

Arterial stiffness expressed as brachial–ankle pulse wave velocity and gait assessment independent of lower extremity strength: a cross-sectional study in the older men population

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ABSTRACT

BACKGROUND Older men are more vulnerable to fatal falls than women, and gait disturbances contribute to the risk of falls. Studies have assessed the association between arterial stiffness and gait dysfunction, but the results have been inconclusive. This study aimed to conduct a cross-sectional analysis to evaluate the association between brachial–ankle pulse wave velocity (baPWV) and gait assessment in older men.

METHODS Data from the 2014–2015 Korea Institute of Sport Science Fitness Standards project were used for the analysis. The inclusion criteria were men aged > 65 years with gait assessment [the 30-s chair stand test (30s-CST), the timed up and go (TUG) test, the figure-of-8 walk (F8W) test, the 2-min step test (2MST), and the 6-min walk test (6MWT)] and baPWV measurement data. Generalized linear regression analysis was conducted with multiple confounding factor adjustments, including lower extremity isometric strength.

RESULTS A total of 291 participants were included in the analysis. The mean age was 71.38 ± 4.40 years. The mean values were as follows: (1) 30s-CST, 17.48 ± 5.00 ; (2) TUG test, 6.01 ± 1.10 s; (3) F8W test, 25.65 ± 4.71 s; (4) 2MST, 102.40 ± 18.83 per 2 min; and (5) 6MWT, 500.02 ± 85.65 m. After multivariable adjustment, baPWV was associated with the 6MWT ($\beta = -0.037$, 95% CI: -0.072 – -0.002), TUG test ($\beta = 0$, 95% CI: 0.000 – 0.001), and F8W test ($\beta = 0.002$, 95% CI: 0.000 – 0.004). baPWV was not associated with the 30s-CST and 2MST.

CONCLUSIONS The current study showed a statistically significant association between gait assessments and arterial stiffness, independent of lower extremity strength. However, this association was modest. Future prospective studies are needed to elucidate the complex relationship between arterial stiffness and gait dysfunction.

Gait dysfunction is a common comorbidity in the older adult population.^[1] The prevalence increases with age, from approximately 10% at the age of 60 years to 60% at the age of > 80 years.^[1] This can lead to immobility, falls, and increased mortality.^[2] In addition, gait performance is a predictor of survival, cognitive decline, and quality of life.^[3] Owing to this importance, multiple methods to assess a diverse aspect of gait has been suggested. The 30-s chair stand test (30s-CST) has been shown to provide information about functional strength, balance deficit, mu-

scle endurance, and fall risk.^[4,5] The timed up and go (TUG) test is known to effectively assess dynamic balance, mobility, and fall risk.^[6] The figure-of-8 walk (F8W) test is designed to represent the walking skill in everyday life.^[7] The 2-min step test (2MST) reflects physical functional capacity.^[8] The 6-min walk test (6MWT) is a common measure of walking fatigability.^[9] In addition, both the 2MST and 6MWT reflect cardiorespiratory fitness.^[10,11] Each test has proven reliability and validity in the older adult population.^[7,8,12–14]

Although gait is a common activity in daily living, it is

also a complex process.^[1] The multi-level nervous system, musculoskeletal complex, and cardiorespiratory system are involved in gait.^[7] In particular, mobility decline is frequently associated with vascular disease.^[15] Arterial stiffness is a pathological phenomenon caused by decreased compliance of the vasculature, causing changes in flow dynamics and impacting cardiac performance.^[16] Owing to the potential relationship between arterial stiffness and gait dysfunction, previous studies have assessed the association between gait and arterial stiffness.^[15,17,18] However, the results have been inconsistent, and controversies remain.^[15,17–20] In addition, previous studies have mostly focused on the walking speed.^[15,17–20] Furthermore, despite growing evidence that arterial stiffness has a differential impact on physical fitness according to sex, most previous studies did not separately analyze men and women.^[15,17,18,20,21] Considering that gait is a multicomponent process, evaluating the relationship in diverse gait assessments could provide a better understanding of the potential relationship between arterial stiffness and gait assessment.

