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A study on the usefulness of the calf-ankle index

Keiichiro Terayama

Ph.D. program in Gerontology
Graduate School of Gerontology
J.F.Oberlin University

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Abstract

Chapter 1 Introduction

A cheap and non-invasive body measurement exists that can evaluate health and nutritional status. Particularly, body circumference measurement is intended to represent the thickness of the trunk and thickening of the extremities, the degree of muscle atrophy, the body's nutritional status (body mass index, BMI), swelling of the extremities (edema), maturity of amputated limbs; with these, it is possible to obtain physical information such as respiratory function state. The maximum circumference of well-developed muscle is measured if muscle atrophy is seen. The minimum circumference of the proximal joint is measured if swelling around the joints is present. In addition, the minimum circumference is also used to measure bone growth. Further, according to a report of the World Health Organization (WHO) (1995), lower leg circumference has been an indicator of the skeletal muscle mass in the elderly due to increase in age and amount of decreased activity. It has been used to represent the change in lean body mass.

In a previous study, lower leg circumference has the largest part among the limb circumferences, muscle mass, and physical function, especially in movement ability, exercise tolerance, and nutritional status. Long-term prognosis was suggested in a report.

Further, measurement of the lower leg circumference, an inexpensive non-invasive technique, does not require and depend on the effort, motivation, mood, and comprehension of the subject. Moreover, by measuring, excessive exposure is lessened, and it can be cited as an advantage. However, the value of lower leg circumference is different in several races and living environments. In addition, a significant difference was observed in the maximum circumference between men and women when used as an index. Different values are seen in men and women due to individual differences. Calf–ankle index (CAI) is the ratio of the maximum and minimum circumferences of the lower leg, and it does not depend on individual differences, which can be considered as an indicator for evaluating the physical function of the elderly.

Chapter 2 The aim and significance of this study

1. Aim

The CAI is the ratio of the maximum circumference and the minimum circumference of the lower leg, and it evaluates the risk of fall, risk of recurrence, and physical function in the community-dwelling and frail elderly.

2. Significance

It is possible to evaluate body function without the need for much effort by the subject by only measuring the circumference of the lower leg using a tape measure. Moreover, by clarifying the relationship between fall and recurrence risks by a simple evaluation method, it is possible to use CAI as a screening tool if significant results are obtained.

3. Framework of the study

This study consists of a preliminary and two present studies.

1) Preliminary study: Examiner confidence in the lower leg circumference measurement.

2) Study 1: CAI in community-dwelling elderly—The context of physical function and falls.

3) Study 2: CAI in the frail elderly—association with physical function and recurrence.

A preliminary study: to confirm the reproducibility of the measurement of the lower leg circumference.

Study 1 examined the association of physical functions of relatively healthy elderly and CAI.

Study 2 examined the association of physical function and CAI in patients on cardiac rehabilitation as a representative of the frail elderly. Moreover, CAI is considered a simple index for evaluating physical function, including fall and recurrence risks.

The Toho University Sakura Medical Center Ethics Committee (2013-038) approved studies 1 and 2.

Chapter 3 Preliminary study

Examiner confidence in the lower leg circumference measurement.

1) Aim

The aim was to clarify whether the error is caused by the measurement of the lower leg circumference, by using intraclass correlation coefficient (ICC).

2) Subject

A total of 10 cases were used, seven of which belong to the physical rehabilitation part of our hospital, and three student cases.

3) Method

For two subject cases, the examiner measured the lower leg circumference of 10 cases. The subjects were healthy a man and a woman in their 30s. The circumference of the right lower leg maximum site and the minimum site was measured with a tape measure.

4) Analysis method

The measurement result was calculated by using ICC.

5) Results and discussion

The ICC was 0.980 ($p < 0.01$), which was within 0.5cm of any error measurements.

The physical therapist measures the lower leg circumference as an evaluation from day-to-day basis, Similar results were obtained even when the student led the measurement; measurement accuracy improved after practicing a few times.

