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Threshold of lower body muscular strength necessary to perform ADL independently in community-dwelling older adults

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Objective: To determine the thresholds of lower extremity muscle strength below which performing activities of daily living (ADL) is impaired in older adults.
Design: Cross-sectional.
Setting: Community.
Subjects: Forty-nine older adults (81–89 years) were divided into an independent group ($n = 25$) who needed no assistance and a dependent group ($n = 24$) who needed assistance to perform ADL.
Interventions: Not applicable.
Main measures: Functional independence measures to determine level of disability and muscular strength of hip flexors, hip extensors, knee flexors, knee extensors and ankle dorsiflexors assessed by a hand-held dynamometer (HHD). Muscle groups were tested separately for each leg and values were averaged for the two legs. A ratio of maximal muscular strength to body weight was calculated by dividing the muscular strength (N) by body weight (kg).
Results: Muscular strength thresholds to perform ADL independently were 2.3 N/kg for hip flexors, 1.7 N/kg for hip extensors, 0.7 N/kg for knee flexors, 2.8 N/kg for knee extensors and 2.8 N/kg for ankle dorsiflexors.
Conclusion: The thresholds of lower extremity muscle strength below which assistance is required to perform ADL in community-dwelling older adults were identified. Furthermore, results indicate that the muscular strength of hip extensors is more important in performing ADL than other muscles of the lower extremities.

Introduction

It has been well documented that both muscle mass and muscle strength typically decline with advancing age. Total muscle mass decreases by nearly 50% between the ages of 20 and 90 years[1]

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and muscle strength levels begin to decline in the 40–49 years age group.[2] The Framingham Study reported that 41% of women aged 55–64 years, 45% of women aged 65–74 years and 66% of women aged 75–84 years were unable to lift a weight of 4.5 kg.[3] However, muscle strength was not directly measured in that study. The decline of muscle strength is associated with an increased risk of falls, hip fractures and adverse physiological changes such as reduced glucose tolerance and bone mineral density.[4,5] Furthermore, deficits in lower extremity muscle strength are associated with reduced functional capacity and ability to perform activities of daily living (ADL) such as rising from a chair, walking at an appropriate speed, and climbing stairs.[6–13]

Many previous studies have assessed age-related declines in absolute strength or determined the effect of strength training on isometric and/or concentric force production using free-weight machines and other devices in laboratory settings. In field-based research, functional performance tests are often used as an index of lower extremity muscle strength. An example of such an assessment is the 30-second Chair Stand Test where a subject stands from a seated position as many times as possible in 30 seconds.[14] However, tests such as this are limited primarily to knee and hip extension strength and provide limited information about strength capacities of the entire lower extremity.[15] Information about other muscle groups of the lower extremities and their relation to independence is quite limited.

Ploutz-Snyder *et al.*[16] used isokinetic dynamometry to assess knee extension strength thresholds below which performance of ambulatory tasks are compromised. In the field of rehabilitation, a hand-held dynamometer is often used for muscle strength testing in patients. Compared with other common strength tests, such as isokinetic dynamometry, this method is simple, economic and easy to perform for both the technician and patient.[17–19] Furthermore, studies have shown that the hand-held dynamometer is a suitable mode of strength testing in older adults.[20–22] Previous studies have described specific muscles that are required to perform mobility functions in older individuals.[23,24] However, the level of strength needed within these muscles to perform ADL without assistance is unknown. If functionally relevant thresholds of strength could be identified, they would be useful for targeting individuals for exercise interventions that may attenuate further declines in strength and reduce levels of disability.

To cope with the increasing number of older adults requiring assistance in their daily life, the long-term care insurance system was implemented in Japan in 2000. Thus, strategies to prevent or reduce the need for assistance are important for promoting the health of older adults.

The purpose of this study was to define functional thresholds of lower extremity muscle strength below which assistance (care) is required to perform ADL and to identify lower extremity muscle groups that are most important in performing ADL in community-dwelling older adults.

