Peripheral Arterial Stiffness in Primary Aldosteronism

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Summary
Aldosterone overproduction increases arterial wall stiffness by accumulation of different types of collagen fibres and growth factors. Our previous studies showed that central (aortic) arterial stiffness is increased in primary aldosteronism (PA) independently of concomitant hypertension and that these changes might be reversible after successful adrenalectomy. There is limited data available on the potential impact of mineralocorticoid overproduction on the deterioration of peripheral arterial stiffness. The current study was thus aimed at investigating the effect of aldosterone overproduction on peripheral arterial stiffness assessed by peripheral (femoral-ankle) pulse wave velocity (PWV) in PA patients compared with essential hypertension (EH) patients. Forty-nine patients with confirmed PA and 49 patients with EH were matched for age, blood pressure, body mass index, lipid profile, and fasting glucose. PWV was obtained using the Sphygmocor applanation tonometer. Both peripheral and central PWV were significantly higher in PA patients compared to EH patients, while clinical blood pressures were similar. Plasma aldosterone level was the main predictor of peripheral PWV in PA. Our data indicate aldosterone overproduction in PA does not preferentially affect central arterial system. Fibroproliferative effect of higher aldosterone levels lead to alteration of central-elastic as well as peripheral-muscular arteries with subsequent increase in its stiffness.

Key words
Peripheral arterial stiffness • Primary aldosteronism • Peripheral pulse wave velocity

Introduction
Primary aldosteronism (PA) is characterized by the autonomous overproduction of aldosterone by the adrenal glands generally caused by adrenocortical adenoma or bilateral adrenal hyperplasia. The prevalence of PA in patients with any stage of hypertension varies from 5 to 15% (Funder et al. 2008, Mulatero et al. 2011, Rossi 2010, Takeda et al. 2011). We have previously shown that PA is the most frequent form of secondary hypertension with a prevalence of 19% in moderate to severe hypertension (Štrauch et al. 2003) among patients admitted to our hypertension unit.

Previous studies also indicated that patients with PA might be at higher cardiovascular risk than patients with essential hypertension (EH) (Catena et al. 2008). Increased left ventricular mass, significant impairment of diastolic dysfunction (Rossi et al. 1996), more frequent renal function impairment (Wu et al. 2011), increased intima-media thickness of common carotid arteries (Holaj et al. 2007), or impaired diurnal blood pressure variation (Zelinka et al. 2004) are all present more frequently in patients with PA than in EH.

Aldosterone overproduction leads to functional and structural changes of arterial system. Animal models demonstrate that aldosterone substantially contributes to
the accumulation of different types of collagen fibres and growth factors in vascular smooth muscle cells. Aldosterone receptor antagonists (e.g. spironolactone) may prevent or be able to reverse these changes (Martin-Fernandez et al. 2011). However, there are limited studies examining aldosterone effect on vascular changes in humans (Joffe and Adler 2005, Mahmud and Feely 2005). Different effect of aldosterone overproduction might be present in different segments of arterial tree with changing vascular wall’s composition.

The prognostic value of central arterial stiffness is well established (Mitchell et al. 2010) and aortic pulse wave velocity (PWV) predicts cardiovascular mortality and morbidity beyond classical risk factors (Vlachopoulos et al. 2010). However, there are currently limited studies dealing with the predictive value of peripheral arterial stiffness for cardiovascular morbidity and this relationship remains unclear (Bernini et al. 2008, Choi et al. 2010, Khandanpour et al. 2009, Tsuchikura et al. 2010). Peripheral arterial stiffness investigation might be valuable in screening for and evaluating the severity of peripheral arterial disease (Khandanpour et al. 2009). On the other hand, the preferential increase in central arterial stiffness is found not only in coronary artery disease but in cerebrovascular disease and peripheral artery disease as well (Tsuchikura et al. 2010). Similarly, aging has a greater effect on the central than the peripheral arterial system (Choi et al. 2010).

Patients with PA had greater aortic wall stiffness by PWV compared to EH patients in our previous study (Štrauch et al. 2006). Similar results were seen in the study by Bernini et al. (2008) and specific treatment with adrenalectomy might reverse these changes (Štrauch et al. 2008). There is lack of data concerning the relationship between aldosterone overproduction and changes in peripheral, muscular arteries in humans. The current study was thus aimed at investigating the effect of aldosterone overproduction on peripheral arterial stiffness assessed by femoral-ankle PWV in PA patients in comparison to EH patients.

**Methods**

**Study population**

A total of 49 patients with confirmed PA and 49 patients with EH were assessed. The examination of all subjects was performed after discontinuation of their usual antihypertensive therapy. Patients were switched to an alpha-blocker (doxazosine) and/or slow-release calcium channel blocker (verapamil) at least 14 days prior to admission to eliminate the interference of other antihypertensive drugs with the renin-angiotensin-aldosterone system (RAAS). Spironolactone was stopped 6 weeks before investigation. This wash out period is generally accepted in PA diagnosis algorithm (Funder et al. 2008). The screening for the diagnosis of PA was based on an elevated aldosterone-to-renin ratio (ARR) ≥40 ((ng/dl)/(ng/ml/h)) when plasma renin activity (PRA) and aldosterone levels were measured post 2hours in the upright position also with suppressed PRA (≤0.7 ng/ml/h) and elevated plasma aldosterone (≥15 ng/dl). The diagnosis of PA was confirmed by the absence of plasma aldosterone suppression (plasma aldosterone ≤7 ng/dl) after saline infusion (2 liters 0.9 % saline infused over 4 hours) (Funder et al. 2008, Mulatero et al. 2011).

