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Long-term physical activity is associated with reduced arterial stiffness in older adults: longitudinal results of the SAPALDIA cohort study

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Abstract

Background: longitudinal analyses of physical activity (PA) and arterial stiffness in populations of older adults are scarce. We examined associations between long-term change of PA and arterial stiffness in the Swiss Cohort Study on Air Pollution and Lung and Heart Diseases in Adults (SAPALDIA).
Methods: we assessed PA in SAPALDIA 2 (2001–03) and SAPALDIA 3 (2010–11) using a short questionnaire with a cut-off of at least 150 min of moderate-to-vigorous PA per week for sufficient activity. Arterial stiffness was measured oscillometrically by means of the brachial-ankle pulse wave velocity (baPWV) in SAPALDIA 3. We used multivariable mixed linear regression models adjusted for several potential confounders in 2,605 persons aged 50–81.
Results: adjusted means of baPWV were significantly lower in persons with sufficient moderate-to-vigorous PA (i) in SAPALDIA 2 but not in SAPALDIA 3 ($P = 0.048$) and (ii) in both surveys ($P = 0.001$) compared with persons with insufficient activity in both surveys. There was a significant interaction between sex and the level of change in PA concerning baPWV ($P = 0.03$). The triples of parameter estimates describing the association between level of PA change and baPWV were not significantly different between the two sex-specific models ($P = 0.07$).
Conclusions: keeping up or adopting a physically active lifestyle was associated with lower arterial stiffness in older adults after a follow-up of almost a decade. Increasing the proportion of older adults adhering to PA recommendations incorporating also vigorous PA may have a considerable impact on vascular health at older age and may contribute to healthy ageing in general.

Keywords: *arterial stiffness, cardiovascular disease, longitudinal, physical activity, pulse wave velocity, older people*

Introduction

Early vascular ageing is a major determinant of increased cardiovascular (CV) risk [1]. Structural changes of the arterial system related to advanced ageing such as accelerated thickening of the arterial wall, degeneration of elastin and collagen proliferation are associated with higher arterial stiffness [2]. The velocity of the pulse waves propagating along the arterial wall is a measure of stiffening of the vasculature and increased CV risk [3]. Increased arterial stiffness was found to be independently associated with increased CV risk and CV events, as well as all-cause and CV mortality [4, 5]. Furthermore, arterial stiffness is an important surrogate end point of CV disease, because it reflects not only target organ damage but also

pathological processes and underlying risk factors connected with vascular ageing [3, 5].

Lack of physical activity (PA) is a well-documented risk factor for CV disease [6, 7] and one of the main components of the global burden of disease [8]. PA has been shown to be a modifiable lifestyle factor with the potential to decelerate vascular ageing and arterial stiffness in short-term interventional studies up to 16 weeks including persons aged 18–72 [9]. A physically active lifestyle throughout life has protective effects on the vasculature and the risk of CV events also in older adults with accelerated vascular modifications [10]. In cross-sectional population-based studies of older adults, PA at both light and moderate-to-vigorous intensity was beneficially associated with lower arterial stiffness compared with inactive persons [11–13].

There are no longitudinal population-based studies of PA and arterial stiffness measured as brachial-ankle pulse wave velocity (baPWV) in older adults. baPWV is correlated with higher risk of CV events and all-cause mortality [14]. In 274 overweight young adults, a 1-year increase in moderate PA was associated with lower baPWV, suggesting a reduction of future CV risk [15]. On the basis of this lack of longitudinal evidence in ageing populations, the present study aimed at examining the associations of long-term PA and change of PA with arterial stiffness in a cohort of community-dwelling adults aged 50–81. The main question was whether even older adults benefit from adopting a physically active lifestyle in terms of lower arterial stiffness and CV risk in the long term.

Methods

Study design and participants

The Swiss Cohort Study on Air Pollution and Lung and Heart Diseases in Adults (SAPALDIA) is an ongoing multicentre cohort study initiated in 1991 among randomly selected adults (18–65 years, $n = 9{,}651$) [16]. The present analyses include all participants who gave information on their PA behaviour in SAPALDIA 2 (year 2001–03) and SAPALDIA 3 (year 2010–11) and participated in the arterial stiffness measurements in SAPALDIA 3 ($n = 2{,}605$). Participants gave written informed consent, and the respective Swiss cantonal ethical committees had granted ethical approval.

