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Characteristics of blood pressure, arterial stiffness, and physical fitness in older adult Japanese community dwellers: a cross-sectional observational study

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Abstract The numbers of “old-old” and “young-old” adults (age ≥ 75 y [years] and 65-74 y, respectively) are now about the same, but less is known about the physiological characteristics such as arterial stiffness in old-old adults, especially those aged >85 y. Therefore, the present cross-sectional observational study aimed to determine the characteristics of blood pressure (BP), arterial stiffness, and physical fitness among 559 (male, $n = 213$; female, $n = 346$) Japanese community dwellers aged >65 y in Osaka and Kawakami Village, Nara. BP and arterial stiffness were measured in the supine position using a semi-automated device. Physical fitness was assessed by measuring handgrip strength and walking speed, as well as findings of the sit-and-reach and pegboard tests. Values for systolic BP, mean BP, and arterial stiffness were significantly higher in the old-old than young-old community dwellers. Trends in BP and arterial stiffness significantly increased, whereas those of physical fitness significantly decreased with age per decade. This is the first study to show that the physiological characteristics of BP, arterial stiffness, and physical fitness in Japanese community-dwelling older adults over 80 y. These novel findings indicate that community-dwelling older adults, especially nonagenarians, can maintain the longevity characteristics of lower arterial stiffness and higher physical fitness such as handgrip strength.

Keywords : arteriosclerosis, cardio-ankle vascular index (CAVI), handgrip strength, longevity, nonagenarian, pulse wave velocity

Introduction

The increasing global population of aging elderly persons between 1990 and 2013 can explain the increase in the number of deaths from cardiovascular diseases in most regions, despite an overall decrease in age-specific death rates¹⁾. The World Health Organization has reported that among the top 10 global causes of death are ischemic heart disease and stroke, which accounted for 15.2 million deaths in 2016²⁾. Hypertension or high blood pressure (BP) is an established independent risk factor for cardiovascular diseases³⁾. One study has found that among the risk factors, high BP comprises the second-most prevalent risk factor for adult mortality from non-communicable diseases and injuries in Japan⁴⁾. Preventing and reducing high BP is thus of paramount importance in reducing risk of cardiovascular events.

Arterial stiffness is also an independent risk factor for cardiovascular disease⁵⁾. Many studies have found that arterial stiffness increases with age and results in impaired ability of the arteries to buffer the pulsation of BP and blood flow⁶⁻⁹⁾. That is, increased arterial stiffness is one cause of elevated BP, especially among middle-aged and older adults. However, regular aerobic exercise or physical activity can reduce arterial stiffness and BP even among older adults¹⁰⁻¹³⁾ and should therefore be implemented throughout life.

The numbers of old-old (age ≥ 75 y) and young-old (age 65-74 y) adults have recently become about the same in Japan¹⁴⁾. However, the characteristics of BP, arterial stiffness, and physical fitness that are associated with longevity among older adults have remained obscure. Several studies have identified pulse wave velocity (PWV) and the cardio-ankle vascular index (CAVI) as clinical indicators of arterial stiffness in older adults^{7,8,15-17)}, but most domestic and international data on PWV and CAVI have

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been obtained from persons aged <80 y. Accordingly, little is known about arterial stiffness levels among old-old community dwellers, although one study has evaluated arterial stiffness in centenarians in Okinawa, Japan¹⁸⁾. This study's findings indicated that aortic PWV was significantly higher in centenarians than in a control group of relatively young older adults in Okinawa (*i.e.*, the centenarians had stiffer arteries)¹⁸⁾. However, aortic PWV of the centenarians was 10.15 ± 2.04 m/s¹⁸⁾, and the value seems lower than that of other studies of older people¹⁹⁻²¹⁾. Moreover, systolic and diastolic BP was significantly lower in the centenarians than in the controls¹⁸⁾. These limited findings raise the possibility that nonagenarians or centenarians might have relatively lower arterial stiffness and BP than older adults in general; but the physiological characteristics of longevity remain controversial. As far as we can ascertain, the characteristics of arterial stiffness, BP, and physical fitness among Japanese community-dwelling older adults, including those aged ≥ 80 y, have not yet been comprehensively investigated.