Chapter 4 Study 1

"CAI in community-dwelling elderly—The context of physical function and falls."

1. Study 1-1: cross-sectional study

1) Aim

The aim of the study was to clarify the relationship between CAI and physical function and risk of falls in community-dwelling elderly people who participated in care prevention seminars.

2) Subject

The study enrolled 165 subjects who participated in the care prevention classroom in the region from 2013 to 2015. Subjects with left–right difference of more than 1.0 cm in the maximum circumference were to be excluded from the study. Furthermore, it was decided to exclude subjects when edema was seen during lower leg circumference measurements.

3) Method

We conducted a survey to study the risk of falls and physical fitness test during the first classroom session. Physical fitness measurement, lower leg minimum and maximum circumferences, grip strength, knee extension strength, one-leg stand with eyes open, 5-m

walk, and timed up and go ""(TUG) test were measured. Fall risk assessment and falling self-efficacy questionnaires were also used.

4) Analysis method

Calf circumference is the maximum value; the minimum value is the average of the right calf and the left calf; and CAI is calculated by taking the ratio of the maximum value/ minimum value. It was corrected by taking the ratio of the weight and knee extension strength. In each measurement item, the average value is calculated of the left and right. Moreover, two groups were classified as men and women, and the difference was analyzed with the Mann–Whitney U test. Further, the CAI and maximum circumference were analyzed using Spearman's rank correlation coefficient, which was associated with the measurement result of the other items. Moreover, a significant correlation was found between the independent and dependent variables of the fall risk assessment questionnaire using multiple regression analysis.

5) Results and discussion

The study included 158 patients (17 men and 141 women), and excluded seven patients. Four items of height, weight, grip strength, and 5-m comfortable walking were found to have a significant difference between men and women. Both men had significantly become overpriced.

The maximum circumference of the men was 34.8 cm, and the minimum circumference was 21.4 cm. The maximum circumference of the women was 33.5 cm, and the minimum circumference was 20.3 cm. Men had higher values than did women. In addition, the CAI is 1.62 and 1.64 for men and women, respectively. The woman has a higher CAI value, but no significant difference was observed.

Each measurement item such as age ($\rho = -0.312$),BMI ($\rho = 0.193$), grip strength ($\rho = 0.253$), 5-m comfortable walking ($\rho = -0.180$), 5-m maximum walking ($\rho = -0.223$), TUG ($\rho = -0.236$), and fall risk assessment questionnaire ($\rho = -0.289$) had a significant correlation with CAI. Moreover, only BMI ($\rho = 0.729$) and grip strength ($\rho = 0.389$) correlated significantly with the maximum circumference. BMI and grip strength had a significant correlation to both CAI and maximum circumference. Therefore, we tested the difference between the correlation coefficients. As a result, BMI had a significant difference, and grip strength was not significantly different.

A significant correlation was found in CAI and BMI ($\rho = 0.211$), one-leg stand with eyes open ($\rho = -0.307$), 5-m comfortable walking ($\rho = 0.372$), 5-m maximum walking ($\rho = 0.354$), and the TUG ($\rho = 0.368$) in the fall risk assessment questionnaire.

The independent variables one-leg stand with eyes open, 5-m comfortable walking, CAI, and BMI and the dependent variable fall risk assessment questionnaire were calculated by multiple regression analysis. As a result, CAI (β = −0.326), and 5-m comfortable walking (β = 0.234) were extracted as independent factors (R = 0501).
From these, CAI reflects the body functions related to fall, and the possibility that it may be indicative of risk for comprehensive fall has been suggested. Furthermore, it is not influenced by the individual difference, and the subcutaneous fat has less influence.

2. Study 1-2: Longitudinal study

1) Aim

The CAI measured by study 1-1 as a baseline investigated the effects on physical function after six months. Moreover, the aim is to clarify the relevance of the fall and the CAI in the next year.

2) Subject

All cases in study 1-1 were the subjects.

