1. Introduction

Aging causes decline of arterial wall compliance (Nichols and O’Rourke 1998). The decline is clear in the aorta and the central arteries (Nichols and O’Rourke 1998), and central arterial compliance (the ratio between systemic arterial volume change and systemic arterial pressure) is declined in elderly people. The decline in central arterial compliance causes malfunction of the systemic arteries that mitigate the heartbeat arterial pressure and smooth the intermittent blood flow, and this results in a rise of systolic blood pressure. Systolic hypertension, that morbidity rate is higher in the elderly, is considered mainly caused by the aging-induced decline of central arterial compliance. However, systolic hypertension is not a harmless symptom: rather, it is one of the worst risk factors of cerebral hemorrhage, a leading cause of bed confinement in old age. It is also a factor in high morbidity rates from heart disease and death. (Kocemba, et al., 1998).

The main cause of the decline of arterial wall
compliance in the elderly is considered to be the degeneration and decrease of elastica, a major elasticity substance of media, and also aging-induced acceleration of organic changes such as an increase of collagen fibers (Nichols and O’Rourke 1998). Also, changes in the endothelium function to adjust the tone of the smooth muscle cells in the media and in the function of the autonomic nervous system, both of which are aging-induced, seem to relate to the decline of arterial wall compliance (Matsuda, et al., 2003). The decline of arterial wall compliance is reversible to some degree, as is suggested in many cross-sectional studies (Mohiaddin, et al., 1989; Vaitkevicius, et al., 1993; Kingwell, et al., 1995; Kakiyama, et al., 1998a; Kakiyama, et al., 1998b; Tanaka, et al., 2000; Tanabe, et al., 2003; and Tanabe, et al., 2004). The same is also suggested in many longitudinal studies (Cameron and Dart, 1994; Tanaka, et al., 2000; Kakiyama, et al., 2001; Moreau, et al., 2003; Edward, et al., 2004; and Kakiyama, et al., 2005). They report that regular exercises increase the distensibility or compliance of the central arteries, and contain aging-induced decline, not only in athletes who train themselves with highly intensive exercises but also general people with no health problems, including middle-aged and elderly people. This may be because exercises have some positive effects on the soothen muscles adjustment function (Matsuda, et al., 2003), and inhibit aging-induced organic changes in the arterial wall (Tanaka, et al., 2005).

Our previous studies (Tanabe, et al., 2003; Tanabe, et al., 2004) suggest that an increase of daily physical activity contains inhibitions of the decline of systemic arterial compliance and the rise of systolic blood pressure in the middle-aged and the elderly. These studies examine the effects of the total energy consumption per day produced by physical activity. However, effects of physical activity need to be assessed not only from physical activity volume but from the intensity of the exercise as well. Exercise intensity for the middle-aged and the elderly should be moderate, rather than intense, considering the safety of exercises. LaMonte, et al., (2001), by examining the risk of physical activity of ischemic heart disease patients at different levels of exercise intensity, report that the risk is low in patients who regularly conduct moderate or high intensity exercises than patients who conduct low intensity exercises. This seems to suggest that moderately intense exercises are effective in preventing ischemic heart diseases. However, mild leasure sports activities do not have any significant effects on central artery compliance (Tanaka, et al., 2000). Kakiyama, et al., (1998b) examine aortic pulse wave velocity, which is a central artery’s stiffness index, by comparing people who do not perform intense sports activities with people who are regularly engaged in vigorous sports activities, while sub-dividing the former group of people, or people with little intense sports activities, into two types: those with lots of daily physical activity and those with little daily physical activity. The results suggest that the subjects whose physical activity volume is high, most of whom enjoy sports as leisure, have faster aortic pulse wave velocity than the subjects with vigorous sports activities, but their aortic pulse wave velocity is slower, to a significant degree, than the subjects with little physical activities. In conclusion, regarding mild to moderate intensity exercises, there is no agreement so far on how it affects central arteries’ distensibility/compliance, or systemic arterial compliance.