We hypothesized that older community dwellers, especially those aged ≥ 85 y, would have lower BP and arterial stiffness and be more physically fit. The present cross-sectional study thus aimed to determine the characteristics of BP, arterial stiffness, and physical fitness among older Japanese community dwellers including those aged ≥ 80 y.

Methods

Participants. This cross-sectional observational study recruited older Japanese community dwellers aged ≥ 65 y in Osaka and Kawakami Village, Nara, using local advertisements and referrals from public offices. We excluded 74 participants due to missing data associated with arterial stiffness and physical fitness, refusal to cooperate, pain, technical errors associated with measuring arterial stiffness such as not detecting a pulse wave, and one with an unmatched ID number. Thus, we analyzed data from 559 (male, $n = 213$; female, $n = 346$) older Japanese community dwellers who met the inclusion criteria. The purpose, procedures, and risks of the study were explained to the recruits, all of whom provided written informed consent to participate. The Human Ethics Committee at the Osaka Institute of Technology reviewed and approved the study (2012-8, 2016-7, and 2018-1), which was implemented according to the guidelines of the Declaration of Helsinki.

Measurements. The participants abstained from vigorous exercise for at least 24 h before, cigarette smoking and medications on the day of, and caffeine and food for ≥ 4 h before testing, as described^{22,23)}. We measured the height and weight of participants wearing light clothing, then body mass index (BMI) was calculated as weight divided by height squared. We also determined smoking status, chronic diseases such as cardiovascular disease or diabetes, and use of anti-hypertensive or anti-hyperlipid-

emic medications in face-to-face interviews. All parameters were measured in a quiet air-conditioned room at 22-24°C.

Arterial stiffness, blood pressure, and heart rate. After resting for ≥ 15 min, PWV, systolic BP (SBP), diastolic BP (DBP), mean BP (MBP), pulse pressure (PP), and heart rate (HR) were measured in the supine position using a VS-1500AE/AN semi-automated device (Fukuda Denshi, Japan)²⁴⁻²⁶⁾. Brachial-ankle PWV (baPWV) and cardio-ankle vascular index (CAVI) were calculated as indicators of arterial stiffness^{22,23,26)}. The intraobserver CV for baPWV and CAVI measured in the laboratory on two separate days were all $<4\%$ ²⁴⁻²⁶⁾.

Physical fitness test. Flexibility was measured with the sit-and-reach test using a T-283 device (Toei Light, Japan) as described^{22,23)}. Handgrip strength was measured in duplicate using a dynamometer (T.K.K.5001 Grip-A; Takei Scientific Instruments Co. Ltd., Japan) and mean left and right values were analyzed^{22,23)}. Hand-finger dexterity in both hands was assessed in triplicate for 15 seconds (s) each using the pegboard test (T.K.K.1302 hand-finger testing device; Takei Scientific Instruments Co. Ltd., Japan) and the total number of displaced pegs was analyzed¹³⁾. The 6-meter (m) walk test proceeded as follows. The participants started to walk three meters before a start line to exclude the duration of acceleration from normal walking speed, then walked as fast as possible without running for 6 m. Speed was calculated as the ratio between distance and time¹³⁾. All daily coefficients of variation (CV) were $<10\%$.

Data analysis and statistics. Parameters associated with longevity were analyzed in participants grouped according to age as follows: group A, "young-old" (ages 65-74 y, $n = 308$) and "old-old" (ages 75-94 y, $n = 251$); group B, ages 65-74 y ($n = 308$), 75-84 y ($n = 197$), and 85-94 y ($n = 54$); group C: ages 65-69 y ($n = 135$), 70-74 y ($n = 173$), 75-79 y ($n = 122$), 80-84 y ($n = 75$), 85-89 y ($n = 47$), and 90-94 y ($n = 7$). Continuous data were analyzed using one-way ANOVA and ANCOVA that included gender, BMI, HR, MBP, smoking status, chronic diseases, anti-hypertensive medication, anti-hyperlipidemic medication, and the surveyed area as a covariate. Significant F values were assessed using post hoc tests with the Bonferroni correction to identify significant differences among mean values. Trends were analyzed using linearity tests and weighted P values were adjusted for sample size. Differences in non-parametric variables were analyzed using Mann-Whitney U tests and Kruskal-Wallis tests followed by Scheffé tests. All data were statistically analyzed using SPSS for Windows 14.0J (IBM SPSS Japan, Japan). Data are presented as means $\pm$ SD. Differences were considered significant at $P < 0.05$.