Methods

Participants

In response to a public relations magazine advertisement, 53 people in Iida city in Nagano prefecture, Nagoya city in Aichi prefecture and Kawabe town in Mie prefecture in Japan volunteered to participate in this study. Prior to acceptance into the study, a brief health examination was performed and questionnaires regarding medical history were completed. Individuals who could not follow simple instructions or who had known medical conditions for which the muscle strength measurements would be contraindicated were excluded from the study. After exclusionary criteria were applied, the remaining 49 volunteers (81–89 years) were found to be sedentary community-dwelling older adults, some of whom had functional disabilities and needed assistance performing ADL. Based on requiring care using the long-term care insurance system, participants were divided into an independent group (IG: $n = 25$; 10 men, and 15 women; 83 ± 2 years) who were able to perform ADL without assistance and a dependent group (DG: $n = 24$; 5 men, and 19 women; 84 ± 3 years) who needed assistance to perform ADL and participated in a day-care service at their geriatric health facility (Table 1).

General characteristics, physical symptoms, ADL and isometric muscle strength were evaluated in all participants at a local community or day-care centre. The ethical committee of Nagoya City

Table 1 Descriptive data for subjects

	Independent group	Dependent group	
No. of participants	25	24	NS
Sex (men/women)[a]	10/15	5/19	NS
Age (years, mean ± SD)[b]	83 ± 2	84 ± 3	NS
Height (cm, mean ± SD)[b]	150 ± 9	146 ± 6	NS
Weight (kg, mean ± SD)[b]	52 ± 9	51 ± 8	NS
BMI (kg/m^2, mean ± SD)[b]	23 ± 4	24 ± 4	NS

Values are mean ± standard deviation (SD).
NS, not significant; BMI, body mass index.
[a]χ^2 test was used to evaluate differences between groups.
[b]Student's *t*-test was used to evaluate the difference between the groups.

University approved the study. All participants received written and oral instructions for the study and each gave their written informed consent prior to participation.

Measurement of general characteristics

Height and weight were measured using a body fat analyser (TANITA body fat analyzer TBF-202; Tanita Co., Tokyo, Japan). Body mass index (BMI) was calculated as body weight (kg) divided by the square of height (m).

Measurement of muscular strength

Maximal isometric strength was assessed using a hand-held dynamometer (Microfet3; Hoggan Health Industries Co., UT, USA). Maximal isometric strength of hip flexors, hip extensors, knee flexors, knee extensors and ankle dorsiflexors was assessed using a break test according to the Daniels technique.[25] Muscles groups were tested separately for each leg and values were averaged for the two legs. Two trials were administered for each isometric test on each limb. The maximal force of the two trials was used for analysis. A ratio of maximal muscular strength to body weight (Str/Wt) was calculated by dividing the muscular strength (N) by body weight (kg).

The testing position sequence was consistent, beginning in the seated position and progressing to the prone position to avoid subject fatigue from frequent position changes. The force pad of the hand-held dynamometer was always held perpendicular to the limb being tested to prevent injury to the skin and to maximize subject comfort.

Testing sessions were conducted with the subject, the tester and a recorder present. Subjects were shown the movement to be tested and then asked to perform it to confirm their understanding of the movement. They were instructed to avoid explosive contraction and to increase their effort gradually and quickly to a maximum after hearing the signal 'ready, go' from the tester. Subjects were told to stop contracting muscles when the tester finished counting to 3. Rests were permitted if a subject indicated a need or if a maximal effort had not been reached in the judgement of either the tester or the subject. An additional measurement was taken if the subject reported failure to achieve maximum effort or if the tester reported poor stabilization during the test.

All measurements were performed by the same tester. The tester was blind about the participants' ADL scores and their position in the long-term care insurance category. Before conducting the current study, the test–retest reliability of the hand-held dynamometer was confirmed for this tester.[26] The intraclass correlation coefficient of the test–retest reliability of Str/Wt was 0.89 for hip flexion, 0.88 for hip extension, 0.94 for knee flexion, 0.88 for knee extension and 0.80 for ankle dorsiflexor. To evaluate the validity of the hand-held dynamometer, comparisons were made with another dynamometer (Biodex System 3; Biodex Medical Systems, NY, USA) testing of isometric muscle strength in this study position. At all Str/Wt values, the hand-held dynamometer results correlated with those of the Biodex System 3 (0.92 for hip flexors, 0.73 for hip extensors, 0.83 for knee flexors, 0.92 for knee extensors and 0.87 for ankle dorsiflexors; $P < 0.05$).

