written to analyze force plate data. Several parameters were derived from the ground reaction forces (GRFs). Max-LR-VF-Diff was calculated from the maximal absolute difference of vertical GRF between bilateral feet and was normalized as a percentage of body weight. The vertical and horizontal impulses, and the momentum gained by the body, were then computed by integrating the histories of ground reaction forces using a composite trapezoidal method, and peak vertical and horizontal momentums were determined.

Three phases of STS were established based on the observation of vertical GRF and momentum data (Figure 3). Fz denoted the vertical force component of force plates in both feet and Fs was the vertical sit-force in chair force plate. Phase I, the 'flexion-momentum phase', began at the initiation of trunk flexion, detected by the beginning of horizontal momentum changes, and ended at seat off of the buttocks. The seat off was judged as the time when the sit-force (Fs) dropped to only the weight of the chair. Phase II, the 'vertical-acceleration phase', began at seat off of the buttocks and ended at peak vertical momentum. Phase III, the 'vertical-deceleration phase', began at peak vertical momentum and ended at the stop of vertical momentum.

Three trials of each task were averaged to calculate the Max-LR-VF-Diff, peak momentum, phase duration, timing of peak horizontal momentum and VAS of STS strenuosity.

A one-way repeated measure of ANOVA was applied to evaluate the effects of different strategies on the parameters measured. In each case of significance, a *post hoc* analysis was performed to determine the source of significance. The significance level chosen was $p<0.05$.

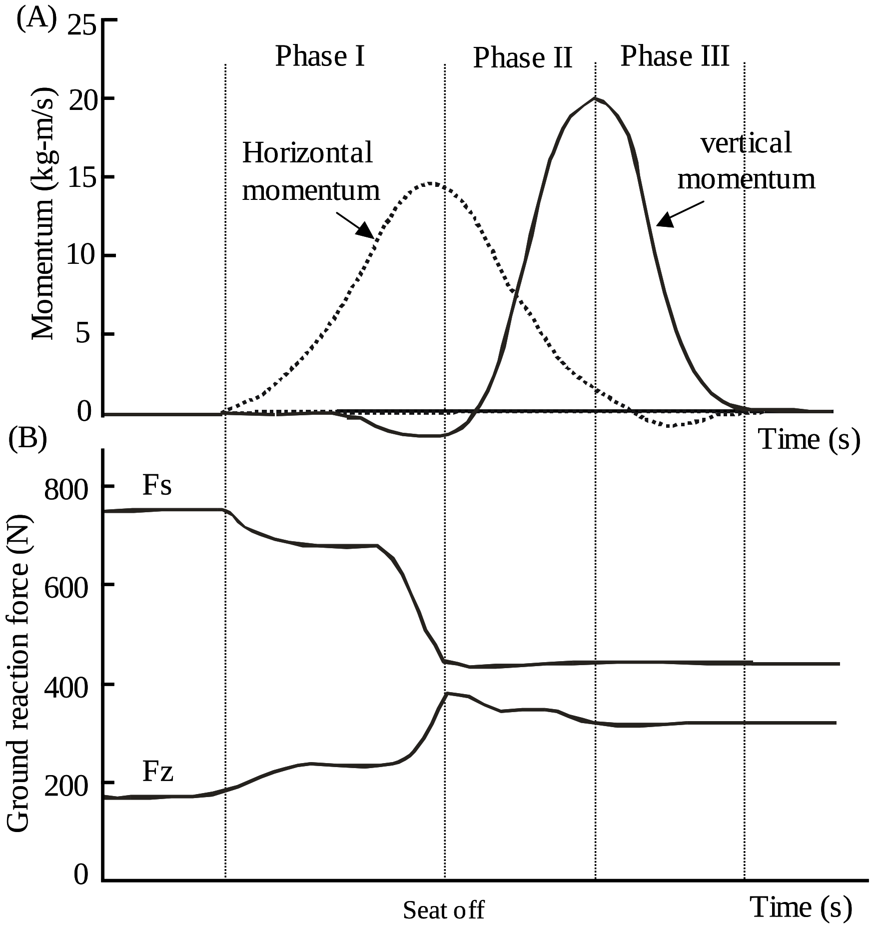


Figure 3. The momentum and force diagrams of a patient with osteoporosis during sit-to-stand. Fs is the sit-force, Fz is vertical ground reaction force. Phase I: flexion-momentum phase; Phase II: vertical-acceleration phase; Phase III: vertical-deceleration phase.

