J Rehabil Med 2004; 36: 42–45

VERTICAL GROUND REACTION FORCE SHAPE IS ASSOCIATED WITH GAIT PARAMETERS, TIMED UP AND GO, AND FUNCTIONAL REACH IN ELDERLY FEMALES

Toshiaki Takahashi,[1] Kenji Ishida,[1] Daisuke Hirose,[1] Yasunori Nagano,[1] Kiyoto Okumiya,[2] Masanori Nishinaga,[2] Yoshinori Doi[2] and Hiroshi Yamamoto[1]

From the [1]Department of Orthopaedic Surgery, Kochi Medical School, Kochi, [2]Department of Medicine and Geriatrics, Kochi Medical School, Kochi, Japan

Objective: **The aim of this study was to evaluate the relationship between knee pain and various indicators of the combined performance of the lower extremity (including gait parameters, functional performance such as timed up and go, and functional reach test) and to determine whether the classification of vertical ground reaction forces correlates with gait parameters and functional performance.**

Subjects and Methods: **Simultaneous analysis of gait, time-distance parameters and vertical ground reaction force. Timed up and go, and functional reach test were examined in 130 elderly women. The vertical component of the ground reaction force was grouped into 2 categories: M-shaped and non-M-shaped.**

Results: **No significant association was found between knee pain and timed up and go, functional reach test, or gait parameters in elderly female participants. There were significant differences between subjects with M- and non-M-shaped vertical ground reaction forces with regard to timed up and go, functional reach test and Japan Orthopaedic Association score. There were also significant differences between the 2 groups (M shaped and non-M-shaped) in gait parameters.**

Conclusion: **Evaluation of the vertical ground reaction force to determine its shape may be a useful and simple tool in the analysis of gait and functional performance.**

Key words: knee pain, gait analysis, elderly females, ground reaction force, osteoarthritis.

J Rehabil Med 2004; 36: 42–45

Correspondence address: Toshiaki Takahashi, Department of Orthopaedic Surgery, Kochi Medical School, Oko-cho, Nankoku, Kochi, 783-8505, Japan. E-mail: takahast@kochi-ms.ac.jp

Submitted January 22, 2003; Accepted August 25, 2003

INTRODUCTION

Osteoarthritis of the knee is one of the most common diseases in elderly females. There are several ways of testing locomotor function of the lower extremity, including measures of muscle strength, gait analysis and some types of knee evaluation scales (1–3). However, there is limited evidence that these parameters are highly correlated with the functional state of the knee. Gait analysis is becoming recognized as an important clinical tool in orthopaedics, in pre-surgery planning, post-surgery monitoring and in a posterior evaluation of various corrective interventions (4, 5). However, it is sometimes difficult for clinicians to analyse the large amounts of data gathered in the assessment of gait time and distance parameters (5).

Objective quantitative assessment of mobility and balance is important for older people because problems with gait and balance can result in a restriction of activity. The Timed Up and Go (TUG) test correlates with gait speed, balance and movement of the lower extremities (6). The Functional Reach (FR) test is a simple measurement of standing balance that can predict falls in elderly people (7, 8).

There have been several reports concerning gait analysis in osteoarthritis of the knee (1, 9). The vertical ground reaction force (VGRF) has been shown to be a reliable and repeatable feature of gait (10–11). There have been numerous studies regarding ground reaction forces during walking (12–14). Gait speed significantly affects VGRF (12, 13, 16). The VGRF varies continually from the instant of initial contact until the foot leaves the supporting surface (17). Body mass, proportions, walking style and balance all affect VGRF (17).

There have been only a few reports regarding the relationship between VGRF and various gait parameters in elderly females with osteoarthritic knees. Analyses that include a classification of VGRF have also been limited. Thus, in this study, we focused on the vertical ground force component, classified into 2 groups: M-shaped, also known as a "dual-hump" shape (18) and non-M-shaped. The purpose of this study was to evaluate the relationship between knee pain and various indicators of the combined performance of the leg, including gait parameters, functional performance, TUG and FR and to determine whether the classification of VGRF is correlated with gait parameters and functional performance.