This study aims at examining effects of daily physical activities at different levels of intensity on systemic arterial compliance. The research hypothesis is that mild to moderate intensity of physical activities can improve, to a significant degree, systemic arterial compliance, independent from total physical activity volume and intensity. The method used to examine the hypothesis is a multivariate analysis, with 413 male and female subjects of middle-aged and elderly, which include some at risk of atherosclerosis.

2. Method

2.1. Subjects

The subjects are comprised of 413 middle-aged and elderly people, from 46 to 85 (66.1±7.0) years old (149 males and 264 females). All female subjects are in the post-menopausal period. People on constant medication and/or having a smoking habit are not included as subjects. The study was approved by the Ethical committee of the Institute of Health and Sport Sciences of the University of Tsukuba. The study was also conducted in accordance with the Declaration of Helsinki, and all subjects gave their written informed consent before inclusion in the study.
2.2. Experimental protocol and measurements

2.2.1. Systolic and diastolic blood pressures
In this study, to measure blood pressure, a non-invasive blood pressure waveform measurement apparatus called PORTAPRE (TNO-TPD: Biomedical Instrumentation Co. Ltd.), and a regression analysis program called Beatscope were used. PORTAPRE and Beatscope use a newly developed system that continuously monitors blood pressure and per-beat stroke volume, and convert minute change of volume caused by blood current fluctuation to blood pressure waveforms by a volume-clamp method. The waveforms obtained in this way were corrected to the upper arm arteries’ blood pressure waveforms and pressure values, with the application of a transfer function accounting for age (Bos, et al., 1996; Gizdulich, et al., 1996; Stergiopulos, et al., 1998).

The blood pressure waveforms were continuously recorded for one minute while the subjects wore the PORTAPRES cuff around their finger in a sitting position after having a 30-minute rest in the same position. The height of the finger position was automatically corrected by the height correction system built in the apparatus. The mean values of five beats whose waveforms were in stable condition were used as values of systolic and diastolic blood pressures, as in Tanabe, et al., (2003; 2004).

2.2.2. Systemic arterial compliance
This study calculates systemic arterial compliance based on per-beat stroke volume and the blood pressure waveform by using the Area-method (Liu, et al., 1986), which is shown as Equation 1 below. Although systemic arterial compliance, equivalent to the compliance of the arteries of the whole body, is considered to be contributed to as much as 60% by the core aorta which is comprised of the ascending aorta and the arcus aorta (Stergiopulos, et al., 1999), the addition of the descending aorta, the abdomen aorta, and the carotid arteries to the core aorta as part of the central arteries, will make their contribution rate to systemic arterial compliance even higher.

\[
SAC = \frac{SV}{K(Ps-Pd)} \quad \therefore K = \frac{(Ad+As)}{Ad}
\]  

(Equation 1)

As: Area under the wave of systolic blood pressure  
Ad: Area under the wave of diastolic blood pressure  
Ps: Systolic blood pressure  
Pd: Diastolic blood pressure

Under this method, systemic arterial compliance is calculated firstly by separating blood pressure waveforms between those in the systolic period and in the diastolic period, by way of the dicrotic knoch method, and then by estimating blood flow volume from the change of blood pressure volume in the diastolic period. In Liu, et al., (1986), stroke volume is measured by the Doppler method and the aorta’s blood pressure waveform is recorded as the blood pressure waveform. Cameron and Dart (1994) and Kingwell, et al., (1997) measure systemic arterial compliance by recording the blood pressure waveform non-invasively with a Tonometry sensor placed on the carotid arteries. This study, as an easier method than these, uses PORTAPRES, a non-invasive blood pressure waveform measurement apparatus, to obtain the blood pressure waveform and per-beat stroke volume. The validity of measuring the pressure waveforms at the fingertip while the subjects are at rest is reported in Parati, et al., (1989). Also, the validity of converting the finger artery blood pressure waveform to the upper arm artery blood pressure waveform by way of the communication function in order to calculate systemic arterial compliance is reported in Otsuki, et al., (2003a, b). The use of blood pressure waveforms as a way of estimating the per-beat stroke volume by applying pulse-contour techniques is supported in Kawano, et al., (1994). In this study, the measurement value is equal to the mean value of the five-stroke volume whose blood pressure waveforms are in stable condition being measured after having ample rest. Systemic arterial compliance, affected by the physical build of a person (Ohtsuk, et al., 1996), is calculated as systemic arterial compliance per surface area, first by determining the surface area (S) in the equation: 

\[
S = W^{0.425} \times H^{0.725} \times 0.007184 \] (Du Bois, et al., 1989), and then by subtracting from the S the systemic arterial compliance value determined in Equation 1 above.