Therefore, this study aimed to conduct a cross-sectional study to elucidate the relationship between arterial stiffness, expressed as brachial-ankle pulse wave velocity (baPWV), and gait function, expressed as the 30s-CST, TUG test, F8W test, 2MST, and 6MWT. We specifically assessed older men, who are known to be more vulnerable to fatal injuries from falls due to gait dysfunction.^[22,23]

METHODS

Study Population and Definition of Conditions

Data from the 2014–2015 Korea Institute of Sport Science Fitness Standards (KISS FitS) project were used for the analysis. The details of the cohort and study methods have been described in previous studies from our team.^[21,24] To summarize briefly, the KISS FitS project recruited study participants among general Korean older adults who agreed to undergo health examination and physical fitness level assessment. Participants who could not participate in the physical fitness level assessment due to medical conditions (e.g., leg claudication, cardiovascular disease, and arthritis) were excluded at the recruitment stage. Participants underwent baPWV testing using the VP-1000 (Colin Co., Komak, Japan) device in a standardized manner.^[21,24] Laboratory analysis,

anthropometric measurement, and the medical history was collected through self-report questionnaires.^[21,24] Smokers are defined as someone who smokes cigarettes every day or some days and smokes at least seven cigarettes per week.^[25,26] In addition, the participants were defined as physically active if they engaged in more than 150 min of moderate-intensity exercise in a week.^[27] Participants were asked to mark the checkbox if they had a history of hypertension and hyperlipidemia in a self-report questionnaire. If they marked a checkbox, they were considered to have hypertension or hyperlipidemia. The Research Ethics Committee of the Korea Institute of Sport Science approved this study (No.KISS-201504-EFS-001-01). Participants who agreed to participate in the study provided informed consent during the recruitment process. Participants with missing data for the analysis were excluded from the analysis.

30s-CST

The participants were asked to sit on a chair. After sitting in the center of the chair, the participants were asked to cross their arms in front of their chest, and both arms were attached to the torso. The participants were asked to repeat sitting and standing on a chair for 30 s with the signal “start,” and the total number of perfect standing postures was recorded.^[28,29]

TUG Test

A cone was placed at a 3-m distant point in a straight line from the chair. The participants were asked to sit in the center of the chair, and both hands were placed on the thighs, with their back against the chair back. With the signal “start,” the participants tried to go to the cone and return to the chair as quickly as possible. The time taken to sit back on the chair was measured, and the minimum value was recorded in 0.001 s by measuring twice with a digital stopwatch.^[30]

F8W Test

A rectangular line of 3.6 m × 1.6 m was drawn on the floor, and cones were fixed at both corners. The participants were asked to sit on a chair located at the center of both corners of the square. The participants started to move to the cone in the right corner with the signal “start” and turned the cone. After turning the cone, the participants returned to sit on the chair, moved to the cone in the left corner, turned the cone, and returned to sit on the chair without resting. This procedure was repeated



twice, and the time required was recorded in units of 0.001 s.^[29,31]

2MST

Before the test, the minimum height at which the knee had to be raised was marked for each participant. The length from the center of the participant's patella to the iliac crest was measured, and a tape was used to mark the middle point. A rubber band was attached to the support fixture at the same height as the point marked to mark the cutoff point. The participants were asked to lift their knees alternatively to touch the rubber band, along with the "start" sign. The participants were asked to start with the right knee, and if both the right and left knees touched the rubber band consecutively, it was counted as one step. The total number of steps was measured in 2 min, and the test was performed once.^[29,32]

6MWT

For the 6MWT, a rectangular track with a width, length, and total length of 20 m, 5 m, and 50 m, respectively, was created. The cones were erected inside each corner, and markings were made at intervals of 1 m from the starting line. The total moving distance when walking on a rectangular track for 6 min was measured in units of 1 m.^[33,34]