3) Method

A survey similar to physical fitness measurement and fall risk was administered for the first time after six months from the physical fitness test.
In addition, after one year from the initial intervention, results using the questionnaire were investigated whether the answers were "fell", "almost fell", or "stumbled".

4) Analysis method

Each item was examined for change in six months using a Wilcoxon signed-rank test. We divided the subjects into two groups, the fall risk group and non-fallers. The difference of each item in the two groups was analyzed in the baseline. Moreover, the cut-off value of CAI was calculated by receiver operating characteristic (ROC) curve and evaluated the area under the curve (AUC) from the presence or absence of a fall.

5) Results and discussion

The risk of falls and physical fitness measurement were investigated in 73 patients (5 men and 68 women) after six months. A significant difference was found in the initial and the final measurements and in the fall self-efficacy maximum and minimum circumferences. The maximum circumference was from 34.0 cm to 33.8 cm, and the minimum circumference has changed significantly from 20.8 cm to 20.3 cm. Fall self-efficacy was from 10.0 point to 11.0

points, which was significantly higher.

In addition, it was confirmed that 63 cases had not a fall in a year from the first measurement and non-fallers. The 24 cases (6, 8, and 10 cases who "fell", "almost fell", and “stumbled”, respectively) was the fall risk group. The two groups were examined for the difference in each item. As a result, the CAI was 1.65 and 1.63 for non-fallers and for fall risk group, respectively. The non-fallers has a low value but was not significantly different.

Then, non-fallers were analyzed including 10 cases who "stumbled", and a total of 14 cases of fall risk group were also analyzed including 6 cases who were "fell" and 8 cases who were "almost fell". As a result, age, one-leg stand with eyes open, 5-m comfortable walking, TUG, and CAI had a significant difference. Age was 73.5 years and 77.0 years for non-fallers and fall risk group, respectively. Age was significantly higher in the fallers. One-leg stand with eyes open was 36.2 s and 11.8 s for non-fallers and fall risk group, respectively. The result was significantly lower in the fall risk group. Time for 5-m comfortable walking was 3.59 s and 4.08 s for non-fallers and fall risk group, respectively. TUG was 8.40 s and 9.42 s for non-fallers and fall risk group, respectively. Both of which was significantly higher in the fallers. CAI was 1.65 and 1.58 for non-fallers and fallers, respectively. CAI had significantly low value in the fall risk group.

In addition, only 6 cases had a fall in the fallers and were examined as the other non-fallers. A significant difference was found in three items: CAI, minimum circumference, and fall risk assessment questionnaire. The minimum circumference was 20.8 cm and 21.6 cm for non-fallers and fallers, respectively, which was significantly higher in the fallers. CAI was 1.65 and 1.56 for non-fallers and fallers, respectively, which was significantly lower in the fallers. The result for risk assessment questionnaire was 8.0 points and 12.0 points for and non-fallers and fall risk group, respectively, which was significantly higher in the fallers.

The 14 cases of fall risk group who "fell", "almost fell", and other forms were analyzed by the ROC curve. AUC was 0.735 (P = 0.006), and the cut-off value, which was1.57, in the risk of falls of the CAI was set so that the sensitivity is 0.8 or more (sensitivity, 0.810; specificity, 0.500). In addition, only 6 cases in the fallers had "fell" and analyzed by the ROC curve. AUC was 0.812 (P = 0.013), and the cut-off point was 1.54 (sensitivity, 0.889; specificity, 0.500).

For these reasons, if CAI is below 1.57, high risk of falling is considered, and it is desirable to intervene more intensively.

Chapter 5 Study 2

“CAI in the frail elderly—association with physical function and recurrence”

1. Study 2-1: Cross-sectional study

1) Aim

In the present study, the elderly who had cardiac rehabilitation at the hospital was the representative of the frail elderly, and the cross-sectional study considered the relationship between CAI and physical function.

2) Subject

From February 2013 to December 2016, 100 hospitalized patients were intended to undergo cardiac rehabilitation in our hospital. At the time of measurement, if a difference of more than 1.0 cm between the right and left lower leg circumferences, independent gait was difficult. If there is a prominent swelling in the lower leg, the subject will be excluded from the present study.