Measurement of activities of daily living (ADL)

The Functional Independence Measure (FIM) assesses four categories: self-care, sphincter management, mobility and executive functioning.[27] The FIM items were assessed by observational study as a measure of ADL. The FIM scale consists of 18 items, with 13 of these items targeting motor (or physical) components (motor FIM) and

5 targeting social-cognitive components. The results from the first 13 items (motor FIM) were summed to develop a motor score with a range of 13–91 for use in this study. The intraclass correlation coefficient for test–retest reliability of FIM has been shown to be above 0.9 ($P<0.05$).[28,29] Motor FIM scores also correlate well with those of the Barthel Index ($r=0.92$, $P<0.05$).[30]

Statistical analysis

All data analysis was performed using SPSS (version 11.5.1J; SPSS Inc., Chicago, IL, USA). The data are expressed as mean ± standard deviation (SD). Comparisons of means between the independent group and the dependent group for age, height, weight, BMI and Str/Wt were performed using independent Student's *t*-test and chi-square test. FIM scores were compared between the groups using the Mann–Whitney *U*-test. Stepwise discriminant analysis (Mahalanobis distance) was used to select the best predictors of the independent category from hip flexors, hip extensors, knee flexors, knee extensors and ankle dorsiflexors. Discriminant analysis was repeated for each predictor variable separately to determine whether the predictors could differentiate the broader categories of independent or dependent in order to identify an acceptable value of individual Str/Wt that could be used to categorize the subject as either independent or dependent. The strength of discriminant analysis outcome was evaluated by comparing with the original care requirement data of the participants assessed by the long-term care insurance system criteria. Risk thresholds for Str/Wt were determined for each muscle functional task by identifying the Str/Wt that optimally discriminates between independent group and dependent group. A *P*-value, set a priori, of less than 0.05 was considered statistically significant.

Results

No differences were found between the independent and dependent groups in terms of age, height, weight and BMI (Table 1). Regarding the disease states of participants, 16 (67%) had a history of osteoarthritis or osteoporosis, 4 (17%) had stroke, 2 (8%) had mild dementia, and 2 (8%) had a history of disuse syndrome.

Table 2 Muscular strength (Str/Wt) of the independent group versus the dependent group

	Independent group	Dependent group	
Hip flexion (N/kg)	2.8 ± 0.6	1.7 ± 0.6	*
Hip extension (N/kg)	2.5 ± 0.6	0.9 ± 0.6	*
Knee flexion (N/kg)	0.9 ± 0.2	0.6 ± 0.4	*
Knee extension (N/kg)	3.4 ± 0.8	2.2 ± 0.9	*
Ankle dorsal flexion (N/kg)	3.2 ± 0.7	2.2 ± 0.7	*

Values are mean ± standard deviation.
Str/Wt is a ratio of maximal muscular strength to body weight calculated by dividing the muscular strength (N) by body weight (kg).
*$P<0.05$, Student's *t*-test was used to evaluate the difference between the groups.

All values of Str/Wt were significantly lower in the dependent group than in the independent group (Table 2). The scores of motor FIM were significantly different between the two groups. The two subscales in sphincter management were not different between the groups while all 11 items in the mobility and self-care subscales were different between the groups (Table 3). For the independent group, the average values for all items were at a level indicating that they could be performed independently. For the dependent group, 'tub/shower transfer', 'stair-climbing' and 'walking/wheelchair management' FIM scores were rated at a level indicating that assistance was required, but other items were rated at a level indicating independence.

When hip flexors, hip extensors, knee flexors, knee extensors and ankle dorsiflexors were used as independent variables in stepwise discriminant analysis, the Str/Wt values of hip extensors came out as the strongest determinant of differentiation between independent and dependent groups.