MATERIAL AND METHODS

Subjects

We defined the subjects with osteoarthritic knee as having knee pain and less than 100 points of Japan Orthopaedic Association (JOA) score. We have been performing annual medical checks of adults aged 65 years and

 ISSN 1650–1977
DOI 10.1080/16501970310018297

Table I. *Japan Orthopaedic Association scores based on the osteoarthritic knee evaluation form*

Pain on walking (maximum 30 points)	*Score*
No pain, walking unlimited	30
Pain, walking unlimited	25
Pain, walking distance of 0.5–1 km	20
Pain, walking less than 0.5 km	15
Pain, walking only indoors	10
Cannot walk	5
Cannot stand	0
Pain on ascending or descending stairs (maximum 25 points)	
No pain	25
Pain, relieved by using handrails	20
Pain, with handrails, but no pain with each step	15
Pain, with each step, pain relieved by using handrails	10
Pain, with each step even with handrail use	5
Cannot ascend or descend	0
Range of motion (maximum 35 points)	
Kneeling	35
Sideways or cross-legged sitting	30
More than 110°	25
75°–109°	20
35°–74°	10
Less than 35°	0
Joint effusion (maximum 10 points)	
No effusion	10
Occasional puncture required	5
Frequent puncture required	0
Maximum total points	100

over who live in the community in Kahoku of Kochi prefecture since 1994. We then examined the locomotor ability of the subjects.

The mean age of the 130 participants was 80 years (range 65–94 years), with a mean height of 143.0 cm. Knee pain while walking was classified into 3 groups: no pain (45%), unilateral pain (28%) or bilateral pain (26%).

Average maximum flexion for all subjects was 140.9 ± 13.4 degrees. Average maximum extension was 5.2 ± 6.1 degrees. JOA scores determined from the osteoarthritic knee evaluation form (Table I) were used for the evaluation of knee function (19). JOA (0–100 points) scores averaged 90.1 ± 12.9 points. The distance between the medial chondyles was evaluated, and averaged 2.5 ± 1.4 fingers breadth.

Co-morbidities of the subjects included hypertension (31.6%), cardiac arrhythmia (6.1%), coronary artery disease (3.2%) and diabetes mellitus (5.7%). Eighteen subjects with the following conditions were excluded from this study: knee disorders after total knee arthroplasty (5 patients), high tibial osteotomy (2 patients), miscellaneous knee operations (2 patients), osteosynthesis (1 patient), multiple cerebral infarctions (7 patients) and Parkinson's disease (1 patient).

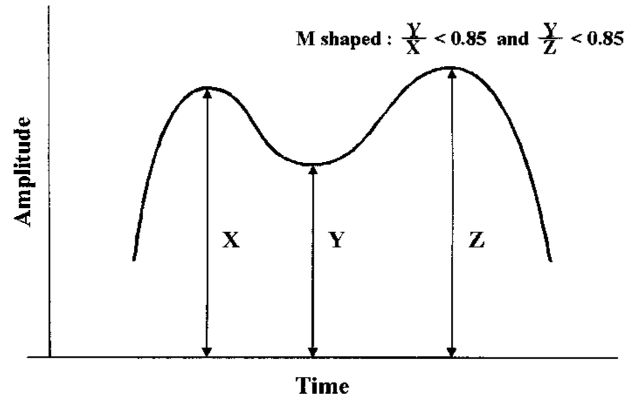

Fig. 1. Calculation of M-wave shape of vertical ground reaction force. M-shaped was defined as Y/X and Y/Z less than 0.85. All others were defined as non-M-shaped.

Gait analysis

The interviewer asked to record the gait parameters of subjects who were able to walk a distance of 10 metres. Subjects were allowed to wear their usual clothes and use their preferred (normal) speed while walking a 7-metre-long course. The first and last 2–3 metres on the walkway were not considered for measurement.

A Gait Scan™ 8000 (Nitta Co. Ltd, Osaka, Japan) of gait-pattern measurement system consisting of a thin-film sensor walkway, a computer for automatic recording of the data was used in this study. This gait analysis device consists of a sensor seat (264 × 52 cm), a connector unit which fixes the sensor seat, and an interface board with a personal computer and software for data analysis.

Gait parameters, temporal distance and time factors, and ground reaction forces were measured simultaneously. Ground reaction force data for both legs was collected at a self-selected walking speed. The peak force was measured as the highest VGRF that occurred anytime during the stance phase, while the lowest VGRF occurred during the mid-stance phase.