Arterial stiffness measurement

Arterial stiffness was measured oscillometrically in SAPALDIA 3 by the baPWV using a VaSera VS-1500N vascular screening system (Fukuda Denshi, Tokyo, Japan). The reproducibility of this measurement has been shown to be high with a mean coefficient of variation of 3.9% in the studied population [17]. All measurements were performed in a quiet room with constant temperature in supine position after 10 min of rest. A detailed description of this measurement has been reported previously [17]. In brief, blood cuffs were placed at each upper arm and above each ankle. ECG electrodes at each wrist and a phonocardiogram on the sternal border in the second intercostal space were attached. PWV was calculated automatically by the VSS-10 software (Fukuda Denshi) by dividing the arterial length between the sites of interest on the basis of a height-based formula by the time delay of the pulse wave determined by a foot-to-foot method.

Physical activity assessment

The same short self-reported PA questionnaire was administered to classify the participants' PA level in SAPALDIA 2 and SAPALDIA 3 [18]. Four questions were asked regarding the frequency and duration of PA per week. PA associated with getting a bit out of breath was categorised as moderate intensity PA and with getting out of breath and sweating as vigorous intensity PA. We calculated minutes per week of moderate and vigorous PA and summed these two to moderate-to-vigorous PA, whereby minutes derived from vigorous PA were counted twice [19]. Participants with at least 150 min/week of moderate-to-vigorous PA or at least 1 h of vigorous PA were categorised as active, both in SAPALDIA 2 and in SAPALDIA 3, and participants with less as inactive [19]. The participant's change of PA from SAPALDIA 2 to SAPALDIA 3 was categorised as follows: (i) as remaining inactive if the participant was inactive in both assessments, (ii) as becoming inactive if active in SAPALDIA 2 but inactive in SAPALDIA 3, (iii) as becoming active if inactive in SAPALDIA 2 but active in SAPALDIA 3 and (iv) as remaining active if active in SAPALDIA 2 and 3.

Co-variates

Age at the time of the SAPALDIA 3 baPWV assessment and sex were taken as primary co-variates. Change of body mass index (BMI [kg/m^2]) was calculated as BMI of SAPALDIA 3 minus BMI of SAPALDIA 2. Heart rate, diastolic and systolic blood pressure were measured in sitting position after 10 min of rest in SAPALDIA 2 and 3 (Omron 705IT, Omron Healthcare, Japan). Mean arterial pressure was calculated as mean arterial pressure = [(2 × diastolic blood pressure) + systolic blood pressure]/3. Medication was assessed by a self-administered questionnaire in SAPALDIA 3 and coded as 0, for no medication intake; 1, for hyperlipidaemia, kidney disease and hypertensive medication; 2, for diabetes, arrhythmia, myocardial infarction, heart failure and stroke medication. Socioeconomic status was assessed by the maximal level of education in SAPALDIA 2 and 3 (low: primary school; middle: secondary school, middle school or apprenticeship; high: Technical College or University). Pack-years of cigarettes smoked were calculated in SAPALDIA 2 and 3.

Statistical analyses

Unless stated otherwise, data are expressed as mean (standard deviation [SD]). Sex differences in the variables were assessed using *t*-tests or non-parametric Wilcoxon–Mann–Whitney tests as appropriate. We analysed the association between long-term change in PA from SAPALDIA 2 to SAPALDIA 3 and arterial stiffness in SAPALDIA 3 using multivariable mixed linear regression models. Based on the literature and previous

analyses in this cohort, we pre-selected potential confounding co-variates. Co-variates were considered as potential confounders if the *P*-value of their association with the respective outcome was <0.2. We used backward selection of variables using the Akaike Information Criterion (AIC) and tested non-linear terms to derive the best fitting model. We tested a set of interaction terms between PA, age, sex and mean arterial pressure to be included in the final model if $P < 0.1$. The fully adjusted model included age, sex, mean arterial pressure, heart rate, change of BMI, pack-years of cigarettes smoked, educational level, medication intake and an interaction term between change of PA and sex as fixed effects, and study area as random effect to account for the multi-centre study setting. Chi-square tests were used to compare effect estimates of sex-stratified analyses. All statistical analyses were performed using the statistical software STATA (StataCorp LP, USA) with $P < 0.05$ defining statistical significance.