Results

Table 1 shows the characteristics of the participants in each age category. Height and weight trends significantly decreased with advancing age. However, BMI trends or differences were not significant among any age groups. Trends in SBP, MBP, and PP significantly increased with advancing age; SBP, MBP, and PP values were significantly higher in individuals aged 75-84 y and 85-94 y compared to 65-74 y. DBP tended to significantly decrease with age in group C.

Fig. 1 shows baPWV (A) and CAVI (B) among the age categories. Triadic analysis (A-C) significantly associated increasing baPWV and CAVI trends with advancing age. Values for baPWV and CAVI were significantly higher in the old-old than in the young-old categories in group A. Analysis of group B revealed significantly higher baPWV and CAVI at ages 75-84 y and 85-94 y than ages 65-74 y, and significantly higher baPWV values at ages 85-94 y than ages 75-84 y. However, the absence of significant differences in baPWV and CAVI was notable between persons aged 90-94 y and all other age categories in group C. The results remained significant after adjusting baPWV and CAVI for gender, BMI, HR, MBP, smoking status, chronic diseases, anti-hypertensive medication, anti-hyperlipidemic medication, and surveyed area in ANCOVA, with the exception of CAVI in group C. After adjusting for confounding factors, the significant increasing trend in CAVI conspicuously disappeared from group C and the CAVI was significantly lower at ages 90-94 y than at ages 85-89 y.

Table 1 also shows the physical fitness outcomes for age category. Trends in sit-and-reach, handgrip strength, pegboard, and walking speed significantly decreased with advancing age in all analyzed groups (A-C). Physical fitness parameters in group A were significantly lower in the old-old than in the young-old group. Those in group B were lower in the groups aged 75-84 y and 85-94 y than 65-74 y, and notably lower at ages 85-94 y than 75-79 y. In contrast, handgrip strength did not significantly differ between persons aged 90-94 y and any other age category. These results remained significant after adjusting physical fitness for gender, BMI, HR, MBP, smoking status, chronic diseases, anti-hypertensive medication, anti-hyperlipidemic medication, and surveyed area in ANCOVA.

Discussion

The salient findings of the present study are as follows. Values for SBP, MBP, PP, and arterial stiffness were significantly higher and those for physical fitness were significantly lower in the old-old than in the young-old category. Secondly, trends for SBP, MBP, PP, and arterial stiffness significantly increased, whereas all parameters of physical fitness significantly decreased as age advanced by decade. Thirdly, arterial stiffness did not significantly

differ between those aged 90-94 y and any other age category, and in fact handgrip strength tended to be better in the group aged 90-94 y than in the groups aged 75-79 y, 80-84 y, and 85-89 y. To our knowledge, this is the first description of the physiological characteristics of BP, arterial stiffness, and physical fitness in older Japanese community dwellers, particularly among those aged ≥ 80 y.

Both baPWV and CAVI are widely accepted as clinical indicators of arterial stiffness^{7,8,16,17}, which increases with age^{7,8,22}. Arterial stiffening is thought to result from structural changes in elastin and collagen, changes in vasoconstrictor tone and endothelial functions, or both^{9,27}. Reference values for baPWV and CAVI in older Japanese community dwellers have been published^{7,8,16,17}. A recent systematic review and meta-analysis found that an increase in PWV of 1 m/s corresponded to a $>10\%$ increase in risk for cardiovascular events or mortality^{16,28}. However, reports and reference values for old-old adults, especially those aged ≥ 80 y, are limited. The present cross-sectional analysis of old-old adults found significantly higher SBP, MBP, PP, and arterial stiffness and significantly lower physical fitness parameters in the old-old than in the young-old category after adjusting for confounding factors. Therefore, these findings indicate that arterial stiffness, SBP, MBP, and PP certainly increase according to advancing age in old-old adults, and that the risk of cardiovascular events is higher in old-old than young-old adults.