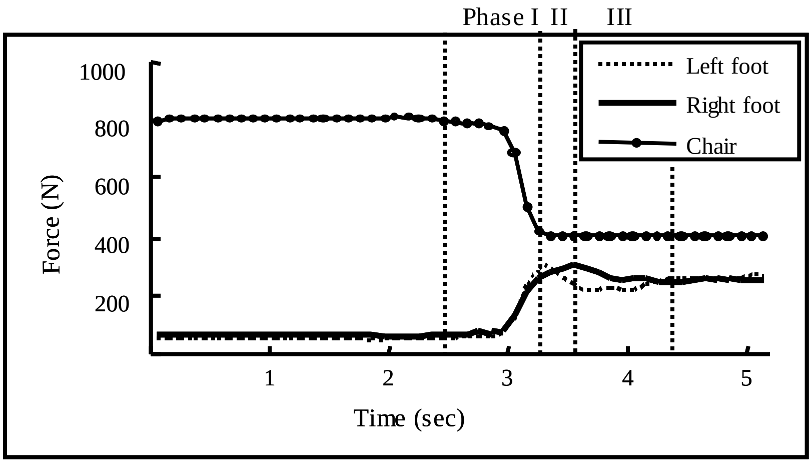
RESULTS

The vertebral compression types of the 14 osteoporotic female patients consisted a total of 10 anterior wedges, 11 biconcave and 7 crush types. The distributions and types of the compression fractures are presented (Figure 1). According to the questionnaire, 3 out of 14 (21%) had experienced accidental falls when performing STS.

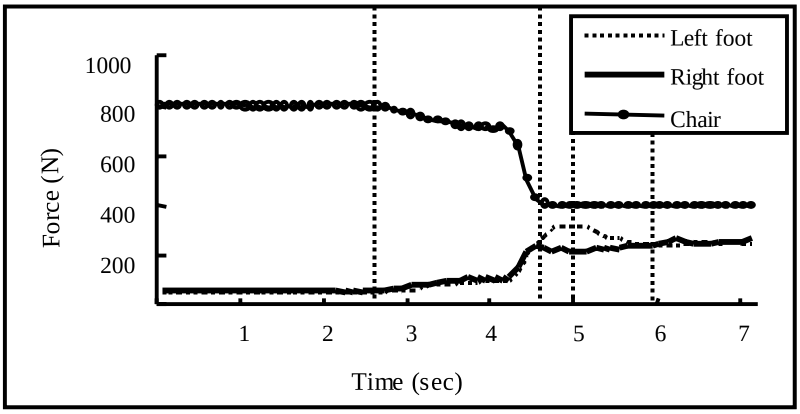
Vertical GRF and chair force plate center of pressure patterns

In the simple and extension strategies, the drop of sit-force began near the end of Phase I, accompanied by an increase in the GRFs in both feet (Figure 4). This phenomenon represents the shift of the body weight from the chair to both feet and the anterior displacement of the COP during the end of Phase I. When the buttocks lifted off the chair, the chair force plate revealed only the weight of the chair since the body weight of the subject was transferred to both feet. In addition, the vertical ground reaction force patterns revealed no remarkable difference between the extension and simple strategies.

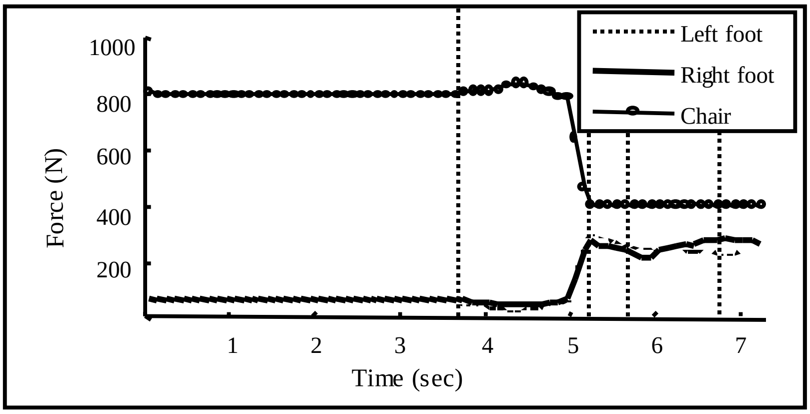
However, the flexion strategy revealed a pattern (Figure 4) quite different to those of the simple and extension strategies. It demonstrated a prolonged and gradual diminution of the sit-force and a gradual rise of GRFs in bilateral feet during Phase I. This represented a prolonged period of adjustment for the anterior displacement of COG, resulting from an extensive trunk flexion.