Patients were classified into 2 groups based on the VGRF: M-shaped and non-M-shaped (Fig. 1). We defined M-shaped as lowest/highest × 100 (%) of less than 85. We assessed the shape of the VGRF for every step and classified individuals based on the result that was obtained for the greater number of steps. The mean gait variables measured in this study were walking speed (metres/sec), stride length, step width (cm), time of stride, time of single stance and time of double stance (sec). The distance parameters of stride length and step width were normalized for the height of the subject (15).

Functional performance

Timed up and go

To measure TUG, subjects were given oral instructions to stand up from

Table II. *Data (mean (SD)) for patients without pain, with unilateral and bilateral pain in elderly females*

	No pain ($n = 59$)	Unilateral pain ($n = 37$)	Bilateral pain ($n = 34$)
Body weight (kg)	45.2 (7.53)	47.2 (7.49)	52.2 (8.94)
Timed up and go (sec)	13.0 (3.0)	13.8 (4.51)	15.1 (7.28)
Functional reach (cm)	20.6 (7.2)	21.0 (7.07)	23.1 (6.89)
Stride length (cm)	63.2 (9.21)	61.1 (11.7)	61.7 (10.9)
Stride width (cm)	5.4 (2.20)	5.7 (2.14)	5.6 (1.92)
Time of stride (sec)	1.1 (0.117)	1.1 (0.179)	1.2 (0.167)
Time of single stance (sec)	0.58 (0.059)	0.59 (0.073)	0.60 (0.082)
Time of double stance (sec)	0.16 (0.037)	0.17 (0.052)	0.18 (0.069)
Gait speed (m/s)	0.6 (0.115)	0.56 (0.147)	0.54 (0.135)

Table III. *Participant characteristics given as mean (SD)*

	Height (cm)	Weight (kg)	JOA (point)	TUG (sec)	FR (cm)
Right side					
M-shaped ($n = 32$)	143.8 (7.2)	46.1 (8.6)	95.2 (10.3)	11.6 (2.3)	22.5 (6.9)
Non-M-shaped ($n = 47$)	142.4 (5.2)	45.9 (7.4)	86.6 (13.5)	14.6 (4.5)	18.4 (8.2)
	$p = 0.187$	$p = 0.96$	$p = 0.0013$	$p < 0.0001$	$p = 0.026$
Left side					
M-shaped ($n = 29$)	143.1 (8.1)	45.8 (8.1)	96.9 (6.25)	11.35 (2.25)	22.9 (7.56)
Non-M-shaped ($n = 50$)	142.9 (4.7)	46.2 (7.8)	86.1 (14.1)	14.5 (4.44)	18.45 (7.74)
	$p = 0.41$	$p = 0.92$	$p = 0.0002$	$p < 0.0001$	$p = 0.026$

JOA: Japan Orthopaedic Association; TUG: timed up and go; FR: functional reach

a chair, walk 3 metres as quickly and as safely as possible, cross a line marked on the floor, turn around, walk back and sit down (6).

Functional reach. FR represents the maximal distance a subject can reach forward beyond arm's length while maintaining a fixed base of support in the standing position (7, 20).

Statistics

Data were expressed as a mean and standard deviation (SD). Differences between groups were evaluated using a Kruskal Wallis test for the analysis of knee pain (Table II) and a Mann-Whitney U test for the analysis of VGRF (Tables III and IV). Statistical significance was set at $p < 0.05$.

RESULTS

Occurrence of knee pain showed a significant association with body weight; however, there was no significant difference between patients with or without pain and TUG, FR, or any gait parameters (Table II).

The shape of the VGRF was associated with certain measures of functional performance, as well as the JOA score (Table III). Patients exhibiting an M-shaped VGRF on the right and left sides had shorter TUGs and longer FRs than patients with a non-M-shaped VGRF. The total JOA score was greater for the M-shaped group than for the non-M-shaped group. Within both groups, the ground reaction forces were similar on left and right sides.

Several gait parameters varied according to the shape of the VGRF (Table IV). Stride length was longer for the M-shaped VGFR group than for the non-M-shaped VGRF group. The times of stride and single and double stance were shorter in the M-shaped VGRF group than in the non-M-shaped group. The walking speed of the M-shaped group was faster than that of the non-M-shaped group. There was no significant difference between the 2 groups in the step width on both sides.