Our results also indicate that trends in SBP, MBP, PP, and arterial stiffness significantly increased as age advanced by decade, whereas physical fitness parameters significantly decreased. Participants aged 85-94 y were almost the same average life span in 2017¹⁴, but values for SBP, MBP, PP, and arterial stiffness were significantly higher among those ages 85-94 y than those ages 65-74 y and 75-84 y. Recent studies have found that scores for trunk flexibility or strength are associated with arterial stiffness^{22,29}, and our study indicated that all parameters of physical fitness were significantly lower in those ages 85-94 y than those ages 65-74 y and 75-84 y, the opposite of BP and arterial stiffness. In the present study, these underlying physiological relationships between arterial stiffness and physical fitness are unclear. However, our results suggest that the older adult group aged 85-94 y do not always have the longevity characteristics such as lower arterial stiffness and better physical fitness. That said, as far as we can ascertain, for the first time, our data determine the physiological profile of BP, arterial stiffness, and physical fitness in Japanese community dwellers aged 85-94 y.

We analyzed parameters associated with longevity among individuals stratified by age in increments of five years including nonagenarians. A study of arterial stiffness among centenarians in Okinawa, Japan, indicated aortic PWV was significantly higher in centenarians than in the control group of relatively young older adults in

Table 1. Characteristics of the participants according to each age category.