Thresholds for Str/Wt of different muscle groups are described in Figure 1. The risk thresholds are 2.3 N/kg (88%) for hip flexors, 1.7 N/kg (95%) for hip extensors, 0.7 N/kg (74%) for knee flexors, 2.8 N/kg (82%) for knee extensors and 2.8 N/kg (82%) for ankle dorsiflexors. The percentage (%) indicates the strength of individual discriminant analysis outcome to differentiate the independent and dependent groups, as originally assessed by the

Table 3 Functional Independence Measure score

	Independent group ($n=25$)	Dependent group ($n=24$)	
FIM motor score	90.7 (87–91)	77.6 (47–90)	*
Self-care			
Eating	7.0 (7–7)	6.8 (6–7)	*
Grooming	7.0 (7–7)	6.5 (4–7)	*
Bathing	7.0 (7–7)	6.1 (4–7)	*
Dressing upper body	7.0 (7–7)	6.2 (3–7)	*
Dressing lower body	7.0 (7–7)	6.0 (2–7)	*
Toileting	7.0 (7–7)	6.1 (1–7)	*
Sphincter control			
Bladder	6.9 (5–7)	6.6 (3–7)	NS
Bowel	6.9 (6–7)	6.7 (3–7)	NS
Mobility			
Bed-to-chair/wheelchair transfer	7.0 (7–7)	6.2 (4–7)	*
Toilet transfer	7.0 (7–7)	6.3 (4–7)	*
Tub/shower transfer	7.0 (6–7)	5.0 (1–7)	*
Walking/wheelchair management	7.0 (7–7)	5.9 (2–7)	*
Stair-climbing	6.9 (6–7)	3.3 (1–6)	*

Values are mean (minimum–maximum) of FIM score. Mann–Whitney *U*-test was used to evaluate the difference between the groups. Each item is rated with a score from 1 to 7 (1 = complete assistance to perform basic ADL, 2 = maximal assistance, 3 = moderate assistance, 4 = minimal assistance, 5 = supervision, 6 = modified independence, and 7 = complete independence in performing basic ADL).
NS, not significant.
*$P<0.05$.

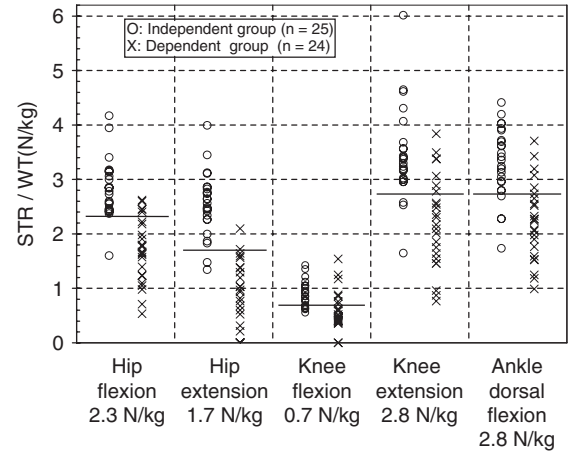

Figure 1 Threshold of muscular strength (Str/Wt). The horizontal line for each muscle group represents the strength threshold for that muscle group. Str/Wt is a ratio of maximal muscular strength to body weight calculated by dividing the muscular strength (N) by body weight (kg).

long-term care insurance system criteria. The scores of individual FIM components are described in Table 4 based on hip extension threshold level. It has been noted that all but two participants in the independent group with a hip extension score above the threshold level had a FIM score of 6 or 7, indicating that they were independent in their everyday life. On the other hand, all but two participants in the dependent group with a hip extension score below the threshold level had a FIM score of 5 or less, indicating that they needed some or total assistance to perform their ADL.

There was no report of physical injury or cardiorespiratory complaints in this study.

Discussion

The number of older people who require assistance is increasing and a simple and effective measure is needed to identify people who are at immediate risk of disability. Decreases in muscle strength, balance, flexibility and endurance with ageing predispose individuals to disability. It has been suggested that strength tests could be used to identify people who independently perform ADL but are at increased risk of becoming dependent due to poor muscle strength.[11] The results of the current study indicate that a hand-held dynamometer may be an effective measure of strength testing in community-dwelling older people. The strength thresholds noted in this study can be used for quick screening of older people who are at increased risk of becoming dependent in the near future. Prescribing resistance exercises that target strength deficiencies may then help them to maintain independence for longer periods of time.