2.2.3. Daily physical activity and physical active time
Daily physical activity is assessed with the Lifecorder (Suzuken Co. Ltd.), a walking counter equipped with a multiple-memory velocity sensor. With this apparatus, daily physical activity volume is calculated every four seconds by way of the estimated equation, based on physical activity intensity determined from the detected velocity
and the height, weight and age of the person. The apparatus allows the estimation of consumed calories at different levels of exercise intensity, ranging from very low to relatively high (1 to 10 METs), and the use of estimated calorie consumption for the calculation of physical activity volume has been verified in comparisons with other measurement methods, such as the Doubly-labelled water and the breath-by-breath (Bassett, et al., 2000, Kumahara, et al., 2004). The duration in which the subjects wear the Lifecorder walking counter is two consecutive weeks. Of the two weeks, data on one week’s physical activity are used to calculate per-day physical activity. The calculation is made after subtracting water sports and sleeping time from the physically active time, by referring to diaries kept by the subjects. To examine the effects of physical activity on systemic arterial compliance, this study categorized physical activity intensity into three levels: light (less than 3 METs); mild to moderate (3 to less than 6 METs); and vigorous (6 METs and above), and calculated the per-day physically active time at each intensity level. The diaries that the subjects kept when wearing the Lifecorder indicated that they were not engaged in water sports or highly intensive sports activities, during which the Lifecorder cannot estimate the volume of physical activity. Taking into account that the body build of the person affects physical activity volume, this paper assesses physical activity volume as the consumed calories per unit weight.

2.2.4. Blood analysis

Following the recording of the blood pressure waveform, blood samples were taken from the cubital vein of the subjects, who had fasted more than twelve hours over the previous night. The blood was then tested for atherosclerosis risk factors such as: total cholesterol (T-C), HDL cholesterol (HDL-C), triglyceride (TG), and fasting glucose. LDL cholesterol is calculated in the equation: (LDL-C) = (TC) – (HDL-C) – (TG/3).

2.3. Statistical analysis

Measurement values are expressed as means ± SD. With a simple correlation analysis, relations of two variables are examined to determine Pearson’s correlation coefficient. Significance of the correlation coefficient is tested with the Fisher r to z conversion. In order to assess the effects of different exercise intensities on systemic arterial compliance, a multiple regression analysis was conducted by using systemic arterial compliance as the dependent variable, and per-day activity time at each physical activity intensity and age as independent variables. As for differences at each variable between the subjects with more than 30 minutes physical activity and the subjects with less than 30 minutes physical activity, they were tested with a non-corresponding t test, at each level of activity intensity. Also, the two groups were compared by a covariance analysis, which uses systemic arterial compliance as the dependent variable and age and per-day physical activity as co-variable quantities.

The statistical analyses in this study were conducted with Stat View 5.0 for Windows (Hulinks Co. Ltd.), and the statistically significant standard was set at less than 5% in each test.

3. Results

Table 1 shows the mean values of tested items each: systemic arterial compliance, daily physical activity, age, systolic blood pressure, and arteriosclerosis risk factors, for the 413 middle-aged and elderly subjects. Table 2 shows simple correlations coefficients between these tested items. Between systemic arterial compliance and daily physical activity, a positive correlation of significant degree is indicated (r = 0.19, p<0.01), and between systemic arterial compliance and the age, a negative correlation of significant degree is indicated (r = -0.19, p<0.01). Daily physical activity decreases with age (r = -0.18, p<0.05) and systolic blood pressure increases with age (r = 0.18, p<0.01). Between systolic blood pressure and systemic arterial compliance, a negative correlation of significant degree was observed (r = -0.28, p<0.01). The higher the daily physical activity, the lower the systolic blood pressure, though not to a statistically significant degree (r = -0.08, p=0.15). Between atherosclerosis risk factors and systemic arterial compliance, there is no indication of a significant relation.