Variables	Analysis A				Analysis B				Analysis C						
	All	Young-old	Old-old	P for trend	65-74 y	75-84 y	85-94 y	P for trend	65-69 y	70-74 y	75-79 y	80-84 y	85-89 y	90-94 y	P for trend
Age, y	n = 559 75 ± 7	n = 308 70 ± 3	n = 251 81 ± 4*	P < 0.001	n = 308 70 ± 3	n = 197 79 ± 3*	n = 54 87 ± 2*	P < 0.001	n = 135 67 ± 1	n = 173 72 ± 1*	n = 122 77 ± 1*	n = 75 82 ± 1*	n = 47 87 ± 1*	n = 7 92 ± 1*	P < 0.001
Number of male (%)	214 (38.3)	127 (41.2)	87 (34.7)	-	127 (41.2)	59 (29.9)*	28 (51.9)†	-	61 (45.2)	66 (38.2)	37 (30.3)	22 (29.3)	23 (48.9)	5 (71.4)	-
Height, cm	154.4 ± 8.8	156.9 ± 8.5	151.4 ± 8.3*	P < 0.001	156.9 ± 8.5	151.6 ± 7.8*	150.7 ± 9.9*	P < 0.001	158.0 ± 8.4	156.0 ± 8.5	152.6 ± 7.3*	150.0 ± 8.4*	150.4 ± 10.1*	153.0 ± 8.4	P < 0.001
Weight, kg	54.7 ± 9.5	56.6 ± 9.2	52.5 ± 9.4*	P < 0.001	56.6 ± 9.2	52.9 ± 9.6*	50.9 ± 8.9*	P < 0.001	56.9 ± 9.4	56.3 ± 9.1	53.7 ± 9.9	51.6 ± 8.8*	50.9 ± 9.1*	50.9 ± 8.6	P < 0.001
Body mass index, kg/m ²	22.9 ± 2.9	22.9 ± 2.7	22.8 ± 3.3	P = 0.729	22.9 ± 2.7	22.9 ± 3.4	22.3 ± 2.8	P = 0.387	22.7 ± 2.6	23.1 ± 2.7	23.0 ± 3.5	22.9 ± 3.2	22.4 ± 2.9	21.6 ± 2.4	P = 0.555
Heart rate, beats/min	70 ± 12	70 ± 12	70 ± 11	P = 0.591	70 ± 12	70 ± 11	69 ± 12	P = 0.549	69 ± 12	71 ± 12	70 ± 10	69 ± 12	71 ± 12	58 ± 10	P = 0.690
Systolic BP, mmHg	140 ± 18	137 ± 17	144 ± 19*	P < 0.001	137 ± 17	143 ± 18*	145 ± 22*	P < 0.001	138 ± 17	137 ± 16	143 ± 18†	143 ± 18	144 ± 21	152 ± 30	P < 0.001
Diastolic BP, mmHg	83 ± 10	83 ± 9	82 ± 10	P = 0.225	83 ± 9	82 ± 10	81 ± 12	P = 0.164	84 ± 9	82 ± 9	84 ± 10	80 ± 9*	81 ± 11	85 ± 17	P = 0.021
Mean BP, mmHg	105 ± 13	103 ± 12	107 ± 14*	P < 0.001	103 ± 12	107 ± 13*	110 ± 17*	P < 0.001	104 ± 12	103 ± 12	107 ± 13	106 ± 14	109 ± 16†	117 ± 23	P < 0.001
Pulse pressure, mmHg	57 ± 14	54 ± 12	61 ± 14*	P < 0.001	54 ± 12	61 ± 14*	64 ± 14*	P < 0.001	53 ± 12	55 ± 13	60 ± 14*	62 ± 15*	63 ± 13*	67 ± 17	P < 0.001
Number of smokers (%)	30 (5.4)	16 (5.2)	14 (5.6)	-	16 (5.2)	7 (3.6)	7 (13.0)*†	-	10 (7.4)	6 (3.5)	2 (1.6)	5 (6.7)	7 (14.9)	0 (0.0)	-
Number of participants using a-hypertensive med. (%)	227 (40.6)	110 (35.7)	117 (46.6)*	-	110 (35.7)	85 (43.1)	32 (59.3)*	-	40 (29.6)	70 (40.5)	52 (42.6)	33 (44.0)	28 (59.6)*	4 (57.1)	-
Number of participants using a-hyperlipidemic med. (%)	125 (22.4)	56 (18.2)	69 (27.5)*	-	56 (18.2)	58 (29.4)*	11 (20.4)	-	22 (16.3)	34 (19.7)	36 (29.5)	22 (29.3)	10 (21.3)	1 (14.3)	-
Number of chronic disease participants (%)	71 (12.7)	26 (8.4)	45 (17.9)*	-	26 (8.4)	32 (16.2)*	13 (24.1)*	-	5 (3.7)	21 (12.1)	20 (16.4)*	12 (16.0)	10 (21.3)*	3 (42.9)*	-
Sit-and-reach, cm	31.8 ± 10.0	33.6 ± 9.9	29.6 ± 9.7*	P < 0.001	33.6 ± 9.9	30.4 ± 9.7*	26.9 ± 9.0*	P < 0.001	34.8 ± 9.8	32.7 ± 9.9	31.1 ± 9.7*	29.1 ± 9.7*	27.1 ± 8.9*	25.3 ± 10.6	P < 0.001
Handgrip strength, kg	26.9 ± 8.5	29.6 ± 8.4	23.4 ± 7.3*	P < 0.001	29.6 ± 8.4	23.6 ± 7.4*	22.6 ± 6.9*	P < 0.001	31.3 ± 9.0	28.4 ± 7.6*	24.7 ± 7.7*	21.9 ± 6.7*	22.2 ± 6.8*	25.2 ± 7.1	P < 0.001
Pegboard, number of pegs	n = 317 40 ± 9	n = 149 44 ± 8	n = 168 37 ± 9*	P < 0.001	n = 149 44 ± 8	n = 119 38 ± 9*	n = 49 35 ± 10*	P < 0.001	n = 60 45 ± 8	n = 89 43 ± 9	n = 67 40 ± 9*	n = 52 37 ± 9*	n = 42 36 ± 9*	n = 7 28 ± 11*	P < 0.001
Walking speed, m/s	1.63 ± 0.38	1.81 ± 0.34	1.47 ± 0.34*	P < 0.001	1.81 ± 0.34	1.53 ± 0.34*	1.31 ± 0.28*	P < 0.001	1.91 ± 0.36	1.74 ± 0.31*	1.58 ± 0.33*	1.47 ± 0.34*	1.32 ± 0.26*	1.25 ± 0.39*	P < 0.001

BP, blood pressure; a-hypertensive med., anti-hypertensive medication; a-hyperlipidemic med., anti-hyperlipidemic medication; Young-old, age 65-74 y; Old-old, age ≥75 y. Age categories in decade increments: 65-74 y, 75-84 y, and 80-94 y. Age categories in five-year increments: 65-69 y, 70-74 y, 75-79 y, 80-84 y, 85-89 y, and 90-94 y. *P < 0.05 vs. the youngest group within the same analysis; †P < 0.05 vs. the second youngest group within the same analysis; ‡P < 0.05 vs. the third youngest group within the same analysis; #P < 0.05 vs. the fourth youngest group within the same analysis; \$P < 0.05 vs. the fifth youngest group within the same analysis; Data are expressed as means ± SD.