3) Method

Physical strength measurement was performed at during discharge and physician judgment. Items were similar to those measured in study 1.

In addition, a correlation in the maximum oxygen uptake conducted for the 6-min walk test, which was used as an indicator of exercise tolerance.

4) Analysis method

Similar to study 1, the difference between men and women was analyzed using the Mann–Whitney U test. Furthermore, the CAI and maximum circumference were analyzed using Spearman's rank correlation coefficient associated with the other items. The 6-min walk distance was the dependent variable, and multiple regression analysis was calculated in independent variable items that had significant correlations with the 6-min walk distance.

5) Results and discussion

A total of 100 cases were enrolled, of which, 79 cases were male, and 21 cases were female. Other items that had a significant difference between men and women were height, weight, 6-min walk distance, grip strength, knee extensor strength to body weight ratio, 5-m maximum walk, and lower leg maximum circumference. In any of these items, men significantly had higher results. CAI was calculated from the ratio of the lower leg maximum and minimum circumferences, and CAI was 1.65 and 1.59 for men and women, respectively. However, no significant difference was observed.

In each measurement item, a significant correlation was found in the CAI, age (ρ = −0.426), BMI (ρ = 0.440), 6-min walk distance (ρ = 0.623), grip strength (ρ = 0.426), one-leg stand with eyes open (ρ = 0.340), 5-m comfortable walking (ρ = −0.362), 5-m maximum walking (ρ = −0.450), and TUG (ρ = −0.352). In addition, items that had a significant correlation with the maximum circumference were BMI (ρ = 0.811), 6-min walk distance (ρ = 0.413), grip strength (ρ = 0.455), one-leg stand with eyes open (ρ = 0.275), 5-m comfortable walking (ρ = −0.214), and 5-m maximum walking (ρ = −0.292).

In addition, a significant correlation with the CAI and the maximum circumference was found for BMI, 6-min walk distance, grip strength, one-leg stand with eyes open, 5-m comfortable walking, and 5-m maximum walking. As a result, a significant difference in the correlation coefficient was found in BMI, 6-min walk distance, and 5-m maximum walking. BMI is more strongly correlated with the maximum circumference, whereas 6-min walk distance and 5-m maximum walking had a stronger correlation with CAI.

The 6-min walk distance as a dependent variable was calculated by multiple regression analysis. As a result, 5-m maximum walking (β = −0.608) and CAI (β = 0.274) (R = 0.829) became the independent factors. It should be noted that, in the multiple regression analysis of the independent variable, the maximum circumference instead of CAI, the maximum circumference (β = −0.191) and 5-m maximum walking (β = −0.697) was extracted as an independent factor (R = 0.814).

From these, CAI was difficult to influence because of the presence of subcutaneous fat than the lower leg maximum circumference in cardiac rehabilitation patients, and it is suggested as an index to comprehensively reflect balance, exercise tolerance, and the whole body function.

2. Study 2-2: Longitudinal study.

1) Aim

The CAI was measured in study 2-1 as a baseline, and the relationship was examined longitudinally between the recurrences in one year. In addition, the aim was to calculate the cut-off point of CAI related to the prediction of recurrence in the frail elderly.

2) Subject

All cases in study 2-1 were the subjects.

3) Method

One year after CAI was measured for the first time with end point, medical records were investigated to find whether re-hospitalization and death (following event) occurred because

of recurrence. Re-hospitalization was done in elective surgery, and inspection purposes were excluded.

4) Analysis method

Subjects were classified into two groups. The group of no recurrence had no event, and the group with recurrence had an event in one year after the physical fitness test. The difference of each item in the baseline was analyzed by Mann–Whitney U test. Furthermore, CAI and maximum circumference by events created an ROC curve, and AUC was evaluated to calculate the cut-off value of recurrence risk.

5) Results and discussion

Among the subjects in study 2-2 from March 13, 2016, 9 of the 70 cases had been re-hospitalized after one year because of an event; however, no deaths occurred.