Measurement of Lower Extremity Isometric Strength

Lower extremity extension/flexion forces were measured using a specialized device (AP3150; Hur, Finland). The participants were asked to sit on a chair. The center point of the knee joint was adjusted to be located at the same point as the axis of rotation. The waist and thigh were fixed with a belt to eliminate external forces from the hip joint and quadriceps femoris. The angle of the lever arm tip was adjusted to fit the participant's ankle. With a "start" signal, the maximum extension and flexion forces of the knee joint were measured. Each participant performed two times each on the left and right sides. The maximum value was recorded in increments of 0.01 kg.^[35]

Statistical Analysis

The degree of linear association was assessed using the Pearson's correlation test. For the gait parameters that showed significant linear associations in the Pearson's correlation test, the linear relationship between baPWV

and gait parameters was plotted using a scatterplot and fit line function. The goodness of fit was expressed as R-squared. Owing to the skewed distributions of the variables and mixed continuous and categorical variables, a generalized linear model was used to assess the adjusted linear relationship between baPWV and each gait parameter. We created a different sequential multivariable model to adjust for multiple confounding factors: (1) crude model; (2) model 1, which was a minimally adjusted model, adjusted for age and resting heart rate; (3) model 2, which was adjusted for variables in model 1 plus smoking, physical activity, history of hypertension, history of dyslipidemia, body mass index, serum low-density lipoprotein level, serum glucose level, and systolic blood pressure; and (4) model 3, which was adjusted for variables in model 2 plus lower extremity extension force and lower extremity flexion force. The beta coefficient (β) was used to assess the association between baPWV and each gait parameter. The 95% confidence interval (CI) was calculated, and a two-tailed *P*-value < 0.05 was considered statistically significant. All statistical analyses were conducted using SPSS 28.0 (SPSS Inc., IBM, Chicago, IL, USA).

RESULTS

Baseline Characteristics

Initially, 324 male participants who underwent gait assessment and baPWV measurements were considered for the analysis. Patients with missing data for the analysis were excluded: body mass index ($n = 3$), serum low-density lipoprotein level ($n = 24$), serum glucose level ($n = 24$), lower extremity extension force ($n = 7$), and lower extremity flexion force ($n = 7$). After exclusion, 291 participants were included in the analysis ($n = 291$) (Figure 1). All the participants with available data had an ankle-brachial index of ≥ 0.9 . The mean age of the participants was 71.38 ± 4.40 years. The mean values were as follows: (1) 30s-CST, 17.48 ± 5.00 ; (2) TUG test, 6.01 ± 1.10 s; (3) F8W test, 25.65 ± 4.71 s; (4) 2MST, 102.40 ± 18.83 per 2 min; and (5) 6MWT, 500.02 ± 85.65 m. The mean lower extremity extension and flexion forces were 117.62 ± 33.15 kg and 68.91 ± 19.56 kg, respectively. The mean baPWV was 1633.89 ± 288.23 cm/s. Among the study participants, 57.4% of the participants were physically active population, and 37.8% of the participants had hypertension. Moreover, 7.2% of the participants were active smokers (Table 1).

Participants aged 65 years or older men who had gait assessment and brachial-ankle pulse wave velocity measurement in strength certification centers in Korea from January 2014 to December 2015
(*n* = 324)

Participants with missing data for the analysis were excluded:
body mass index (*n* = 3), serum low-density lipoprotein level (*n* = 24),
serum glucose (*n* = 24), lower extremity extension force (*n* = 7), lower
extremity flexion force (*n* = 7)
Total exclusion (*n* = 33)

Final study population
(*n* = 291)

Figure 1 Flow diagram of study participants.

Table 1 Baseline characteristics.

Variables	Minimum	Maximum	Mean or Median
Age, yrs	64	85	71.38 ± 4.40
Body mass index, kg/m ²	17.5	30.2	23.89 ± 2.49
Low-density lipoprotein, mg/dL	42	264	115 (92.00–138.00)
Glucose, mg/dL	66	291	98 (90.00–108.00)
Systolic blood pressure, mmHg	93	198	130 (120.00–140.00)
Heart rate at rest, beats/min	39	128	61 (55–67)
30-s chair stand test	7	37	17.48 ± 5.00
Timed up and go test, s	3.19	11.37	6.01 ± 1.10
Figure-of-8 walk test, s	10.14	42.29	25.65 ± 4.71
2-min step test, per 2 min	40	160	102.40 ± 18.83
6-min walk test, m	246	768	500.02 ± 85.65
Lower extremity extension force, kg	36.8	237.2	117.62 ± 33.15
Lower extremity flexion force, kg	24	124.7	68.91 ± 19.56
Brachial-ankle pulse wave velocity, cm/s	1130.00	2500.00	1633.89 ± 288.23
Active smoking	21/291	7.2%	–
Physically active	167/291	57.4%	–
Hypertension	110/291	37.8%	–
Hyperlipidemia	45/291	15.5%	–

