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Analysis of spastic gait in cervical myelopathy: Linking compression ratio to spatiotemporal and pedobarographic parameters

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ABSTRACT

Background: Gait dysfunction associated with spasticity and hyperreflexia is a primary symptom in patients with compression of cervical spinal cord. The objective of this study was to link maximum compression ratio (*CR*) to spatiotemporal/pedobarographic parameters.
Methods: Quantitative gait analysis was performed by using a pedobarograph in 75 elderly males with a wide range of cervical compression severity. *CR* values were characterized on T1-weighted magnetic resonance imaging (MRI). Statistical significances in gait analysis parameters (speed, cadence, stride length, step with, and toe-out angle) were evaluated among different *CR* groups by the non-parametric Kruskal-Wallis test followed by the Mann-Whitney *U* test using Bonferroni correction. The Spearman test was performed to verify correlations between *CR* and gait parameters.
Results: The Kruskal-Wallis test revealed significant decline in gait speed and stride length and significant increase in toe-out angle with progression of cervical compression myelopathy. The post-hoc Mann-Whitney *U* test showed significant differences in these parameters between the control group ($0.45 < CR$) and the worst myelopathy group ($CR \le 0.25$). Cadence and step width did not significantly change with *CR*. On the other hand, the Spearman test revealed that *CR* was significantly correlated with speed, cadence, stride length, and toe-out angle.
Conclusion: Gait speed, stride length, and toe-out angle can serve as useful indexes for evaluating progressive gait abnormality in cervical myelopathy. Our findings suggest that $CR \le 0.25$ is associated with significantly poorer gait performance. Nevertheless, future prospective studies are needed to determine a potential benefit from decompressive surgery in such severe compression patients.

1. Introduction

Gait dysfunction associated with spasticity and hyperreflexia is a primary symptom in patients with compression of cervical spinal cord, such as observed in cervical spondylotic myelopathy (CSM) [1–8]. Progression of cervical myelopathy may lead to an increased risk of falling accident and its related cervical cord injury [8]. The accepted treatment for spinal cord compression is surgical decompression [9,10], and there is a difficulty in quantitatively determining the most appropriate stage in the disease at which surgeons should perform the procedure. In these circumstances, an intense attention has been given to the role and effectiveness of gait analysis in cervical myelopathy patients [1–8]. There is evidence that CSM patients have significant abnormalities in several gait analysis parameters as compared to healthy individuals [1–8]. These findings suggest that poor gait function may be an important indication for surgical treatment. Nevertheless, a quantitative correlation between severity of the disease and gait performance remains to be fully elucidated.

In the present study, gait analysis was performed using a pedobarograph in elderly male subjects with various severities of cervical compression, which were characterized as the maximum compression ratio (*CR*) of cervical spinal cord on T1-weighted magnetic resonance imaging (MRI) [11]. A smaller value of *CR* reflects a more significant compression in cervical spinal cord. The purpose of this study was to find a correlation between a clinical imaging finding and spatiotemporal/pedobarographic parameters such as gait speed, cadence, stride length, step width, and toe-out progression angle. This paper represents the first report on linking *CR* to these gait analysis

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parameters, which potentially provides us with more insights into the quantitative determination of the surgical indication in cervical myelopathy patients.

2. Methods

2.1. Participants

Approval was obtained from the Institutional Review Board (IRB) of our institute. All subjects gave informed consent prior to their inclusion in the study, which has been performed in accordance with the ethical standards as certified by our ethics committee board. The study involved patients diagnosed between February 2012 and August 2017 as cervical compression myelopathy due to CSM or ossification of the posterior longitudinal ligament (OPLL) in our hospital corroborated by MRI.

Since it was previously pointed out that the gender and age differences in gait analysis parameters were present [12–14], care was taken in the recruitment of the study subjects to eliminate or minimize the effect of potential confounders (*e.g.*, race, gender, age, body height, and BMI [body mass index]). The previous Japanese surveys [15,16] reported that the patients of cervical myelopathy in their 50 s and 60 s accounted for the largest population, and its incidence was higher in males than females. The Health and Welfare statistics provided by the Ministry of Health, Labour and Welfare (MHLW) of Japan [17] showed that, in 50s–60 s Japanese, the mean height and BMI of males were 167.8 cm and 23.8 kg/m^2, whose values were higher than females (154.7 cm and 22.7 kg/m^2). In the above context, we recruited patients at initial presentation based on the following inclusion criteria: (1) Japanese male; (2) $50 \leq$ age ≤ 70 years; (3) $160 \leq$ body height ≤ 170 cm; (4) $20 \leq$ BMI ≤ 30 kg/m^2; (5) no other symptomatic musculoskeletal problems and neurological disorders affecting gait; (6) no history of previous decompression and surgery on lower extremity (*e.g.*, hip, knee, and ankle joint); and (7) having an ability to walk at least 10 m without assistance of another person.

45 cervical myelopathy patients (37 with CSM and 8 with OPLL) and 30 healthy individuals without myelopathy and other disability (referred to as control subjects) were included who met the above criteria. The mean age, body height, and BMI of all the 75 subjects were 61.0 ± 9.4 years, 166.3 ± 4.4 cm, and 24.5 ± 3.0 kg/m^2. MRI scans and gait data were obtained at the same point in time.