DISCUSSION

Osteoarthritis of the knee is common in elderly females and it is well-known that it is associated with gait disturbances. There have been numerous reports regarding the relationship between osteoarthritis and gait parameters. An evaluation of the relationship between gait parameters and knee pain in elderly females found no significant association between knee pain and gait parameters or functional performance. Findings such as these have suggested that numerous factors, such as the posture of the trunk, lumbar lesions, the condition of other joints (such as the hip and ankle) and mental status, all contribute to gait parameters in elderly females. Therefore, it is important to consider these factors in the analysis of people with knee pain.

An advantage of gait analysis as a diagnostic or research tool is that many factors can be assessed at one time; however, proper evaluation of the resulting data can be complex. Quantitative data of time and distance parameters of gait analysis is difficult to understand and interpret whether it is within normal or not.

One study showed no overall abnormality in the shape or amplitude of the ground reaction force measured for the natural gait of knee-pain subjects (21). The present study, which involved the evaluation of one simple aspect of the VGRF (classified as M-shaped and non-M-shaped), showed that the shape of the ground reaction force was correlated with the pain

Table IV. *Gait parameters (mean (SD)) for subjects with M-shape and non-M-shape of vertical ground reaction force*

	Stride length (cm)	Step width (cm)	Time of stride (sec)	Time of single stance (sec)	Time of double stance (sec)	Gait speed (m/s)
Right side						
M-shaped ($n = 32$)	70.1 (8.7)	5.5 (2.1)	1.03 (0.09)	0.5 (0.04)	0.1 (0.02)	0.7 (0.11)
Non-M-shaped ($n = 47$)	55.8 (89.9)	5.8 (2.3)	1.2 (0.15)	0.6 (0.07)	0.2 (0.047)	0.5 (0.1)
	$p < 0.0001$	$p = 0.712$	$p < 0.0001$	$p < 0.0001$	$p < 0.0001$	$p < 0.0001$
Left side						
M-shaped ($n = 29$)	70.6 (9.2)	5.5 (2.08)	1.0 (0.087)	0.54 (0.042)	0.1 (0.02)	0.69 (0.12)
Non-M-shaped ($n = 50$)	56.5 (9.9)	6.0 (2.47)	1.8 (0.15)	0.61 (0.075)	0.2 (0.046)	0.5 (0.11)
	$p < 0.0001$	$p = 0.146$	$p < 0.0001$	$p < 0.0001$	$p < 0.0001$	$p < 0.0001$

component of the JOA score. In another study, increased gait speed was associated with shorter force periods and larger peak forces (16).

In the present study we found that there were no differences between the right and left legs with respect to gait parameters, functional performance or the shape of the ground reaction force. Consistent with our findings, another study showed no significant differences between the right and left foot with respect to ground reaction force during walking (22).

In our study we found that both gait parameters and functional performance were significantly correlated with the shape of the VGRF. Several previous studies have examined VGRFs in normal subjects and patients with osteoarthritis; however, prior to the present study, there was little known concerning the relationship between the VGRF and gait parameters or functional performance in elderly females with knee osteoarthritis. In one study it was found that the 2 peaks in the vertical component measured for the affected side in knee-osteoarthritis patients became less apparent, with significantly lower magnitudes than in normal subjects (18). In addition, patterns of VGRFs were nearly identical during overground and treadmill walking (23) and the general waveform and its characteristic features did not seem to be affected by the sex of normal subjects (18). In the present study, we could not find a correlation between pain and the mechanism of the shape of VGRF. Further study is needed to clarify the changing mechanism of VGRF in osteoarthritic knee.

In the present study, we did not examine inter-rater reliability: future study is needed to investigate this and the validity with respect to M-shape and gait analysis.

In conclusion, our classification of VGRF is a simple and useful tool for assessment of gait function. It was correlated with many parameters of gait and functional performance, such as TUG and functional reach. Our study indicated that a change in the VGRF, from non-M-shaped to M-shaped, is crucial to the improvement of gait parameters and gait performance. Further studies are needed to seek methods for altering the shape of the ground reaction force.

ACKNOWLEDGEMENTS

We thank all staff members and elderly residents of Kahoku in Kochi prefecture who were involved in this study.