From the multiple regression analysis conducted with systemic arterial compliance as the dependent variable and per-day physical active time and age as the independent variables, the following results emerged: Between the physically active time at the mild to moderate exercise intensity (3 to 6 METs)
Table 1  Subjects’ characteristics for the cross-sectional study

<table>
<thead>
<tr>
<th></th>
<th>All Subject (n=413)</th>
<th>male (n=149)</th>
<th>female (n=264)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age [yrs]</td>
<td>63 ± 8</td>
<td>62 ± 7</td>
<td>64 ± 7</td>
</tr>
<tr>
<td>SBP [mmHg]</td>
<td>126 ± 20</td>
<td>126 ± 23</td>
<td>128 ± 23</td>
</tr>
<tr>
<td>SAC [ml/mmHg/cm²]</td>
<td>1.17 ± 0.4</td>
<td>1.05 ± 0.4</td>
<td>1.23 ± 0.5</td>
</tr>
<tr>
<td>DPA [kcal/day]</td>
<td>201 ± 130</td>
<td>274 ± 204</td>
<td>174 ± 90</td>
</tr>
<tr>
<td>HDL-C [mg/dl]</td>
<td>61.9 ± 14.8</td>
<td>61.3 ± 14.8</td>
<td>62.1 ± 14.8</td>
</tr>
<tr>
<td>LDL-C [mg/dl]</td>
<td>112.7 ± 31.8</td>
<td>112.3 ± 31.1</td>
<td>112.2 ± 31.6</td>
</tr>
<tr>
<td>TG [mg/dl]</td>
<td>112.9 ± 31.7</td>
<td>103.1 ± 37.0</td>
<td>112.3 ± 28.3</td>
</tr>
<tr>
<td>Glucose [mg/dl]</td>
<td>101 ± 24</td>
<td>104 ± 28</td>
<td>99 ± 21</td>
</tr>
<tr>
<td>Physically active time (3METs ≤ x &lt; 4METs) [min]</td>
<td>49.5 ± 21.6</td>
<td>53.9 ± 18.0</td>
<td>46.5 ± 25.4</td>
</tr>
<tr>
<td>Physically active time (6METs ≤ x) [min]</td>
<td>17.7 ± 24.0</td>
<td>12.4 ± 14.3</td>
<td>25.6 ± 32.2</td>
</tr>
</tbody>
</table>

SBP: systolic blood pressure, SAC: systemic arterial compliance, DPA: daily physical activity, HDL-C: high density lipoprotein cholesterol, LDL-C: low density lipoprotein cholesterol, TG: triglyceride

Table 2  Simple correlation coefficient matrix between variables

<table>
<thead>
<tr>
<th></th>
<th>SBP</th>
<th>SAC</th>
<th>DPA</th>
<th>Age</th>
<th>LDL-C</th>
<th>HDL-C</th>
<th>TG</th>
<th>Glucose</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBP</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAC</td>
<td>-0.28**</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DPA</td>
<td>-0.07</td>
<td>0.19**</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>0.18*</td>
<td>-0.19**</td>
<td>-0.18**</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDL-C</td>
<td>0.02</td>
<td>0.08</td>
<td>0.07</td>
<td>0.07</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDL-C</td>
<td>-0.03</td>
<td>-0.06</td>
<td>0.01</td>
<td>-0.12*</td>
<td>-0.01</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TG</td>
<td>0.05</td>
<td>0.05</td>
<td>-0.04</td>
<td>0.03</td>
<td>-0.11*</td>
<td>-0.38**</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Glucose</td>
<td>0.06</td>
<td>-0.07</td>
<td>-0.04</td>
<td>0.19*</td>
<td>-0.04</td>
<td>0.06</td>
<td>0.16</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**: p<0.01, *: p<0.05