Fig. 1 Comparison of baPWV (A) and CAVI (B) among older adults at various ages.

Abbreviations: baPWV, brachial-ankle pulse wave velocity; CAVI, cardio-ankle vascular index of arterial stiffness. Group A: young-old, age 65-74 y; old-old, age ≥ 75 y. Group B: age categories in decade increments; 65-74 y, 75-84 y, and 85-94 y. Group C: age categories in five-year increments; 65-69 y, 70-74 y, 75-79 y, 80-84 y, 85-89 y, and 90-94 y. P values of D indicate statistical differences; P values of T indicate statistical trends; P values determined by ANOVA (ANCOVA). * $P < 0.05$ vs. the youngest group within the same analysis; † $P < 0.05$ vs. the second youngest group within the same analysis; ‡ $P < 0.05$ vs. the third youngest group within the same analysis; Data are expressed as means $\pm$ SD.

Okinawa¹⁸⁾. However, aortic PWV of the centenarians was 10.15 ± 2.04 m/s¹⁸⁾, and the value can be lower than that of other studies of older people¹⁹⁻²¹⁾. Thus, these results suggest that the centenarians might have relatively lower arterial stiffness than the general elderly population. The present study found that arterial stiffness did not significantly differ between the age category of 90-94 y and any other age category after adjustment for confounding factors. Furthermore, the significantly increasing CAVI trend disappeared after adjustment for confounding factors. Therefore, our data indicate that arterial stiffness can be relatively lower among the nonagenarians than among those aged 75-79 y, 80-84 y, and 85-89 y. At first glance, the results of arterial stiffness among 90-94 y are likely to be debatable. However, Windkessel effects in compliant arteries can suppress reductions in DBP and excess increases in SBP³⁰⁾. Our results indicate that DBP did not decrease any more among those ages 90-94 y than in any

other age category, which partially supports our findings of arterial stiffness.

Handgrip strength also did not significantly differ between those ages 90-94 y and any other age categories analyzed. In general, handgrip strength predicts incident disability and closely correlates with power in other muscle groups^{31,32)}. In addition, although walking speed tended to be lower among those ages 90-94 y, it did not differ from the 85-89 y age group. Thus, skeletal muscle mass and the walking ability of persons ages 90-94 y can be comparatively maintained, and lower arterial stiffness would be sustained by participating in regular physical activity. A previous study found that more time spent in even light physical activity is associated with the attenuation of arterial stiffening among older persons³³⁾. Therefore, our results suggest that older community dwellers, especially nonagenarians, apparently have the longevity characteristics of lower arterial stiffness and better physi-

cal fitness. Further studies and more data are needed to confirm this notion.

One potential limitation of the present study was that few participants were aged >85 y. Also, the cross-sectional study design limited the ability to determine cause-and-effect relationships among aging, BP, arterial stiffness, and physical fitness. Therefore, further detailed longitudinal studies are required to determine whether older community dwellers, especially those ≥80 y, have the longevity characteristics of lower cardiovascular risk and better physical fitness before our findings could be generalized.

In conclusion, our findings indicate that increasing arterial stiffness and BP are associated with advancing age among old-old adults. Our data also suggest that community-dwelling older adults, especially nonagenarians, have the longevity characteristics of lower arterial stiffness and higher physical fitness such as handgrip strength. However, further investigations of a large-scale population are required to confirm these inferences.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this article. Conceived and designed the study: MN. Performed the study: MN, NO, CN. Analyzed the data: MN and NO. Interpreted the data: MN and NM. Wrote the paper: MN. All authors approved the final version of the article.

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