It is common that older adults in Western countries who need assistance in daily living have BMI values much higher than the BMI values of the participants in the current study. However, The National Nutrition Survey in Japan reported that the reference BMI is 22 ± 3 for Japanese older adults age 80 years and over.[31] Nishiwaki *et al*. reported that mean BMI values among 194 older Japanese (mean age = 84) requiring care and using long-term care insurance at home was 20 ± 4.[32] Thus the noted BMI in the current

Table 4 Functional Independence Measure scores based on hip extension strength threshold

	Independent group ($n=25$)		Dependent group ($n=24$)	
	Above threshold ($n=23$)	Below threshold ($n=2$)	Above threshold ($n=2$)	Below threshold ($n=22$)
Self-care				
Eating	7.0 (7–7)	7.0 (7–7)	7.0 (7–7)	6.7 (6–7)
Grooming	7.0 (7–7)	7.0 (7–7)	7.0 (7–7)	6.5 (4–7)
Bathing	7.0 (7–7)	7.0 (7–7)	6.5 (6–7)	6.0 (4–7)
Dressing upper body	7.0 (7–7)	7.0 (7–7)	6.5 (6–7)	6.2 (3–7)
Dressing lower body	7.0 (7–7)	7.0 (7–7)	7.0 (7–7)	5.9 (2–7)
Toileting	7.0 (7–7)	7.0 (7–7)	7.0 (7–7)	6.6 (1–7)
Sphincter control				
Bladder	6.9 (5–7)	7.0 (7–7)	6.9 (5–7)	6.6 (3–7)
Bowel	6.9 (6–7)	6.5 (6–7)	6.9 (6–7)	6.6 (3–7)
Mobility				
Bed-to-chair/wheelchair transfer	7.0 (7–7)	7.0 (7–7)	7.0 (7–7)	6.1 (4–7)
Toilet transfer	7.0 (7–7)	7.0 (7–7)	7.0 (7–7)	6.2 (4–7)
Tub/shower transfer	7.0 (6–7)	7.0 (7–7)	6.0 (6–6)	4.9 (1–7)
Walking/wheelchair management	7.0 (7–7)	7.0 (7–7)	7.0 (7–7)	5.8 (2–7)
Stair-climbing	7.0 (6–7)	7.0 (7–7)	6.0 (6–6)	3.0 (1–6)

Values are mean (minimum–maximum) of FIM scores.
Each item is rated with a score from 1 to 7 (1 = complete assistance to perform basic ADL, 2 = maximal assistance, 3 = moderate assistance, 4 = minimal assistance, 5 = supervision, 6 = modified independence, and 7 = complete independence in performing basic ADL).

study is not unusual in older adults who need assistance.

In this study, motor FIM scores were used to evaluate basic ADL performance as a measure of disability. FIM scores less than 6 for individual items suggest that assistance or supervision from a caregiver is needed. In the current study, one group of subjects (independent group) had FIM scores for each item that identified them as being independent (i.e. >6). The other group (dependent group) also had scores that designate independence with the exception of 'tub/shower transfer' and 'climbing stairs'. Low scores on these two items reflect difficulties in general ambulation that are related to reduced strength and ability to perform ADL.

The Str/Wt ratios of muscle groups for people in the dependent group were 30–65% lower than those in the independent group in the current study (Table 2). This suggests that loss of muscle strength contributes to a loss of independence. Most of the members in the dependent group required some sort of assistance from a caregiver for tub/shower transfer, climbing stairs and other ADL.

Ploutz-Snyder *et al*. assessed only knee extensors strength thresholds below which performance of ambulatory tasks are compromised in laboratory settings.[16] Community-dwelling older adults with a Str/Wt for knee extensors less than 3.0 Nm/kg as measured by isokinetic dynamometers were found to be at a substantial risk for impaired function in chair rise, gait speed and stair ascent/descent. Bohannon estimated that 330 N is needed in bilateral knee extension force to successfully stand up once from a chair, but did not account for body weight.[33] Ferrucci *et al*. reported that hip flexor strength of 147 N (15 kg) or below was a significant predictor of walking speed or time to complete five chair stands, and knee extensors strength of 98 N (10 kg) or below was associated with time to complete five chair stands.[20] On the other hand, Ikezoe *et al*. reported that at least 1.9 N/kg of Str/Wt in knee extensors measured by hand-held dynamometer is needed to rise from a seat 40 cm high.[21] Other reports indicate that frail people with Str/Wt ratios for knee extensors of 2.0 N/kg or more were able to walk at least 300 m, and

