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Assessment of Gait Symmetry in Elderly Women with Low Bone Mineral Density Using a Portable Trunk Accelerometer: A Pilot Study

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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
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Background: Convincing evidence regarding gait and balance function in elderly women with low bone mineral density (BMD) and/or osteoporosis is limited. In the present study, we aimed to compare the gait characteristics in elderly women with and without low BMD and to analyze plausible parameter(s) for predicting low BMD.

Material/Methods: We retrospectively analyzed prospectively collected data of 26 consecutive postmenopausal women aged >65 years who were admitted to our geriatric outpatient service. They were assigned to 2 groups, with (n=14) and without (n=12) low BMD based on T-score (<–1 standard deviation of the mean for healthy adults) of dual-energy X-ray absorptiometry. We compared gait parameters derived from a portable Tri-Axial trunk accelerometer that included cadence, walking speed, average acceleration, horizontal/vertical displacement ratio, and symmetry index of the Lissajous figure (LI) during a 5-meter walk test at comfortably fast speed between groups.

Results: Women with low BMD tended to show increased LI compared with healthy subjects (*P*=0.04). No statistically significant differences were noted in cadence, walking speed, average acceleration, and ratio of horizontal and vertical displacement (*P*>0.05). Receiver operating characteristic curve analysis demonstrated that LI can predict low BMD in the femur neck with moderate accuracy (area under the curve=0.75, 95% confidence interval 0.55–0.95; *P*=0.031). The optimal cut-off value was 17%, with 67% specificity and 86% sensitivity.

Conclusions: These results suggest that elderly women with low BMD may walk with asymmetrical trunk movement, but they are able to generate gait patterns similar to healthy peers. The LI may provide valuable quantitative information for preventing fractures in subjects with osteoporosis.

MeSH Keywords: **Absorptiometry, Photon • Accelerometry • Bone Density • Frail Elderly • Gait • Osteoporosis**

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Background

Osteoporosis is a major global public health problem which proportionally increases with age, and is generally characterized by reduced bone mineral density (BMD) and increased incidence of fractures, resulting in shorter life expectancy [1]. Therefore, early detection of osteoporosis and treatment are critical for well-being and independence and for reducing associated healthcare costs.

During the course of aging, postmenopausal women are more susceptible to osteoporosis due to related hypoestrogenism [2]. Such elderly women tend to show reductions in muscle mass and strength, which may affect gait patterns [3,4]. A recent kinetic study demonstrated decreased external hip extension and adduction moments, power generation at the hip and ankle, or hip and knee in postmenopausal women with low BMD compared to normal BMD subjects [5]. These findings support the idea of strengthening these muscle groups for improving gait patterns of elderly women to prevent them from falling [6]. However, a comparison of functional gait parameters, including the symmetry of trunk movement, in this category of patients has not been well investigated. Recently, we introduced a simple method of gait analysis using a portable tri-axial accelerometer in children with cerebral palsy, which provides spatiotemporal quantitative data that can be instantly analyzed [7,8].

We hypothesized that establishing an easily recognizable gait parameter(s) related to low bone mass in elderly women would be helpful in developing a gait training strategy to prevent low BMD and subsequent progression to osteoporosis. Therefore, the present study aimed to determine the gait characteristics of elderly women with low BMD compared with age-matched subjects with normal BMD, and to explore related parameters for predicting low BMD. In addition to conventional gait parameters, a planar figure view consisting of 2 types of oscillations derived from the tri-axial accelerometer, the so-called Lissajous figure, has recently been introduced [9]; this parameter will facilitate understanding of the lateral trunk deviation of the gait cycle during walking [10].

Material and Methods

Participants

We retrospectively analyzed prospectively collected data of consecutive patients included in our cohort study. In total, 26 women (12 women with healthy BMD levels, 4 with osteopenia, and 10 with osteoporosis) were admitted to our geriatric outpatient service and were subsequently recruited and assessed between July 2018 and January 2019. Inclusion criteria were as follows: postmenopausal women aged ≥65 years and who had a whole-body dual-energy X-ray absorptiometry (DXA) scan on the same day as gait analysis. Patients were excluded if they had: 1) evidence of neurologic or psychiatric disorders (e.g., stroke, Parkinson's disease, dementia, or depression) and 2) coexisting severe medical conditions or terminal diseases that would compromise the patient's ability to safely complete the gait trial. Ethics approval was obtained from the Ethics Committee of the Graduate School of Medicine, Tohoku University (registry number: 2018-1-298). This study adhered to the ethical standards originating in the Declaration of Helsinki.