Results

The mean follow-up time was 8.3 (SD 0.5) years. The final analytic sample consisted of 2,605 participants with complete data. In SAPALDIA 3, the cohort was on average 63.4 (SD 8.0) years old with 50.7% of them being females, mean BMI 26.3 (SD 4.3) kg/m^2, had a mean arterial pressure of 99.7 (SD 11.5) mmHg and a mean baPWV of 13.8 (SD 2.5) m/s. Among them, 74.0% were sufficiently active with at least 150 min of moderate-to-vigorous PA in SAPALDIA 2 and 75.1% in SAPALDIA 3. The main characteristics by sex and PA level for SAPALDIA 2 and 3 are listed in Tables 1 and 2.

The mean of minutes per week of moderate PA was significantly higher by 23.9% in SAPALDIA 3 than in SAPALDIA 2 (median 180 [inter-quartile range 60, 360] versus 180 (60, 420) min/week, $P < 0.001$). Vigorous PA decreased significantly in all participants on average by 18% from SAPALDIA 2 to 3 (median 30 [inter-quartile range 0, 150] versus 30 (0, 60) min/week, $P < 0.001$). BMI (mean 25.7 [SD 4.0] versus 26.3 [SD 4.3] kg/m^2) and mean arterial pressure (mean 96.2 (SD 12.9) versus 98.1 (SD 12.1) mmHg (each $P < 0.001$) increased significantly in both sexes from SAPALDIA 2 to 3. Mean heart rate decreased from 70.0 (SD 10.2) to 69.2 (SD 10.3) bpm ($P < 0.001$).

baPWV was lower in persons with sufficient PA in one of the two or both SAPALDIA follow-ups compared with persons with insufficient PA in both assessments. In the entire cohort, covariate-adjusted means of baPWV were significantly lower in persons with sufficient moderate-to-vigorous PA (i) in SAPALDIA 2 but not in SAPALDIA 3 ($P = 0.048$) and (ii) in both surveys ($P = 0.001$) compared with persons with insufficient activity in both surveys (Figure 1).

There was a significant interaction between sex and the level of change in PA concerning baPWV ($P = 0.03$). The fully covariate-adjusted means of baPWV were significantly lower in men becoming active (13.8 m/s, $P = 0.04$) and in men remaining active (13.8 m/s, $P = 0.01$) compared with men remaining inactive (14.3 m/s). In females with sufficient activity in SAPALDIA 2 but not in SAPALDIA 3 (13.6 m/s, $P = 0.02$) and in females remaining active (13.7 m/s, $P = 0.03$), the fully covariate-adjusted means of baPWV were significantly lower compared with females remaining inactive (13.9 m/s). Analyses stratified by sex confirmed these results. The triples of parameter estimates describing the association between level of PA change and baPWV were not significantly different between the two sex-specific models ($P = 0.07$).

Discussion

Key findings

In this longitudinal cohort study of older adults, adoption or maintenance of a physically active lifestyle over an average time of 8.3 years was associated with lower arterial stiffness in males and in females later in life. As our analyses were adjusted for several potential confounders, this is suggestive of an independent association. In the total study population, individuals with insufficient PA in both surveys had higher CV risk in terms of higher arterial stiffness compared with persons with sufficient PA in at least one of the two surveys.