2.5 N/kg or more were able to descend and ascend stairs.[23,24] The results of the current study indicate that subjects with Str/Wt ratios for knee extensors of 2.8 N/kg or more are able to perform bathing and stair-climbing independently, not ADL as a whole. Thus the subjects with Str/Wt ratios for knee extensors of less than 2.8 N/kg have substantial risk for needing assistance when performing ADL. The threshold of muscular strength to discriminate dependence and independence in the current study was higher (2.8 N/kg) for knee extensors compared with these previous studies. This is likely due to the participants living in the community and needing higher levels of muscular strength to live independently compared with subjects of Yamazaki *et al*. and Ohmori *et al*., who were hospitalized frail older patients.[23,24] Thus it can be said that the threshold for Str/Wt of knee extensors differs between community-dwelling older adults and hospital inpatients.

Rantanen *et al*. in a 5-year prospective study examined changes in maximal isometric strength of hand grip, elbow flexion, knee extensors and trunk flexion and extension as a predictor of losing independence in ADL and concluded that all the strength tests predicted ADL dependence, with those in the lowest tertile having two to three times greater risks than those in the highest tertile of strength.[11] Of the five measures of strength, only one (knee extensors) focused on the lower extremities. Little information is currently available regarding strength thresholds of lower extremity muscles other than knee extensors in older adults. In the current study, the muscular strength of five muscle groups (hip flexors, hip extensors, knee flexors, knee extensors and ankle dorsiflexors) in the lower extremities was examined. Discriminant analysis was used to determine the best predictor of the independent category from hip flexors, hip extensors, knee flexors, knee extensors and ankle dorsiflexors and it was found that the Str/Wt ratios of hip extensors accounted for the most variability when performing ADL. Previously, knee extensors strength had been identified as the most important factor limiting performance on a variety of ADL.[16] Further study may be needed to determine the specific role of knee extensors and hip extensors strength on individual's ADL.

In our participants, Str/Wt ratios of hip extensors below the thresholds led to difficulty performing stair-climbing, transfer, bathing, dressing, and walking. These items are needed to perform in dynamic and/or stabilized standing positions (Table 4).

It was determined that a threshold of Str/Wt ratio for hip flexors of 2.3 N/kg, for hip extensors of 1.7 N/kg, for knee flexors of 2.3 N/kg, for knee extensors of 2.8 N/kg, and for ankle dorsiflexors of 2.8 N/kg differentiated between independent and dependent individuals. These threshold values could be applied to other community-dwelling older adults in order to identify those who are at increased risk of losing independence. As resistance training improves muscular strength even in community-dwelling older adults,[34] the threshold levels of muscular strength noted in the current study may be useful in recruiting older adults for home- and community-based exercise programmes and then individualizing exercise prescription.

In the current study, a hand-held dynamometer was used to evaluate muscular strength in community-dwelling older people. However, the hand-held dynamometer is limited when testing relatively strong people using the quadriceps. It has been reported that the hand-held dynamometer underestimates absolute quadriceps strength compared with the Biodex, particularly in stronger people, although a strong correlation exists between the measures ($r = 0.91$, $P < 0.0001$) as noted in the same study.[19] In addition, there are two HDD techniques to measure strength: the make test and the break test. The make test requires the examiner to hold the HDD stationary while the subject exerts a maximal force against it, whereas the break test is performed when the subject's maximal muscular effort is overcome by the examiner and the tested joint gives way. Bohannon found that muscle force measured by the break test was approximately 1.3 times greater than that measured by the make test. However, the force values obtained by the make and break tests were correlated ($r = 0.81$–0.87; $P < 0.05$).[35] Nevertheless, a hand-held dynamometer is a useful tool for measuring muscle strength of older adults in field-based research, and provides a quick and objective assessment.

Our modest sample size limited our ability to fully summarize the functional thresholds of

lower extremity muscle strength below which assistance (care) is required to perform ADL. Findings from 49 participants, albeit informative with regard to assessed strength of five lower extremity muscle strength, have a restricted range of implications. Future study is needed to overcome this limitation.

Clinical messages

- Our results indicate that hip extensors muscle strength is more essential in performing mobility-related ADL than other muscles of the lower extremities.
- This finding may help to determine the risk of dependence in apparently independent community-dwelling older adults, and to prescribe resistance training to prevent dependence when performing mobility-related ADL.

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