A statistical power analysis software program (BellCurve for Excel, SSRI, Tokyo, Japan) was used to determine the sample size. In our preliminary study, gait analysis was performed in the following 2 groups: 10 normal women and 8 with low BMD. Therefore, it was determined that 11 participants were required in each group to detect a mean difference of 9 steps/min in cadence, with a medium size effect of r=1.28, a power of 0.8, and α level of 0.05.

DXA-based BMD measurements

BMD was obtained in the year preceding entry into the study via DXA and was obtained at the Tohoku University Hospital using specialized DXA equipment (QDR 4500a, Hologic, Inc., Bedford, MA, USA) by the same protocol in all cases, as part of the routine clinical examination. DXA provides both total and regional body composition via a 3-compartment method that distinguishes total bone mineral content from soft tissue, allowing for assessment of whole-body and site-specific lean mass. From these measurements, appendicular lean mass index (skeletal muscle mass index [SMI]) can be determined [11]. Subjects were assigned into 2 groups in accordance with the World Health Organization criteria of T-score of a young healthy adult BMD. If patients had T-scores lower than −1 SD, they were assigned to the low BMD group. T-scores between −1 and −2.5 SD were categorized as osteopenic, and those lower than −2.5 SD were categorized as osteoporotic. Femoral neck, lumbar, and whole-body DXA images were used for this study.

Protocol

Gait function was assessed by 2 walking trials at a comfortable, self-selected speed along a 5-meter level walkway using the guideline previously described [12]. Briefly, we first accompanied the patient to the designated area, which was unobstructed and had markers at 0 and 5 meters. The patient was positioned at the 0-m start line and was instructed to "walk at your comfortable pace" until a few steps past the 5-m mark before slowing down. Each patient was timed (the timer started with the first footfall after the 0-m line and stopped with the first footfall after the 5-m line) by an examiner who walked behind. The examiner started the timer with the first

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Table 1. Participant characteristics.

	Low BMD (n=14)		Normal BMD (n=12)		‘P-value
Age (years)	73.6±6.3	(65–84)	70.8±4.3	(65–77)	0.47
Height (cm)	150±5	(147–158)	153±7	(141–163)	0.27
YAM (%)	70±7	(98–81)	89±9	(98–81)	0.007
T-score (SD)	−2.2±0.5	(−1.4 to −2.8)	−0.4±0.7	(−1.0–0.5)	0.003
Osteoporosis (T-score of <−2.5 SD)	10	(71)	0	(0)	N/A
BMI (kg/m^2)	23.3±2.6	(19.9–28.9)	22.5±4.4	(18.0–35.0)	0.26
SMI (kg/m^2)	5.84±0.63	(4.99–7.06)	6.46±0.71	(5.50–7.02)	0.12
Prevalence of sarcopenia (AWGS criteria)	3	(21)	0	(0)	N/A
History of fractures	2	(14)	0	(0)	N/A

Data are expressed as mean ± standard deviation (range) or number of subjects (percentage). BMD – bone mineral density; BMI – body mass index; SD – standard deviation; SMI – skeletal muscle mass index; AWGS – The Asian Working Group on Sarcopenia in Older People.

footfall after the 0-m line and stopped with the first footfall after the 5-meter line.