Data are presented as means ± SD or median (interquartile range).

Linear Association between baPWV and Gait Parameters

The linear association between baPWV and gait parameters was assessed using the Pearson's correlation test. baPWV showed a significant inverse linear relationship with the 6MWT ($r = -0.222$, 95% CI: -0.329 – -0.11 , $P < 0.001$). In addition, baPWV showed a significant positive relationship with the TUG test ($r = 0.157$, 95% CI: 0.042 – 0.267 , $P = 0.007$) and F8W test ($r = 0.174$, 95% CI: 0.06 – 0.283 , $P = 0.003$). baPWV was not significantly associat-

ed with the 30s-CST ($r = -0.042$, 95% CI: -0.156 – 0.074 , $P = 0.478$) and 2MST ($r = -0.061$, 95% CI: -0.175 – 0.054 , $P = 0.3$) (Table 2, Figure 2).

Multivariable Analysis to Assess the Relationship between baPWV and Gait Parameters

In the crude model, baPWV was significantly associated with the TUG test ($\beta = 0.001$, 95% CI: 0.000 – 0.001), F8W test ($\beta = 0.003$, 95% CI: 0.001 – 0.005), and 6MWT ($\beta = -0.066$, 95% CI: -0.099 – -0.033). However, the 30s-CST ($\beta =$



Table 2 Linear association between brachial-ankle pulse wave velocity and gait parameters by Pearson's correlation test.

	<i>r</i>	95% CI	<i>P</i> -value
30-s chair stand test	-0.042	-0.156–0.074	0.478
Timed up and go test	0.157	0.042–0.267	0.007
Figure-of-8 walk test	0.174	0.06–0.283	0.003
2-min step test	-0.061	-0.175–0.054	0.3
6-min walk test	-0.222	-0.329–0.11	< 0.001