A. Vertical ground reaction force pattern in simple strategy



B. Vertical ground reaction force pattern in flexion strategy



C. Vertical ground reaction force pattern in extension strategy

Figure 4. Vertical ground reaction force pattern in force plates of the three STS strategies. Vertical dashed line in (A)(B)(C) represented the initiation and termination of each phase of the STS movement. Left foot: left foot force plate, Right foot: right foot force plate, Chair: chair force plate, STS: sit-to-stand.

The chair force plate anterior–posterior COP patterns in the simple and flexion strategies were similar, but a posterior deviation before the trunk initial flexion was noted in the extension strategy (Figure 5). In the simple and flexion strategies, the sit-force started from a static initial sitting posture and was followed by an anterior shift of COP throughout Phase I. This began with the initiation of trunk flexion and ended at seat off of the buttocks. Nevertheless, the extension strategy resulted in a posterior deviation of the COP in the initiation of Phase I, while the succeeding portion of COP pattern was similar to that of the other two strategies. It reflected the preparatory posture in the extension strategy, the neck and trunk extension before initiation of STS.

Temporal parameters

Among the three different strategies, the total STS duration and the Phase I duration was greatest in the flexion strategy (Table 1). The means and standard deviations for the total STS duration in the simple, flexion, and extension strategies were 2.11 ± 1.41, 3.65 ± 1.75, and 2.95 ± 2.01 seconds, respectively, and a significant difference was found between the simple strategy and the other two strategies ($p<0.01$). The flexion strategy demonstrated a significantly longer Phase I duration than the simple or extension strategies ($p<0.01$). There was no difference between the durations of Phases II and III.

Kinetic data and STS strenuosity

The flexion strategy revealed smaller peak vertical momentums than the simple ($p<0.01$) and extension strategies ($p<0.05$) (Table 2). Both the flexion and extension strategies showed smaller peak horizontal momentum than the simple strategy ($p<0.01$). Different strategies exhibited different Max-LR-VF-Diff ($p<0.01$), and *post hoc* analysis indicated that the extension strategies showed less Max-LR-VF-Diff (33%) than the simple strategy. A more symmetrical vertical ground reaction force pattern was shown in the extension strategy.

VAS of STS strenuosity of the simple, flexion, and extension strategy were 2.9 ± 3.6, 4.2 ± 4.0 and 2.9 ± 3.9, respectively, and did not reveal a statistically significant difference among the three strategies ($p>0.05$).

DISCUSSION

Because these patients are osteoporotic, incidental falls can easily result in femoral fractures, vertebral fractures, or other severe morbidities. Fall prevention was important to avoid possible injury and to improve daily

Table 1. Comparison of temporal parameters in the three STS strategies

	Simple strategy	Flexion strategy	Extension strategy
Phase I (sec)	0.95 ± 1.12	2.29 ± 1.48*	1.59 ± 1.51*†
Phase II (sec)	0.26 ± 0.09	0.29 ± 0.13	0.31 ± 0.18
Phase III (sec)	0.91 ± 0.26	1.06 ± 0.47	1.05 ± 0.51
Total (sec)	2.11 ± 1.41	3.65 ± 1.75*	2.95 ± 2.01*

*: Significantly different from the simple strategy ($p<0.01$); †: Significantly different from the flexion strategy ($p<0.01$).

Table 2. Comparison of kinetic data and VAS of STS strenuosity in the three STS strategies

Parameters	Simple strategy	Flexion strategy	Extension strategy
PVM (kg-m/s)	24.3 ± 6.5	18.5 ± 7.6*	23.2 ± 6.4†
PHM (kg-m/s)	15.8 ± 3.8	8.8 ± 4.2*	11.2 ± 4.5*
Max-LR-VF-Diff (%BW)	37.0 ± 14.6	30.8 ± 9.9	24.8 ± 9.1*
VAS	2.9 ± 3.6	4.2 ± 4.0	2.9 ± 3.9

*: Significantly different from the simple strategy ($p<0.01$); †: Significantly different from the flexion strategy ($p<0.05$).