During the 5-m walk test, a Tri-Axial accelerometry-based portable motion device (MG-M1110, LSI Medience, Japan) with a wired remote control device (*Inset*) was fixed with a belt placed around the hip parallel to the lumber spine (*http://www.searchgait.com/cgi-bin/blog/filecontroller.cgi?file=1364975653MG-M1110-HW_Ver1.pdf*), and this was used for recording mediolateral (X-axis), vertical (Y-axis), and anteroposterior (Z-axis) plane of trunk acceleration. The resulting motion signals were then recorded at a sampling rate of 100 Hz, stored on a Windows PC for off-line analysis, and used for quantifying walking speed (m/min), cadence (step/min), step length (cm), ratio of horizontal (cm) and vertical (cm) displacements in the frontal plane [7,8], and average acceleration [m/s^2 (G)]. The Lissajous index (LI) as an indicator of the trunk symmetry was calculated as the product of the maximum value of X-axis (G) and the maximum value of Y-axis – 0.98 (downward force) (G) of the frontal plane (R_{right} and R_{left}, respectively) [10], using the following formula:

$$LI = |\frac{2 \times (R_{\text{right}} - R_{\text{left}})}{(R_{\text{right}} + R_{\text{left}})} \times 100|$$

Statistical analysis

The Mann-Whitney *U* test was performed for comparing gait parameters between groups. Fisher's exact test was used for comparing categorical variables. Spearman's correlation coefficients were used for evaluating the relationship between BMD and gait variables. Discriminative properties of selected gait variables were assessed using receiver operating curve (ROC) analysis. All analyses were performed using BellCurve for Excel (SSRI, Tokyo, Japan) and Prism (version 7.0, GraphPad Software, La Jolla, CA). Data are presented as means ± standard deviation (range) or number (%), unless otherwise described. The significance level was set at $P<0.05$.

Results

Patients' demographic data in this prospective cross-sectional study are described in Table 1. No significant differences were noted in age, weight, height, body mass index (BMI; weight in kg divided by height in meters square), or SMI between the 2 groups. In the low BMD group, most patients (75%) had a history of osteoporosis, 3 patients met the criteria for sarcopenia based on the Asian Working Group on Sarcopenia in Older People (AWGS), and 2 patients had a history of bone fractures.

Table 2 represents gait parameters of normal and low BMD groups. No significant differences were noted in cadence, walking speed, step length, average acceleration, or the ratio of horizontal/vertical displacement between the groups. Figure 1 displays representative Lissajous figures (LFs) from low or normal BMD subjects during a 10-meter walk test. Elderly women with low BMD showed decreased LI compared to normal peers ($P=0.031$).

BMD was negatively correlated to the LI (r=−0.517, 95% confidence interval −0.793 to −0.066; $P=0.028$), suggesting a relationship between BMD and gait variables in all subjects. No significant correlations were observed between BMD and other parameters ($P\geq0.05$).

Figure 2 displays the ROCs of gait variables associated with BMD as demonstrated in this study (LI), and walking speed and cadence, which have previously been shown to be a potential parameter associated with low BMD [4,13]. The ROCs

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Table 2. Gait parameters derived from the tri-axial trunk accelerometer.

	Low BMD (n=14)		Normal BMD (n=12)		‘P-value
Cadence (steps/min)	117±9	(104–139)	122±8	(132–109)	0.079
Walking speed (m/s)	1.08±0.29	(27–87)	1.11±0.22	(46–87)	0.768
Step length (cm)	54.8±14.9	(23–75)	53.8±8.9	(36–66)	0.327
Average acceleration (G)	0.29±0.07	(0.19–0.39)	0.28±0.06	(0.20–0.39)	0.662
Horizontal/vertical displacement ratio	1.18±0.63	(0.49–2.52)	1.28±0.56	(0.54–2.21)	0.472
Lissajous index (%)	30.7±18.6	(2.0–66.7)	15.5±11.8	(2.6–44.0)	0.031

Data are presented as mean ± standard deviation (range). BMD – bone mineral density.