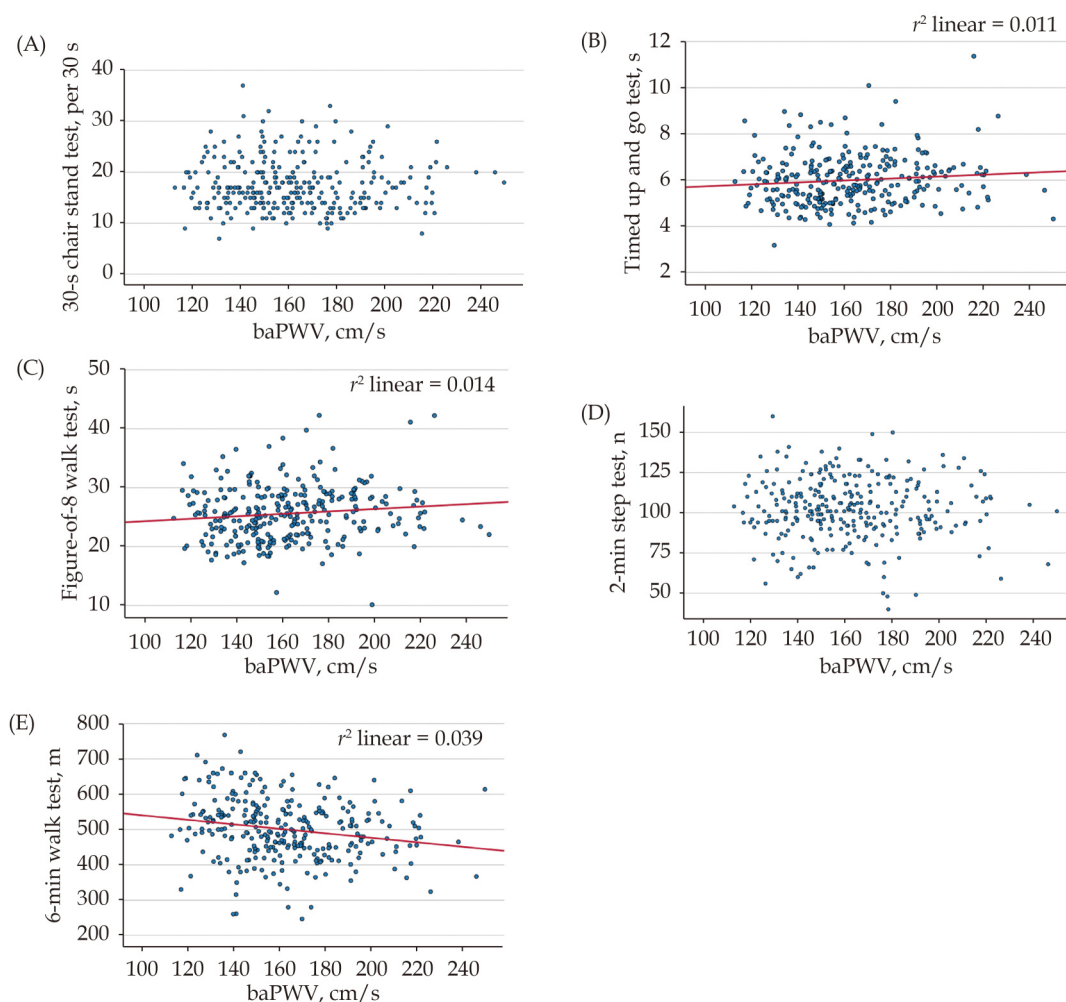


Figure 2 Linear association between baPWV and gait parameters. (A): X axis = baPWV (cm/s), Y axis = 30-s chair stand test (per 30 s), no linear association found; (B): X axis = baPWV (cm/s), Y axis = timed up and go test (s), $y = 5.31 + 0.000422x$; (C): X axis = baPWV (cm/s), Y axis = figure-of-8 walk test (s), $y = 22.23 + 0.00207x$; (D): X axis = baPWV (cm/s), Y axis = 2-min step test (per 2 min), no linear association found; and (E): X axis = baPWV (cm/s), Y axis = 6-min walk test (m), $y = 604 - 0.06x$. baPWV: brachial-ankle pulse wave velocity.

–0.001, 95% CI: –0.003–0.001) and 2MST ($\beta = -0.004$, 95% CI: –0.011–0.004) did not show a significant association. In model 1, after adjustment for age and resting heart rate, the results were similar. In model 2, after adjustment for lifestyle factors, medical conditions, and serologic values, the statistical significance of the results did

not change in comparison to the crude model. [(1) 30s-CST, $\beta = -0.001$, 95% CI: –0.004–0.001, $P = 0.193$; (2) TUG test, $\beta = 0.001$, 95% CI: 0.000–0.001, $P = 0.006$; (3) F8W test, $\beta = 0.003$, 95% CI: 0.001–0.005, $P = 0.003$; (4) 2MST, $\beta = -0.004$, 95% CI: –0.013–0.004, $P = 0.306$; and (5) 6MWT, $\beta = -0.056$, 95% CI: –0.094–0.019, $P = 0.003$]. In model

3, after additional adjustment with lower extremity strength, numerical association was weakened overall; however, the statistical significance of the results did not change compared to model 2 [(1) 30s-CST, $\beta = 0$, 95% CI: -0.003–0.002, $P = 0.682$; (2) TUG test, $\beta = 0$, 95% CI: 0.000–0.001, $P = 0.036$; (3) F8W test, $\beta = 0.002$, 95% CI: 0.000–0.004, $P = 0.028$; (4) 2MST, $\beta = -0.001$, 95% CI: -0.01–0.007, $P = 0.727$; and (5) 6MWT, $\beta = -0.037$, 95% CI: -0.072–0.002, $P = 0.038$] (Table 3).