Previous cross-sectional studies of adults aged 60 years and older have shown that a higher amount of regular PA of light and moderate-to-vigorous intensity was associated with lower aortic stiffness measured as carotid-femoral pulse wave

Table 1. Main characteristics by sex and moderate-to-vigorous physical activity (PA) level in SAPALDIA 2

	Units	Female (n = 1,316)		*P* value	Male (n = 1,289)		*P* value
		Inactive	Active		Inactive	Active	
n (%)		377 (28.6)	939 (71.4)		299 (23.2)	990 (76.8)	
Age	Mean (SD) years	54.7 (7.7)	55.5 (8.2)	0.10	55.4 (7.7)	55.0 (8.0)	0.49
BMI	Mean (SD) kg/m^2	25.3 (4.4)	24.7 (4.2)	<0.05	27.0 (3.3)	26.4 (3.4)	<0.05
MAP	Mean (SD) mmHg	92.4 (11.8)	92.3 (12.5)	0.85	100.8 (11.8)	99.8 (12.5)	0.20
Heart rate	Mean (SD) bpm	71.1 (9.5)	70.2 (9.6)	0.12	71.3 (10.2)	68.8 (10.8)	<0.001
Smoking	Median (p25, p75) pack-years	1 (0, 18)	0.4 (0, 17)	0.65	3.8 (0, 21)	0 (0, 16)	0.005
Education	*n* (%)						
Low		39 (9)	55 (6)	0.30	20 (5)	22 (2)	
Middle		307 (71)	651 (74)		221 (60)	534 (58)	
High		85 (20)	179 (20)		126 (35)	366 (40)	<0.05
Moderate PA	Median (p25, p75) min/week	15 (0, 60)	240 (120, 420)	<0.001	5 (0, 60)	225 (120, 420)	<0.001
Vigorous PA	Median (p25, p75) min/week	0 (0, 0)	60 (0, 150)	<0.001	0 (0, 0)	60 (30, 150)	<0.001

BMI, body mass index; MAP, mean arterial pressure; p25, 25th percentile; p75, 75th percentile. *P* values relate to sex-specific differences between active and inactive persons.

Table 2. Main characteristics by sex and moderate-to-vigorous physical activity (PA) level in SAPALDIA 3

	Units	Female (n = 1,316)		P value	Male (n = 1,289)		P value
		Inactive	Active		Inactive	Active	
n (%)		371 (28.2)	945 (71.8)		277 (21.5)	1,012 (78.5)	
Age	Mean (SD) years	63.8 (8.5)	63.5 (7.8)	0.59	62.8 (8.4)	63.7 (7.7)	0.08
BMI	Mean (SD) kg/m^2	26.0 (4.9)	25.2 (4.5)	<0.05	27.6 (4.0)	27.0 (3.6)	<0.05
baPWV	Mean (SD) m/s	13.8 (2.6)	13.7 (2.4)	0.56	14.2 (2.6)	13.9 (2.4)	0.11
MAP	Mean (SD) mmHg	95.7 (12.3)	96.2 (12)	0.45	100.3 (11.4)	100.3 (11.9)	0.93
Heart rate	Mean (SD) bpm	70.5 (10.1)	69.0 (9.3)	<0.05	70.9 (10.4)	68.2 (11.2)	<0.001
Smoking	Median (p25, p75) pack-years	0.2 (0, 16.8)	0 (0, 11)	<0.05	3.8 (0, 30.5)	5 (0, 26)	0.73
Medication	n (%)						
0		259 (64)	655 (72)	<0.05	168 (51)	561 (58)	
1		113 (28)	204 (22)		115 (35)	275 (29)	
2		31 (8)	54 (6)		45 (14)	125 (13)	<0.05
Education	n (%)						
Low		46 (11)	48 (5)	<0.05	16 (5)	26 (3)	
Middle		281 (70)	677 (74)		189 (58)	566 (59)	
High		76 (19)	188 (21)		123 (37)	369 (38)	<0.05
Moderate PA	Median (p25, p75) min/week	0 (0, 60)	270 (180, 420)	<0.001	0 (0, 60)	300 (180, 540)	<0.001
Vigorous PA	Median (p25, p75) min/week	0 (0, 0)	60 (0, 150)	<0.001	0 (0, 0)	60 (30, 150)	<0.001

BMI, body mass index; MAP, mean arterial pressure; Medication 0, for no medication intake; 1, for hyperlipidaemia, kidney disease, hypertension and arrhythmia medication; 2, for diabetes, myocardial infarction, heart failure and stroke medication. p25, 25th percentile; p75, 75th percentile. P values relate to sex-specific differences between active and inactive persons.