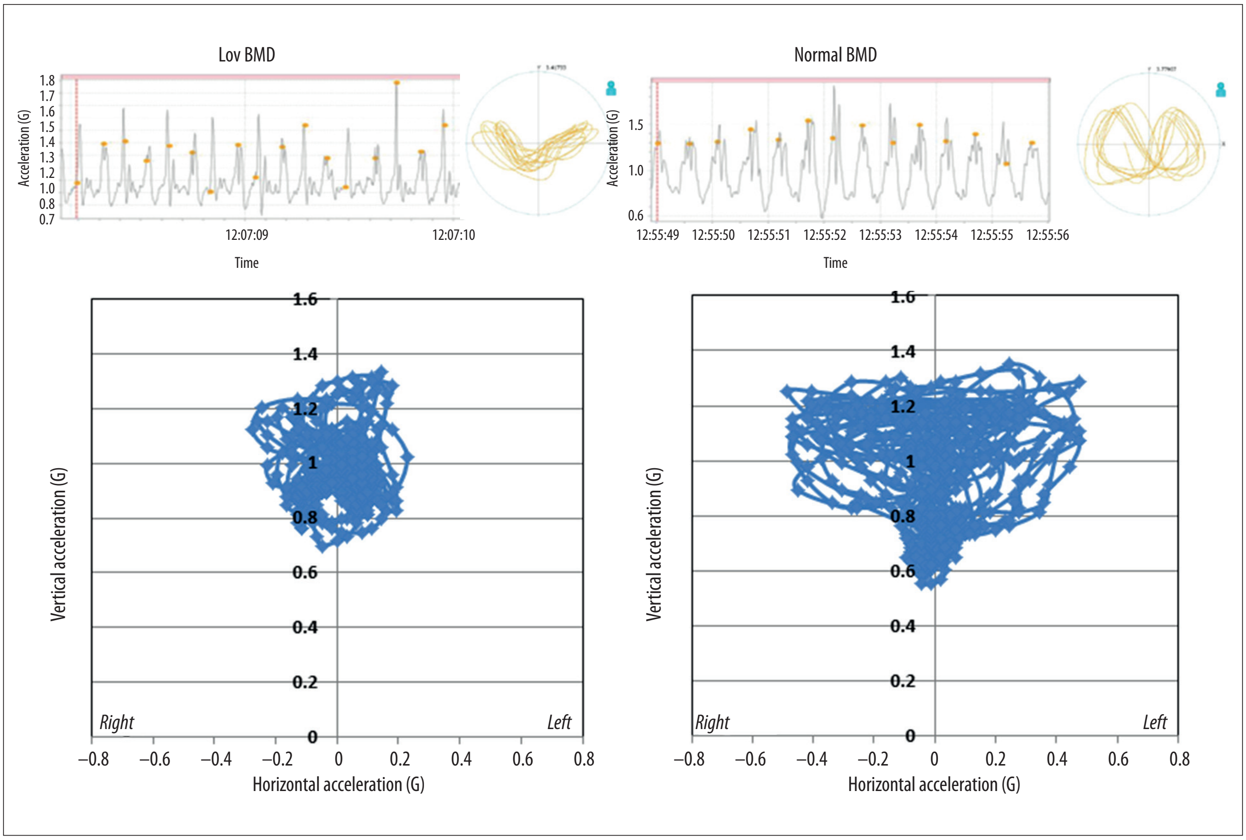

Figure 1. Representative tracings of average trunk acceleration and Lissajous figures (LF) from a 75-year-old woman with low BMD [T-score of -2.7 standard deviation (SD)] and a 69-year-old woman with normal BMD (T-score of –1.0 SD). Upper left and right panels for each subject data show average acceleration (G) and horizontal (X-axis) and vertical (Y-axis) displacements (in cm) and the lower panel shows LF during a 10-meter walk test. Note the slight left upward asymmetry with reduced horizontal oscillation of the LF observed in the subject with low BMD. The symmetry indexes of the LF for each subject were 35.3% and 8.6%, respectively.

of LI, cadence, and walk speed in predicting low BMD were significantly associated with LI [AUC (area under the curve) of 0.75±0.10 (mean ± standard error), 95% confidence interval (CI): 0.55–0.95; *P*=0.031], but not with cadence (AUC of 0.70±0.10, CI: 0.50–0.91, *P*=0.080) or walking speed (AUC=0.5±0.11, CI: 0.27–0.73, *P*≥0.05). The optimized cut-off value of LI was 17%, with 67% specificity and 86% sensitivity.