DISCUSSION

Our study showed that baPWV had statistically significant associations with multiple gait parameters, including the TUG test, F8W test, and 6MWT, independently in the older male population. Furthermore, we showed that the association was significant even after adjusting for lower extremity strength, which is known to be associated with both arterial stiffness and walking function.^[36] However, the overall association was modest. The 30s-CST and 2MST did not show a significant association. To the best of our knowledge, this is the first study to assess the association between arterial stiffness and multiple gait assessments in the older male population, with adjustment for lower extremity strength.

We compared our gait assessment results with those of other studies. First of all, our study participant's mean baPWV value was similar to that of older adults population from a previous study (mean age: 66.5 ± 6.8 years, mean baPWV: 1570 ± 281 cm/s, no difference between men and women).^[37] Slight difference of baPWV could be due to relatively older participants of our study (mean age: 71.38 ± 4.40 years). In a previous study, the mean 30s-CST of men at the age 70–74 group was 17.9 ± 5.6 s.^[38] The mean TUG test value of older Korean men was 6.20 ± 1.81 s.^[29] A previous study reported that the mean 6MWT distance of older Korean men was 470.02 ± 77.31 m (mean age: $76.66 \pm$

4.18 years).^[39] Our study population showed a slightly longer 6MWT distance, which may be due to the relatively younger age of participants. According to the 2015–2019 National Fitness Award dataset, the mean value of the F8W test of the older male population was 26.04 ± 7.01 s, and the mean value of 2MST of the older male population was 107.20 ± 24.90 per 2 min.^[29] Overall, our physical fitness assessment results were similar to those of previous reports of similar age groups.

Previous studies have reported conflicting results regarding the association between arterial stiffness and gait assessment. Gonzales, *et al.*^[19] showed that gait performance assessed using the 400-m walk test was inversely correlated with the carotid-femoral pulse wave velocity. Hinrichs, *et al.*^[20] showed that arterial stiffness assessed by measuring pulse waves at the brachial artery was not associated with the 6MWT. The authors postulated that the demand of the test was not high enough to render arterial stiffness and possibly insufficient leg perfusion during muscle contraction.^[20] However, the study was limited by assessing the pulse wave velocity only at the brachial artery, which may not reflect variations in arterial structure and geometry.^[20] Although our study results showed that the baPWV had a statistically significant association with the 6MWT, the strength of the association was modest. Furthermore, the TUG test and F8W test showed a statistically significant association; however, the strength of the association was minimal.

Our results revealed two interesting findings. Firstly, the assessments that showed a significant association evaluated walking on flat surfaces (TUG test, F8W test, and 6MWT). On the other hand, the 30s-CST and 2MST involves more sitting up and down and climbing than walking on flat surfaces.^[28,40–42] The 30s-CST is related to the most demanding daily life activities, including climbing stairs.^[28] The 2MST also imitates climbing stairs, which is the most exhaustive and difficult form of locomotion.^[41,42] Our results did

Table 3 Association between brachial-ankle pulse wave velocity and gait parameters.

	30-s chair stand test			Timed up and go test			Figure-of-8 walk test			2-min step test			6-min walk test		
	β	95% CI	P-value	β	95% CI	P-value	β	95% CI	P-value	β	95% CI	P-value	β	95% CI	P-value
Crude	-0.001	-0.003–0.001	0.475	0.001	0.000–0.001	0.007	0.003	0.001–0.005	0.003	-0.004	-0.011–0.004	0.298	-0.066	-0.099–0.033	< 0.001
Model 1	0	-0.002–0.002	0.754	0	0.000–0.001	0.006	0.001	0.000–0.003	0.119	0.001	-0.007–0.009	0.792	-0.041	-0.075–0.008	0.015
Model 2	-0.001	-0.004–0.001	0.193	0.001	0.000–0.001	0.006	0.003	0.001–0.005	0.003	-0.004	-0.013–0.004	0.306	-0.056	-0.094–0.019	0.003
Model 3	0	-0.003–0.002	0.682	0	0.000–0.001	0.036	0.002	0.000–0.004	0.028	-0.001	-0.01–0.007	0.727	-0.037	-0.072–0.002	0.038