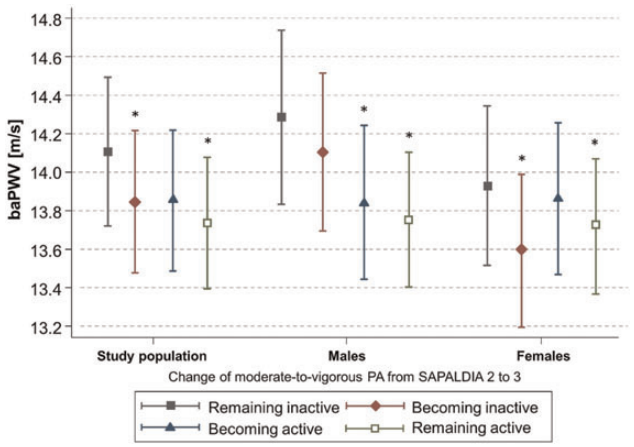

Figure 1. Fully co-variate-adjusted means of baPWV across different levels of change in moderate-to-vigorous physical activity (PA) from SAPALDIA 2 to 3, by sex. Underlying models included age, change of body mass index, mean arterial pressure, heart rate, education, medication, pack-years of cigarettes smoked and an interaction term between sex and change of PA as fixed effects and study area as random effect. *Statistically significant compared with remaining inactive.

velocity [11, 12]. In addition, physical functioning in terms of walking speed was inversely related to aortic stiffness in older adults of the Whitehall II Study in a cross-sectional analysis [20]. The American Heart Association defined regular PA of at least 150 min of at least moderate intensity PA per week as one component of a so-called ideal CV health behaviour [21]. In a 4- to 5-year follow-up among 505 Caucasian persons with a mean age of 61.6 years, adherence to a lifestyle complying with all of the components of an ideal CV health was associated with significantly lower carotid-femoral pulse wave velocity compared with persons with a maximum of two of these CV health components [22]. The independent contribution of long-term PA and change of PA apart from other health behaviours was not assessed in this study. There is one longitudinal interventional study in 198 Japanese aged 65–84 years, which showed that maintenance of a physically active lifestyle over 1 year with a step count of 6,600 steps/day and/or a total activity duration of 16 min/day at moderate-to-vigorous intensity was significantly associated with lower stiffness of central arteries compared with less active persons [23]. This has so far not been shown in a population-based longitudinal cohort study such as SAPALDIA.

The significant sex difference in baPWV is supposed to reflect the cardio-protective effect of hormonal levels, especially oestrogen through vasodilation and reduction of vascular tone [24]. Oestrogen enhances nitric oxide production by stimulation of endothelial nitric oxide synthase stimulation inducing vasodilation as the main suggested pathway [25]. Besides, oestrogen has been beneficially linked with reductions in blood pressure and deceleration of age-associated arterial stiffness in postmenopausal women [26]. It is suggested that the effect of oestrogen is influenced by age, with lower protective effect of oestrogen on the vasculature with longer time from menopause due to lower levels of oestrogen and number of oestrogen receptors [27]. The mostly postmenopausal females of our study population showed beneficial associations of long-term PA with arterial stiffness. The effect estimates were not significantly different between supposedly pre- and postmenopausal women, when taking into account age in SAPALDIA 2 and 3. Nevertheless, the inconsistent results within the females becoming active compared with males need further investigation.

Longevity has been found to be strongly associated with a healthy lifestyle in a population-based prospective study in

males with a mean age of 72 years [28]. Accordingly, in this study, older males with sufficient PA had an almost 30% lower mortality risk and a probability of 54% to live up to the age of 90 years if they were also non-smokers, non-diabetic, normotensive and had a normal weight profile at the age of 70 years. Furthermore, a recent systematic review has shown that an increase in baPWV by 1 m/s is not only associated with increased risk of CV events and CV mortality (12 and 13%, respectively), but also with a 6% increase in all-cause mortality [14]. Building on this, our study results strengthen the evidence that adoption of a physically active lifestyle has the potential to beneficially influence the vasculature in terms of lower arterial stiffness also in later life. This may reduce the risk of CV disease also in older adults having become physically active later in life, with positive effects on mortality and longevity.