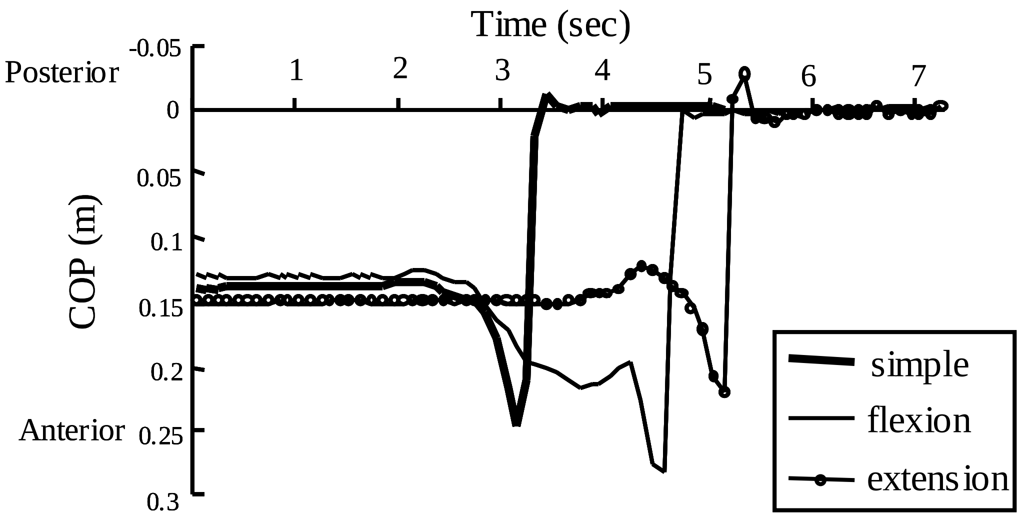


Figure 5. Chair force plate COP pattern in the three STS strategies. These patterns demonstrate the anterior excursion of COP during STS. After seat off of the buttocks, the calculated COP position returned to zero, which was only derived from the experimental chair; Simple: the simple strategy, Flexion: the flexion strategy, Extension: the extension strategy, STS: sit-to-stand, COP: center of pressure.

life. Twenty-one percent of our subjects had a history of incidental falls during STS, indicating that STS potentiate risk for patients with osteoporotic compression fractures.

Specific kinetic features demonstrated by the flexion strategy may support the clinical relevance of the flexion strategy. The STS strategies were controlled by nervous system. Once the strategy was determined, it was up to the nervous system to select the appropriate movement for a given situation.[12] As compared with the simple strategy, the flexion strategy demonstrated a more prolonged period of adjustment in the anterior displacement of COG, a more prolonged total STS duration and Phase I duration, smaller horizontal and vertical momentums, an relatively comparable Max-LR-VF-Diff, and an similar VAS of STS strenuosity. The prolonged total STS and Phase I durations were a result of a greater horizontal COG preparation time before seat off. The flexion strategy had a smaller horizontal and vertical momentum, indicating a slower peak vertical and horizontal velocity, as much as 44% and 24% slower, respectively, during STS movement. As a result, the patient's effort for motor control and neuromuscular system adjustment can be simplified. Since the aged and disabled, such as those with osteoporotic compression fractures, had a generally slower balance reaction and a smaller magnitude of postural responses to pertubation,[13] the flexion strategy seemed less challenging to them to attain the dynamic balance requirement in STS. However, since the total work, muscular activity or COG was not investigated in this paper, the implication of flexion strategy required further study.

Using the flexion strategy, subjects demonstrated a preparatory posture at the time near the end of Phase I, whereas bilateral lower limbs undertook isometric contractions in a closed kinetic chain and then exerted a burst of muscle contraction of the lower limbs to start seat off.[14] Although during flexion strategy, the STS sequence was modified at the expense of a more time-consuming and strenuous pattern, the subjects may benefit from a slower STS movement to achieve better motor control and trunk stability. Many of these compression fractures patients already presented with relatively fixed kyphotic posture, which simulated the initial flexion posture. In addition, the forward bending trunk may utilize the hip strategy with the back remained relatively straight. Papa pointed out that the elder tended to flex the trunk more prior to seat-off compared to the young, bringing the center of mass closer to the base of support.[15] Our results may support the benefits of the flexion strategy for these patients, especially for those who could not tolerate a burse of perturbation and were able to perform a preparatory isometric exercise before seat off. However, the potential risk of increasing intra-discal pressure warrants great caution in carrying out flexion strategy.

Previous study[8] have indicated that the peak momentum of the body's center of mass during an STS task has a relative invariance in the horizontal *vs.* the vertical direction of motion as the speed of ascent increases from natural to fast. However, in this work, the flexion strategy showed a decrease in both horizontal and vertical momentum as compared to the simple strategy, with the horizontal momentum decreased even greater than the vertical. This different finding indicated that the flexion strategy in our work was a different STS strategy rather than a 'simple strategy' at a slower speed.