Model 1: adjusted for age and resting heart rate. Model 2: adjusted for variables in model 1 plus smoking, physical activity, history of hypertension, history of dyslipidemia, body mass index, serum low-density lipoprotein level, serum glucose level, and systolic blood pressure. Model 3: adjusted for variables in model 2 plus lower extremity extension force and lower extremity flexion force.



not show significant associations with the baPWV, 30s-CST, and 2MST. Although both the 2MST and 6MWT reflect cardiorespiratory fitness, only the baPWV and 6MWT showed a significant association.^[10,11] One possible explanation for this result is that arterial stiffness may have a greater influence on walking on flat surfaces than on climbing. Another possible explanation is that the size of our study population was not large enough to sensitively detect the effect of arterial stiffness on the 30s-CST and 2MST, as there was a non-statistically significant trend toward a negative association. Secondly, the relationship and statistical significance did not change, even after adjusting for lower muscle strength. Low muscle strength and arterial stiffness are interconnected.^[43] Weakness of the hip and lower extremity muscles can cause gait dysfunction.^[44] However, our results suggest that arterial stiffness exerts its effect on gait function independent of lower extremity strength.

Gait is an extremely complex process involving the nexus of the nervous, musculoskeletal, and cardiorespiratory systems; balance; motor control; and sociocultural factors.^[1] If a pathological process interrupts any part of this interconnection, this could lead to a gait dysfunction. Furthermore, it often results from lesions or dysfunctions at different levels of the nervous and musculoskeletal systems.^[1] Previous studies have assessed the relationship between arterial stiffness and gait function using walking speed.^[15,17] Our study is unique in that we conducted various gait assessments. In addition, we conducted extensive confounding adjustments, which strengthened the results.

Arterial stiffness is a known marker of increased risk of cardiovascular disease, independent of traditional cardiovascular risk factors.^[45] Overall, our result suggests that if patients show poor performance in TUG test, F8W test, and 6MWT, a clinician should consider increased arterial stiffness in such patients.

LIMITATIONS

Our study requires cautious interpretation. Firstly, as it was mentioned earlier, although there were statistically significant associations between the baPWV and TUG test, F8W test, and 6MWT, it is difficult to postulate the clinical impact of such a weak relationship. As such, our results need further verification in larger-scale studies. Secondly, this is a cross-sectional study. Owing

to its nature, the causal relationship between arterial stiffness and gait assessment cannot be confirmed. Thirdly, we did not have information about the peripheral arterial disease status of the participants. However, the participants were healthy enough to voluntarily participate in the physical function assessment including the 6MWT. We believe that the proportion of participants with significant peripheral arterial disease should be minimal. At the same time, our study included a single ethnicity – Korean. Fourthly, the relatively small sample size is a limitation. However, our study participants who were included in the analysis had complete information regarding baPWV, gait assessment, and laboratory analysis data, which allowed us to perform a thorough confounding factor adjustment. Fifthly, our study was conducted only in older men. Sixthly, our study did not report diabetes mellitus history among participants due to a lack of data. However, we mitigated this limitation by adjusting fasting serum glucose level as a confounding factor. Last but not least, we did not have information about the medication the participants were taking. All the participants were asked to continue their medications before and after the measurements. As some anti-hypertensive and anti-diabetic medications are known to affect arterial stiffness, this could be the potential limitation of our study.^[46,47]

Future prospective cohort studies incorporating diverse ethnicities, sexes, and larger cohorts are needed to confirm the causal relationship and clinical impact of increased arterial stiffness on gait dysfunction.

CONCLUSIONS

In conclusion, our study showed that arterial stiffness was independently but weakly associated with multiple gait assessments, including the TUG test, F8W test, and 6MWT, even after adjusting for lower extremity strength. This result suggests that arterial stiffness is one of the diverse factors that can affect gait dysfunction and affects gait function directly, not by affecting lower extremity strength.

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