2.2. MRI analysis of degree of cervical compression

We characterized *CR* of cervical spinal cord in each subject at the site of maximal cord compression on MRI by an increased signal on T1-weighted images [13]. MRI examinations were performed with a Magnetom Avanto 1.5T system (Siemens, Erlangen, Germany) with a standard head coil and a multi-slice spin echo technique. The slice thickness was 4 mm (slice gap 0.4 mm) and the in-plane resolution was approximately 2.5 × 2.5 mm^2. As shown in Fig. 1**a**, the calculation of *CR* was made by dividing sagittal diameter (d_s) by transverse diameter (d_t) of spinal cord [13]. Note that the smaller the *CR* value the greater the cervical compression. *CR* measurements were performed by two orthopedic surgeons (TN, KE), and their mean values were recorded.

2.3. Gait analysis

Gait analysis was performed on a flat ground using a pedobarograph, the WalkWay MW-1000™ (Anima Co., Tokyo). The device size is 800 × 2400 mm^2 (5-mm thick), and the mounted small strain gages (14,000 points) enable to digitally record the spatial information of subjects' gait based on the center of foot pressure (*CFP*) (Fig. 1**a**). The participants were instructed to continuously walk as straight as possible without any assistance on the long thin sensor sheet. The participants were assessed at self-selected gait speeds. A total of six completed

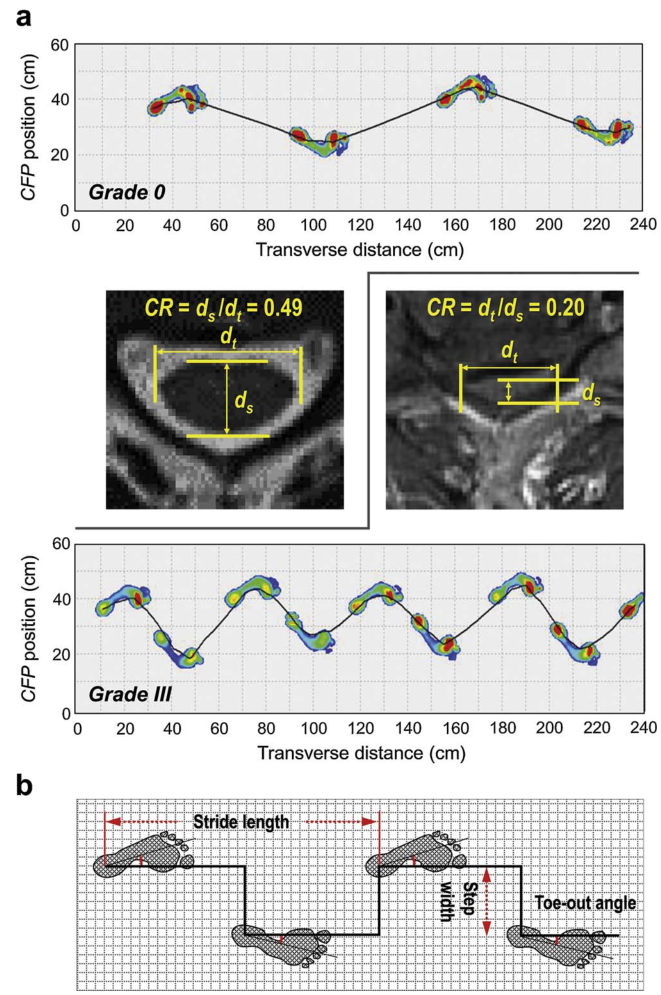

Fig. 1. (a) Difference between gait profiles over the WalkWay obtained from the control (*Grade 0*) and severe compression subject (*Grade III*) corroborated by T1-weighted axial MRIs; (b) schematic of stride length, step width, and toe-out angle.

walking trials were performed over the WalkWay for the purposes of collecting gait data in each participant. The following five parameters were recorded: (1) gait speed; (2) gait cadence (number of walking steps taken within a minute); (3) stride length (the horizontal distance from heel contact from one foot fall to the next heel contact of the same foot); (4) step width (the vertical distance from heel contact from one foot fall to the next heel contact of the opposite foot); and (5) toe-out angle (the angle between the foot-long axis and the line of progression) (*cf.* Fig. 1**b**).

2.4. Statistical analyses

The participants were classified into the following four groups based on their *CR* values: (1) $0.45 < CR$ ($n = 30$; *Grade 0* [control]); (2) $0.35 < CR \leq 0.45$ ($n = 7$; *Grade I*); (3) $0.25 < CR \leq 0.35$ ($n = 14$; *Grade II*); and (4) $CR \leq 0.25$ ($n = 24$; *Grade III*).

Non-parametric statistical analyses were performed using the software OriginPro 2016 (OriginLab Corporation, Northampton, MA, USA). The Kruskal-Wallis test was applied to compare the above four groups of subjects, and the Mann-Whitney *U* test with Bonferroni correction was applied for pairwise post-hoc comparisons. Eta-squared (η^2) and *r* were reported as indicators of effect sizes for the Kruskal-Wallis and the Mann-Whitney U results, respectively, considering that $\eta^2 = 0.01$ and $r = 0.1$ represent a small effect, $\eta^2 = 0.06$ and $r = 0.3$ represent a medium effect, and $\eta^2 = 0.14$ and $r = 0.5$ represent a large effect [18,19]. The Spearman correlation coefficient (r_s) was used to test the