REFERENCES

1. Murray MP, Gore DR, Sepic SB, Mollinger LA. Antalgic maneuvers during walking in men with unilateral knee disability. Clin Orthop 1985; 199: 192–200.
2. Prince F, Corriveau H, Hebert R, Winter DA. Gait in the elderly. Gait Posture 1997; 5: 128–135.
3. Stauffer RN, Chao EYS, Gyory AN. Biomechanical gait analysis of the diseased knee joint. Clin Orthop 1977; 126: 246–255.
4. Kaufman KR, Sutherland DH. Future trends in human motion analysis. In: Harris GF, Smith PA, eds. Human motion analysis. Current applications and future directions. New York: IEEE Press; 1996, p. 187–215.
5. Bertani A, Cappello A, Benedetti MG, Simoncini L, Catani F. Flat foot functional evaluation using pattern recognition of ground reaction data. Clin Biomech 1999; 14: 484–493.
6. Podsiadlo D, Richardson S. The timed “Up & Go”: a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 1991; 39: 142–148.
7. Duncan PW, Weiner DK, Chandler J, Studenski S. Functional reach: a new clinical measure of balance. J Gerontol 1990; 45: 192–197.
8. Weiner DK, Duncan PW, Chandler J, Studenski SA. Functional reach: a marker of physical frailty. J Am Geriatr Soc 1992; 40: 203–207.
9. Goh JC, Bose K, Khoo BC. Gait analysis study on patients with varus osteoarthritis of the knee. Clin Orthop 1993; 294: 223–231.
10. Kadaba MP, Ramakrishnan HK, Wootten ME, Gainey J, Gorton G, Cochran GVB. Repeatability of kinematic, kinetic, and electromyographic data in normal adult gait. J Orthop Res 1989; 7: 849–860.
11. Olsson E, Oberg K, Ribbe T. A computerized method for clinical gait analysis of floor reaction forces and joint angular motion. Scand J Rehabil Med 1986; 18: 93–99.
12. Andriacchi TP, Ogle JA, Galante JO. Walking speed as a basis for abnormal gait measurements. J Biomech 1977; 10: 261–268.
13. Alexander RM, Jayes AS. Fourier analysis of forces exerted in walking and running. J Biomech 1980; 13: 383–390.
14. Balmaseda MT, Koozekanani SH, Fatehi MT, Gordon C, Dreyfuss PH, Tanbonlinog EC. Ground reaction forces, center of pressure, and duration of stance with and without an ankle-foot orthosis. Arch Phys Med Rehabil 1988; 69: 1009–1112.
15. Chao EY, Laughman RK, Schneider E, Stauffer RN. Normative data of knee joint motion and ground reaction forces in adult level walking. J Biomech 1983; 16: 219–233.
16. Nilsson J, Thorstensson A. Ground reaction forces at different speeds of human walking and running. Acta Physiol Scand 1989; 136: 217–227.
17. Cook TM, Farrell KP, Carey IA, Gibbs JM, Wiger GE. Effects of restricted knee flexion and walking speed on the vertical ground reaction force during gait. J Orthop Sports Phy Ther 1997; 25: 236–244.
18. Schneider E, Chao EY. Fourier analysis of ground reaction forces in normals and patients with knee joint disease. J Biomech 1983; 16: 591–601.
19. Takahashi T, Wada Y, Tanaka M, Iwagawa M, Ikeuchi M, Hirose D, Yamamoto H. Dome-shaped proximal tibial osteotomy using percutaneous drilling for osteoarthritis of the knee. Arch Orthop Trauma Surg 2000; 120: 32–37.
20. Okumiya K, Matsubayashi K, Wada T, Kimura S, Doi Y, Ozawa T. Effects of exercise on neurobehavioral function in community-dwelling older people more than 75 years of age. J Am Geriatr Soc 1996; 44: 569–572.
21. Radin EL, Yang KH, Riegger C, Kish VL, O’Connor JJ. Relationship between lower limb dynamics and knee joint pain. J Orthop Res 1991; 9: 398–405.
22. Herzog W, Nigg BM, Read LJ, Olsson E. Asymmetries in ground reaction force patterns in normal human gait. Med Sci Sports Exerc 1989; 21: 110–114.
23. White SC, Yack HJ, Tucker CA, Lin HY. Comparison of vertical ground reaction forces during overground and treadmill walking. Med Sci Sports Exerc 1998; 30: 1537–1542.