Table 2 shows the mean values of tested items and systemic arterial compliance, some statistically significant facilitating effects are indicated (standard regression coefficient: 0.19); between the physically active time at the low exercise intensity (less than 3 METs) and systemic arterial compliance, there is no indication of significant correlation (standard regression coefficient: -0.10); between the physically active time at the high exercise intensity (more than 6 METs) and systemic arterial compliance, there are minus correlations, though not to a statistically significant degree (standard regression coefficient: -0.12, p=0.07). Between age and SAC, there are independent minus correlations to a significant degree (standard regression coefficient: -0.24).

Table 3 shows the mean values of tested items during more than 30 minutes physically active time and less than 30 minutes physically active time at each exercise intensity. It indicates that only at the mild to moderate exercise intensity, systemic arterial compliance indicates significant differences between the two different physically active times. Comparison of systemic arterial compliance between the ≥30 minutes per-day physical active time group (319 subjects) and the <30 minutes group (94 subjects) at mild to moderate physical activity intensity (3 to 6 METs) was conducted by applying a covariance analysis, while using the total physical activity by age and per-day total physical activity as covariable quantities. The analysis indicates that the systemic arterial compliance of the ≥30 minutes...
activity group is significantly higher than that of the <30 minutes group (Figure 1). At the time of high physical activity intensity (≥6 METs), there are no differences in systemic arterial compliance between the ≥30 minutes per-day physical activity group (126 subjects) and the <30 minutes activity group (287 subjects). Among the 321 subjects who are engaged in 3 to 6 METs physical activity for ≥30 minutes a day, those who are engaged in the >6 METs activity for <30 minutes total 193, which indicates that most of the subjects are not engaged in high intensity physical activities, but rather in moderate intensity exercises. The systemic arterial compliance of the subjects engaged in 3 to 6 METs physical activity a day is significantly higher than that for <30 minutes exercise, even comparing them by using age and ≥6 METs per-day physical activity as covariable quantities (p<0.05). In a similar comparison for elderly people 65 years old and over (235 subjects), the subjects conducting 3 to 5 METs exercise intensity for ≥30 minutes (166 subjects) have significantly higher systemic arterial compliance than those conducting <30 minutes (69 subjects).
4. Discussion

This study has tested the hypothesis that mild to moderate intensity of physical activity significantly improves systemic arterial compliance, independent from the volume of total physical activity and vigorousness of the activity. The findings suggest that systemic arterial compliance is affected not only by volume of physical activity but also by its intensity. There is no indication of significant effects from low intensity activity, but moderate, or 3 to 6 METs, intensity physical activity has some improving effects on systemic arterial compliance.

This study objectively assesses daily physical activity volume and physical activity intensity of middle-aged and elderly people by using a calorie meter called the Lifecorder. Some significant relations between daily physical activity volume and arterial distensibility or compliance are already suggested in previous studies such as Kakiyama, et al., (1998a; 1998b) and Tanaka, et al., (2000), based on estimation by way of questionnaire and similar methods. In our previous studies, by targeting the middle-aged and the elderly (Tanabe, et al., 2003; 2004), and using the Lifecorder as a method that provides more objective estimation of the physical active volume, as is the case with this study, we suggest that with the increase of daily physical active volume, systemic arterial compliance increases and the rise of systolic blood pressure is better contained. Regarding the use of the Lifecorder as a method to estimate physical activity volume, it is verified through comparisons with other methods such as the Doubly-labelled water and the breath-by-breath analysis techniques (Bassett, et al., 2000; Kumahara, et al., 2004). Therefore its use in this study seems justified as a method to objectively observe the daily physical activity of the middle-aged and elderly and to make a comparison. There is a drawback, however, that the Lifecorder overestimates walking activity volume, and underestimates calorie consumption from upper-body activities (Bassett, et al., 2000). Although this study makes sure that the data of the Lifecorder does not include water sports and highly intensive sports activity volume, which cannot be measured by the Lifecorder, and refers instead to the subjects’ diaries, its tendency of underestimating upper body activity and bicycling volume are not changed, and this poses a limitation to the study.