Some study limitations need to be considered. Arterial stiffness measurement was only available in SAPALDIA 3. PA has not been assessed objectively because of logistic and financial reasons. However, the used short questionnaire is a valid instrument for population-wide PA assessments [18]. Attrition and selection bias might have affected the analyses, since only persons with full data on PA, arterial stiffness and co-variates were included in this study. However, the analysed sample was not different on average in terms of baPWV, BMI, mean arterial pressure and vigorous PA compared with the rest of the SAPALDIA 3 sample. The analysed sample was significantly older, smoked more and had lower mean arterial pressure and more moderate PA.

Conclusions and implications

In summary, this is the first longitudinal population-based cohort study showing that keeping up or adopting a physically active lifestyle was associated with lower arterial stiffness in older adults after a follow-up of almost a decade. These findings represent a useful basis for generating hypothesis that should be tested in large randomised controlled trials concerning the long-term effects and underlying pathways of PA, exercise training and long-term change towards a physically active lifestyle on arterial stiffness in older adults.

Key points

- Long-term physical activity was associated with reduced arterial stiffness.
- Adopting a physically active lifestyle was beneficial regarding arterial stiffness and cardiovascular risk also in older adults.
- RCTs on the long-term effects and underlying pathways of physical activity on arterial stiffness in older adults are recommended.

Supplementary data

Supplementary data mentioned in the text are available to subscribers in *Age and Ageing* online.

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Conflicts of interest

None declared.

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References

1. Nilsson PM, Lurbe E, Laurent S. The early life origins of vascular ageing and cardiovascular risk: the EVA syndrome. J Hypertens 2008; 26: 1049–57.
2. Najjar SS, Scuteri A, Lakatta EG. Arterial aging is it an immutable cardiovascular risk factor? Hypertension 2005; 46: 454–62.
3. Nilsson PM, Boutouyrie P, Laurent S. Vascular aging: a tale of EVA and ADAM in cardiovascular risk assessment and prevention. Hypertension 2009; 54: 3–10.
4. Mattace-Raso FUS, van der Cammen TJM, Hofman A *et al*. Arterial stiffness and risk of coronary heart disease and stroke: the Rotterdam Study. Circulation 2006; 113: 657–63.
5. Laurent S, Briet M, Boutouyrie P. Arterial stiffness as surrogate end point: needed clinical trials. Hypertension 2012; 60: 518–22.
6. Sattelmair J, Pertman J, Ding EL, Kohl HW, Haskell W, Lee I-M. Dose response between physical activity and risk of coronary heart disease a meta-analysis. Circulation 2011; 124: 789–95.
7. Lee CD, Folsom AR, Blair SN. Physical activity and stroke risk: a meta-analysis. Stroke 2003; 34: 2475–81.
8. Lee I-M, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. Lancet 2012; 380: 219–29.
9. Li Y, Hanssen H, Cordes M, Rossmeissl A, Endes S, Schmidt-Trucksäss A. Aerobic, resistance and combined exercise training on arterial stiffness in normotensive and hypertensive adults: a review. Eur J Sport Sci 2014; 0: 1–15.
10. Tanaka H, Dinenno FA, Monahan KD, Clevenger CM, DeSouza CA, Seals DR. Aging, habitual exercise, and dynamic arterial compliance. Circulation 2000; 102: 1270–5.
11. Gando Y, Yamamoto K, Murakami H *et al*. Longer time spent in light physical activity is associated with reduced arterial stiffness in older adults. Hypertension 2010; 56: 540–6.
12. Havlik RJ, Simonsick EM, Sutton-Tyrrell K *et al*. Association of physical activity and vascular stiffness in 70-to 79-year-olds: the health ABC study. J Aging Phys Act 2003; 11: 156–66.