A significant difference was found in the two groups in the 6-min walk distance, grip strength, one-leg stand with eyes open, 5-m comfortable walking, maximum circumference, and CAI. In the 6-min walk distance, the distances were 480.0 m and 440.0 m in the non-recurrence and recurrence groups, respectively. Grip strength was 30.2 kg and 25.0 kg in the non-recurrence group and recurrence group, respectively. The one-leg stand with eyes open was 22.6 s and 10.0 s in the non-recurrence and recurrence groups, respectively. The maximum circumference was 34.8 cm and 31.5 cm in the non-recurrence and recurrence groups, respectively. Both had significantly smaller value in the recurrence group. In 5-m comfortable walking, the time was 4.38 s and 5.32 s in the non-recurrence and recurrence groups, respectively. The recurrence group had a significantly larger value. CAI was 1.66 and 1.51 for the non-recurrence and recurrence groups, respectively. The recurrence group had significantly low values. There were no significant differences in other items.

In the CAI and the maximum circumference, the non-recurrence and recurrence groups created an ROC curve. As a result, the AUC was 0.882 ($P < 0.001$) and 0.803 ($P = 0.003$) in the CAI and the maximum circumference, respectively. In addition, the cut-off value was set so that the sensitivity is equal to or greater than 0.800. CAI was 1.54, with a sensitivity of 0.881 and specificity of 0.667. The maximum circumference was 32.1 cm, with a sensitivity of 0.851 and specificity of 0.778.

From these results, the subject with CAI below the 1.54 after cardiac rehabilitation should be evaluated just before discharge and after discharge. Continuing the monitoring of the rehabilitation as outpatient, with more focused leadership, should be the intervention.

Chapter 6 Conclusion

The CAI will not be influenced by the individual difference by taking the ratio of the maximum circumference and lower leg minimum circumference. Furthermore, the following items should be considered: the context of the physical function of community-dwelling elderly, the associated fall risk, the context of the physical function, and the recurrence risk in the frail elderly.

As the context of the physical function of community-dwelling elderly, CAI had a significant correlation with age, BMI, grip strength, 5-m comfortable walking, 5-m maximum walking, and TUG. For BMI, the correlation coefficient is significantly lower than the maximum circumference, and the influence of BMI has been a smaller index.

For the context of the fall risk, the dependent variable was the fall risk assessment questionnaire, which is an evaluation tool of comprehensive fall risk, and CAI had become an independent factor. Moreover, there is also the context of the actual fall, the cut-off value of the fall risk in one year, and the inclusion of "almost fell" was 1.57 (sensitivity, 0.810; specificity, 0.500). From these results, CAI has been suggested to be an indicator that reflects the risk of falls.

For the context of the physical function of the frail elderly, we examined the cardiac rehabilitation patient as a representative of the frail elderly in this study. As a result, CAI had a significant correlation with BMI, grip strength, one-leg stand with eyes open, 5-m comfortable walking, 5-m maximum walking, and TUG have been an indicator of exercise tolerance in 6-min walking distance. In the frail elderly, the BMI has a small effect as compared with the lower leg up to circumference, and it was suggested that it is an indicator of exercise tolerance.

For the context of the recurrence risk of the frail elderly, a 6-min walking distance is an independent prognostic factor of the dependent variable, and CAI was extracted as an independent factor. In addition, there is a relation to the actual event, and the cut-off value of the risk of recurrence in one year was 1.54 (sensitivity, 0.881; specificity, 0.667). From these, CAI was suggested as indicator that reflects the recurrence risk in patients in cardiac rehabilitation.

From the above results, CAI is a comprehensive indicator of the physical function, fall risk, and recurrence risk. Furthermore, for CAI below 1.57 in the community-dwelling elderly people, it is necessary to actively implement the intervention of fall prevention. In addition, for cardiac rehabilitation patients, if the CAI at the time of discharge was below 1.54, it was suggested that relapse prevention should be aggressively pursued.