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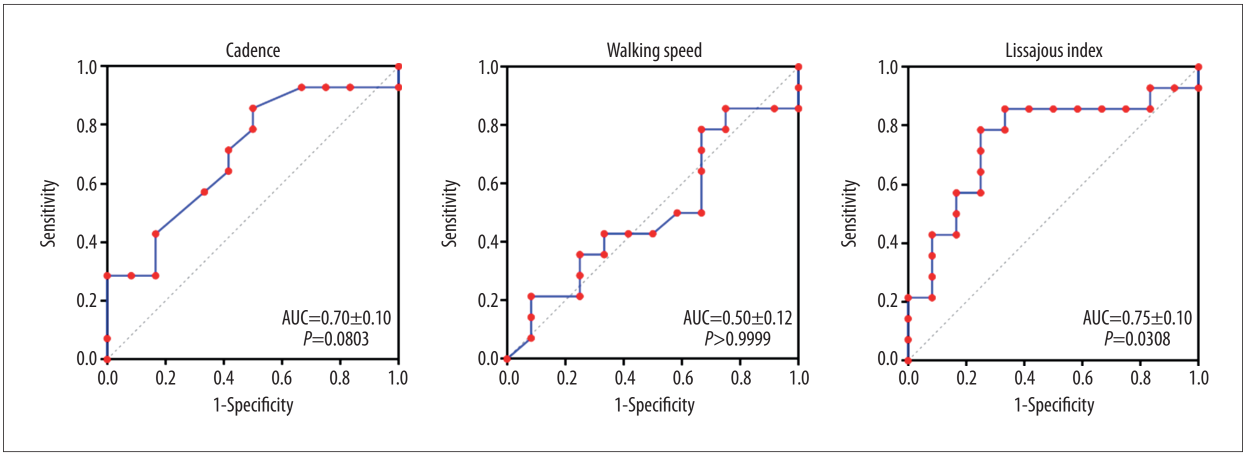

Figure 2. Prediction of low BMD by the ROCs of cadence, walking speed, and Lissajous index in 26 elderly women with low and normal BMD. In this study, moderate certainty was detected only by Lissajous index, while the other 2 gait parameters were not. The diagonal line (45-degree dotted line) represents the line of no discrimination as a reference.

Discussion

Gait analysis allows for insight into the physical status of the musculoskeletal system as well as suspected neurological disorders [14]. It is clinically desirable for gait analysis to assess dynamic/continuous changes of the spatiotemporal gait parameters. However, currently available parameters reflecting trunk movement (e.g., root mean square and harmonic ratio of acceleration), cannot be analyzed instantly or visualized easily. This is, to the best of our knowledge, the initial pilot study to determine the usefulness of a new gait parameter, LI, in elderly women with low BMD, with quantitative analysis in comparison with age-matched normal subjects.

Using kinetic analysis, previous research has characterized postmenopausal women with low BMD with reduced external hip extension and adduction moments, power generation at the hip and ankle, and power absorption at the hip and knee [5]. In that research, the authors asserted that reduced hip extension moment and related eccentric hip work may reduce stress on the lumbar region, thus resulting in bone loss. Also, elderly women with low BMD reportedly preserve trunk rotation in the sagittal and coronal planes, and hip angles in three-dimensional planes [5,15]. This is consistent with the lack of significant difference in conventional gait parameters such as cadence and walking speed between low BMD and normal BMD subjects. Our findings of gait asymmetry in relation to severity of BMD highlight the importance of gait and balance training to reduce risk of falls and fractures. However, these subjects may have compensated for the asymmetry, as they were able to walk at similar intensities and speeds as normal subjects, with less hip extension and adduction moments under similar levels of appendicular skeletal muscle mass.

We previously demonstrated that the sway of horizontal and vertical displacements in the frontal plane as a ratio may be a useful semi-quantitative parameter to estimate trunk symmetry [8,16]. However, the feasibility of this horizontal/vertical displacement ratio may be limited to assessing only the time-course effect of the trunk balance ability in children with cerebral palsy [8], as there has been no reliable baseline data in age-matched normal subjects. Alternatively, LI in the frontal plane can be derived from acceleration in the vertical and mediolateral directions to identify lateral sway of the trunk [10]. Our findings confirm that LI is superior to the displacement ratio in reflecting cross-sectional effects in elderly women with low BMD.