The extensor strategy revealed a less Max-LR-VF-Diff, which reflected a more symmetrical ground reaction force pattern, but its clinical relevance was obscure. Symmetry analysis in STS has been proposed to be important by Lundin,[16] and other investigations demonstrated a close correlation between postural imbalances and falling.[17,18] Max-LR-VF-Diff during STS and sitting down has been proven to be greater in stroke fallers than in non-stroke fallers or healthy adults.[19] In this work, the increased symmetry in the extension strategy may reflect the change of motor control resulting from an extended trunk and neck posture before initiating the trunk flexion motion. Previous investigators had provided some explanation of the neck posture on the motor control system. Stevens[20] observed a smoother STS pattern by inhibiting head movements and changes to the neck posture, and Lindsay[21] indicated that the neck receptor system might be as important as the labyrinthine system for the control of posture and the hindlimb motor neuron excitability.[13] Further, patients with vertebral compression fractures usually exhibit a kyphotic posture. Because the head-arm-trunk segment is the major contributor to horizontal linear momentum,[5] it is postulated that after a modification of the head-arm-trunk segment from a kyphotic to a less kyphotic one by trunk extension, the biomechanical defects resulting from the kyphosis are possibly compensated for.

The limitations of present work were the laboratory setting of chair design as well as the restriction of shoulder and arm movement. The laboratory setting was designed to minimize unnecessary variations and to help characterize differences in the strategies. Conditions were constrained to a knee flexion of 85°, which was reported as more biomechanically advantageous by Shepherd[22] and Stevens.[20] Arms were crossed in front of the chest to avoid any bias caused by inconsistent shoulder and arm movements. However, this simplified laboratory setting might limit the interpretation of results, because these patients have to face various STS situations in daily life which differ from those in our setting, such as pushing up with the armrests to help weight transfer, placing upper limbs on the thighs for assistance, raising from a sofa or chair with back support, or raising from chairs with different seat heights.

CONCLUSION

This study described the kinetic changes of the three STS strategies for patients with osteoporotic compression fractures. The flexion strategy gave a slower STS movement, which may have a role in simplifying the neuromuscular demand for motor control and trunk stability. The extension strategy seemed to offer a more symmetric STS pattern by reduced left–right weight distribution, and its clinical relevance warrants further investigation.

AKNOWLEDGMENTS

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女性骨鬆脊柱壓迫性骨折病患由坐到站不同動作策略在時間與動力學的特性

吳佩璇[1] 裴育晟[1] 廖美雲[1] 洪維憲[2] 柯智裕[1] 黃美涓[1,3]

林口長庚紀念醫院復健科[1] 中國醫藥大學運動醫學系[2]

長庚大學復健科學研究所[3]

本研究的目的在定義骨鬆脊柱壓迫性骨折病患由坐到站(sit-to-stand, STS)的三種不同動作策略的動力學特性的探討，以提供病人動作策略的參考依據。本研究共收集十四位女性骨鬆脊柱壓迫性骨折病患，平均年齡為 68.2±7.8 歲。受測病患坐在可調整、無把手、無靠背之椅子，雙腳放在壓力板上。分別測試三種坐站動作策略，包括簡單型、前屈型、伸展型三種方式。記錄其 STS 動作參數，包括 STS 的時間、水平與垂直動量、左右腳最大垂直作用力差距。前屈型 STS 動作模式提供最長之動作時間，而病患在離開座位前有較長的水平重心移動準備時間。此動作策略和簡單型相比較，其水平和垂直動量分別減少 44% 及 24%。而和簡單型相比較，伸展型動作策略具有較小之左右腳最大垂直作用力差距。從結果發現，前屈型 STS 動作策略對骨鬆脊柱壓迫性骨折病患提供的 STS 動作模式，減少起立時身軀之擺動，或許對此類病患在 STS 動作中可提供較佳的穩定性。而伸展型動作策略具有較小之左右腳最大垂直作用力差距，其臨床意義仍需進一步探討。（台灣復健醫誌 2006；34(3)：129 - 139）

關鍵詞：骨質疏鬆(osteoporosis)，脊柱壓迫性骨折(vertebral compression fractures)，動力學(kinetics)，由坐到站(sit-to-stand)

抽印本索取地址：黃美涓醫師，林口長庚紀念醫院復健科，桃園縣 333 龜山鄉復興街 5 號

電話：(03) 3281200 轉 3846 e-mail：walice@adm.cgmh.org.tw