13. McDonnell BJ, Maki-Petaja KM, Munnery M *et al*. Habitual exercise and blood pressure: age dependency and underlying mechanisms. Am J Hypertens 2013; 26: 334–41.
14. Vlachopoulos C, Aznaouridis K, Terentes-Printzios D, Ioakeimidis N, Stefanadis C. Prediction of cardiovascular events and all-cause mortality with brachial-ankle elasticity index: a systematic review and meta-analysis. Hypertension 2012; 60: 556–62.
15. Hawkins M, Gabriel KP, Cooper J, Storti KL, Sutton-Tyrrell KKriska A. The impact of change in physical activity on change in arterial stiffness in overweight or obese sedentary young adults. Vasc Med 2014; 19: 257–63.
16. Martin BW, Ackermann-Liebrich U, Leuenberger P *et al*. SAPALDIA: methods and participation in the cross-sectional part of the Swiss Study on Air Pollution and Lung Diseases in adults. Soz.-PräventivmedizinSocial Prev Med 1997; 42: 67–84.
17. Endes S, Caviezel S, Dratva J *et al*. Reproducibility of oscillometrically measured arterial stiffness indices: results of the SAPALDIA 3 cohort study. Scand J Clin Lab Invest 2015; 75: 170–76.
18. Shaaban R, Leynaert B, Soussan D *et al*. Physical activity and bronchial hyperresponsiveness: European Community Respiratory Health Survey II. Thorax 2007; 62: 403–10.
19. Federal Office of Sport FOSPO, Federal Office of Public Health FOPH, Health Promotion Switzerland *et al*. Health-Enhancing Physical Activity [Internet]. Magglingen: FOSPO; 2013 [cited 2015 Jan 4]. http://www.hepa.ch/internet/hepa/de/home/dokumentation/grundlagendokumente.html.
20. Brunner EJ, Shipley MJ, Witte DR *et al*. Arterial stiffness, physical function, and functional limitation: the Whitehall II Study. Hypertension 2011; 57: 1003–9.
21. Lloyd-Jones DM, Hong Y, Labarthe D *et al*. Defining and setting national goals for cardiovascular health promotion and disease reduction the American Heart Association's Strategic Impact Goal through 2020 and beyond. Circulation 2010; 121: 586–613.
22. Crichton GE, Elias MF, Robbins MA. Cardiovascular health and arterial stiffness: the Maine-Syracuse Longitudinal Study. J Hum Hypertens 2014; 28: 444–9.
23. Aoyagi Y, Park H, Kakiyama T, Park S, Yoshiuchi K, Shephard RJ. Yearlong physical activity and regional stiffness of arteries in older adults: the Nakanojo Study. Eur J Appl Physiol 2010; 109: 455–64.
24. Miller VM, Duckles SP. Vascular actions of estrogens: functional implications. Pharmacol Rev 2008; 60: 210–41.
25. Hisamoto K, Bender JR. Vascular cell signaling by membrane estrogen receptors. Steroids 2005; 70: 382–7.
26. Scuteri A, Lakatta EG, Bos AJ, Fleg JL. Effect of estrogen and progestin replacement on arterial stiffness indices in postmenopausal women. Aging Milan Italy 2001; 13: 122–30.
27. Vitale C, Mercuro G, Cerquetani E *et al*. Time since menopause influences the acute and chronic effect of estrogens on endothelial function. Arterioscler Thromb Vasc Biol 2008; 28: 348–52.
28. Yates LB, Djoussé L, Kurth T, Buring JE, Gaziano JM. Exceptional longevity in men: modifiable factors associated with survival and function to age 90 years. Arch Intern Med 2008; 168: 284–90.

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Use of a frailty index to identify potentially inappropriate prescribing and adverse drug reaction risks in older patients

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Abstract

Background: potentially inappropriate prescribing (PIP) is a significant problem in health care today. We hypothesise that if doctors were given a single indicator of PIP and adverse drug reaction (ADR) risk on a patient's prescription, it might stimulate them to review the medicines. We suggest that a frailty index (FI) score may be such a suitable indicator.