There are some limitations of this study that warrant discussion. First, we had a relatively small number of participants, although we aimed to mitigate this by recruiting age-matched subjects with normal BMD and achieved the minimum sample size (at least 12 subjects in each group) that was determined a priori. Second, we were only able to access hospital-based data and not community data; therefore, the possibility of selection bias cannot be excluded. This was a preliminary study and thus the external validity of the results must be discussed. Third, we did not gather data on the occurrence of sarcopenia or fracture, being bedridden, or death. Lastly, the BMD as measured using DXA cannot always predict the likelihood of fracture, as BMD does not reflect the quality of bone trabeculae, but rather represents just one aspect of osteoporotic deterioration. These issues must be considered in future long-term longitudinal studies.

Conclusions

The LI may provide valuable quantitative information to help prevent fractures in osteoporotic patients. Our results suggest that elderly women with low BMD may walk with asymmetry

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of trunk movement, although they can generate gait patterns similar to healthy peers.

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Conflicts of interest

None.

References:

1. Compston JE, McClung MR, Leslie WD: Osteoporosis. Lancet, 2019; 393: 364–76
2. Ahlborg HG, Johnell O, Turner CH et al: Bone loss and bone size after menopause. N Engl J Med, 2003; 349: 327–34
3. Maltais ML, Desroches J, Dionne IJ: Changes in muscle mass and strength after menopause. J Musculoskelet Neuronal Interact, 2009; 9: 186–97
4. Dostanpor A, Dobson CA, Vanicek N: Relationships between walking speed, t-score and age with gait parameters in older post-menopausal women with low bone mineral density. Gait Posture, 2018; 64: 230–37
5. Eldeeb AM, Khodair AS: Three-dimensional analysis of gait in postmenopausal women with low bone mineral density. J Neuroeng Rehabil, 2014; 11: 55
6. Kerrigan DC, Lee LW, Collins JJ et al: Reduced hip extension during walking: Healthy elderly and fallers versus young adults. Arch Phys Med Rehabil, 2001; 82: 26–30
7. Mutoh T, Mutoh T, Takada M et al: Application of a tri-axial accelerometry-based portable motion recorder for the quantitative assessment of hippotherapy in children and adolescents with cerebral palsy. J Phys Ther Sci, 2016; 28: 2970–74
8. Mutoh T, Mutoh T, Tsubone H et al: Impact of serial gait analyses on long-term outcome of hippotherapy in children and adolescents with cerebral palsy. Complement Ther Clin Pract, 2018; 30: 19–23
9. Yamaguchi R, Hirata S, Doi T et al: The usefulness of a new gait symmetry parameter derived from lissajous figures of tri-axial acceleration signals of the trunk. J Phys Ther Sci, 2012; 24: 405–8
10. Mutoh T, Mutoh T, Tsubone H et al: Effect of hippotherapy on gait symmetry in children with cerebral palsy: A pilot study. Clin Exp Pharmacol Physiol, 2019; 46: 506–9
11. Imboden MT, Swartz AM, Finch HW et al: Reference standards for lean mass measures using ge dual energy x-ray absorptiometry in caucasian adults. PLoS One, 2017; 12: e0176161
12. Wilson CM, Kostsuca SR, Boura JA: Utilization of a 5-meter walk test in evaluating self-selected gait speed during preoperative screening of patients scheduled for cardiac surgery. Cardiopulm Phys Ther J, 2013; 24: 36–43
13. Löfgren N, Halvarsson A, Ståhle A et al: Gait characteristics in older women with osteoporosis and fear of falling. Eur J Physiother, 2013; 15: 139–45
14. Adams J, Perry J: Gait analysis: Clinical application. In: Rose J, Gamble J (eds.), Human walking, Philadelphia: Williams and Wilkins, 1994; 141–64
15. Tsauo JY, Chien MY, Yang RS: Spinal performance and functional impairment in postmenopausal women with osteoporosis and osteopenia without vertebral fracture. Osteoporos Int, 2002; 13: 456–60
16. Whittle MW, Levine D: Three-dimensional relationships between the movements of the pelvis and lumbar spine during normal gait. Hum Mov Sci, 1999; 18: 681–92

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