Recommendations issued from the American College of Sports Medicine (Pate, et al., 1995) and a statement from the American Heart Association (Eyre, et al., 2004) suggest that middle-aged and elderly people conduct exercise of moderate intensity (3 or 4 to 6 METs) regularly for more than 30 minutes a day for the prevention of arteriosclerosis. When prescribing exercise programs for the middle-aged and elderly, exercise intensity should be as low as possible in terms of safety, but it needs to be high enough to produce some effects. This makes the proper setting of exercise intensity very important. In this study that covers the middle-aged and elderly, low intensity physical activity is set at less than 3 METs, moderate intensity at 3 METs to 6 METs, and high intensity at more than 5 METs. Additionally, the multiple regression analysis is conducted by using as independent variable the physical activity time at each exercise intensity that is measured objectively with the use of a calorie meter. The results show that the physical activity time at moderate intensity exercise significantly correlates with systemic arterial compliance. This means that the longer the physical activity time at moderate intensity exercise, the higher the systemic arterial compliance becomes with increasing significance. From the covariance analysis using age and per-day physical activities as co-variable quantities, it is indicated that the subjects with moderate exercise intensity for more than 30 minutes a day have significantly higher systemic arterial compliance than those with less than 30 minutes of activity time. The finding seems to suggest the possibility that moderate intensity exercise has positive effects on systemic arterial compliance to a significant degree, independent from age and the total sum of physical activity volume. Among the subjects with 3 to 6 METs physical activity for more than 30 minutes a day (321 subjects), 193 conduct more than 6 METs physical activity for less than 30 minutes. The regression analysis using high intensity activity volume and age as covariable quantities also indicates that the systemic arterial compliance of the subjects with more than 30 minutes activity time is significantly higher than those with less than 30 minutes activity time. Thus, it can be concluded that even if high intensity activity time is short, a sufficient length of moderate intensity activity time can provide positive effects on systemic arterial compliance, to a significant degree. In the regression analysis
focusing on elderly people more than 65 years old, it was found that those with 3 to 6 METs intensity physical activity for more than 30 minutes (166 subjects) have significantly higher systemic arterial compliance than those with less than 30 minutes activity time (69 subjects). This indicates that elderly people may benefit from lighter intensity exercise. This study is cross-sectional, but Kakiyama, et al., (2001) reports that a six-month moderate intensity training to improve staying power has produced some significant effects of decelerating aortic pulse wave velocity of middle-aged and elderly women with no health problems. Thus, not necessarily high intensity exercise but mild to moderate intensity exercises, which can be performed by most middle-aged and elderly people easily and safely, seems to have an improving effect on central arterial distensibility or systemic arterial compliance.

However, examination of the exercise time at more than 6 METs intensity suggests some decreasing effects on systemic arterial compliance. Comparison between the subjects with more than 6 METs activity for more than 30 minutes (166 subjects) and those with less than 30 minutes (69 subjects) indicates no significant differences between them. These findings contradict findings in previous studies such as Tanaka, et al., (2000) and Kakiyama, et al., (1998b), which suggest that central arterial compliance or stiffness of people who are regularly engaged in highly insensitive sport activities is significantly higher than not only the least physically active people but also people who often participate in leisurely sport activities. Clarification of such contradiction is difficult, but part of the reason may be that this study does not include subjects who engaged themselves in intensive sports activities, and that few subjects perform more than 6 METs physical activities for more than 30 minutes.

This study indicates that the effects of daily physical activity on the increase of arterial compliance of middle-aged and elderly people depend not only on the total physical activity volume but also on the intensity of the activity, and that mild intensity activities may be effective for that purpose. Although cross-sectional, this study has suggested that most middle-aged and elderly people can increase their arterial compliance safely and easily by conducting moderate intensity exercises and daily physical activities. This seems to provide some potential area to be explored for the benefit of the highly aging Japanese society.

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