The diagnosis of EH was made by exclusion of the most common forms of secondary hypertension (PA, pheochromocytoma, Cushing’s syndrome, renal parenchymal disease and renovascular hypertension). PA was excluded according to normal ARR and aldosterone suppression presence after saline infusion.

**Pulse wave velocity**

All subjects underwent PWV assessment with the applapation tonometer Sphygmocor (AtCor Medical, Australia). Subjects were studied by a single examiner after overnight fasting and after a 15-min resting period, during which the patient was in a supine position in a quiet room. Central (aortic) PWV was assessed by the time difference between pulse wave upstrokes consecutively measured at the right common carotid artery and right femoral artery, then aligned by the ECG-based trigger. The ‘percentage pulse height algorithm’ was used to locate the foot of the pulse waves. To determine the distance between measured sites subtraction method was used (sternal notch to femoral site minus sternal notch to carotid site). Similarly, peripheral femoral-ankle PWV (pPWV) was assessed by the time difference between pulse wave upstrokes measured at the right femoral artery and right tibial anterior or posterior artery.

**Blood pressure measurements**

Clinical blood pressure values were obtained using an oscillometric sphygmomanometer (Dinamap, Critikon, Tampa, FL, USA) according to European Society of Hypertension Guidelines just before PWV measurement (Mancia et al. 2007). Twenty-four hour
ambulatory blood pressure monitoring (ABPM) during hospitalization was performed using an oscillometric device (SpaceLabs 90207; SpaceLabs Medical, Redmond, WA, USA). This was not performed during the saline infusion load.

**Laboratory tests**

All hormonal tests were performed by radioimmunoanalysis using commercially available kits (Immunotech, Beckman Coulter Company, Prague, Czech Republic). All other biochemical parameters were analyzed using multianalyzers (Hitachi 717, Boehringer Mannheim, Germany) in the Institutional Central Laboratory.

**Statistical analysis**

Depending on the normal/non-normal distribution (Shapiro-Wilks W-test) of individual variables, the results are shown as means ± standard deviations or medians (interquartile range). Between-group comparisons were performed by two-tailed t-test for independent samples. The Kruskal-Wallis test was used for non-normally distributed variables. Pearson’s correlation analysis and multiple regression analysis (stepwise forward method) were applied to assess the relationship among central PWV/pPWV and clinical/laboratory parameters (variables which significantly correlated in Pearson’s correlation analysis entered multiple regression analysis). For between-group central PWV/pPWV comparisons, a multivariate regression model was used to adjust for confounding indices. P-value < 0.05 was considered to be significant. The statistical analysis was performed by STATISTICA software version 8 (StatSoft, Tulsa, OK, USA).

Table 1. Clinical characteristics of studied subjects.

|                          | PA                     | EH                     | p-value |
|--------------------------|------------------------|------------------------|---------|
| Number of subjects (female/male) | 49 (13 / 36)           | 49 (16 / 33)          | 0.512   |
| Age [years]              | 51±10                  | 50±12                  | 0.555   |
| Duration of hypertension [years] | 8 (2-14)               | 6 (2-12)               | 0.551   |
| Body mass index [kg.m⁻²] | 29.7±4.3               | 30.1±4.6               | 0.674   |
| Plasma sodium [mmol/l]   | 143±2                  | 141±3                  | 0.008   |
| Plasma potassium [mmol/l] | 3.7±0.4                | 4.1±0.4                | <0.001  |
| Creatinine [µmol/l]      | 79±15                  | 80±17                  | 0.814   |
| Microalbuminuria [mg/l]  | 14 (8-35)              | 6 (4-10)               | <0.001  |
| eGFR [ml/min]            | 2.1±0.5                | 2.1±0.6                | 0.621   |
| CC [ml/s/1.73 m²]        | 2.2±0.6                | 2.1±1.3                | 0.625   |
| 24-h urine sodium excretion [mmol/24 h] | 175±96                | 173±87                 | 0.497   |
| 24-h urine potassium excretion [mmol/24 h] | 58±26                 | 84±32                  | <0.001  |
| Total plasma cholesterol [mmol/l] | 4.9±0.9               | 4.8±1.1                | 0.690   |
| LDL cholesterol [mmol/l] | 3.0±0.8                | 2.9±0.9                | 0.459   |
| HDL cholesterol [mmol/l] | 1.2±0.3                | 1.2±0.3                | 0.626   |
| Triacylglycerides [mmol/l] | 1.3 (1.0-2.0)          | 1.4 (1.1-1.9)         | 0.710   |
| Fasting plasma glucose [mmol/l] | 5.2 (4.8-5.5)         | 5.1 (4.6-5.6)         | 0.434   |
| Smokers, n (%)           | 22 (45)                | 15 (31)                | –       |
| Aldosterone [ng/dl]      | 37.8 (26.6-51.3)       | 13.2 (8.2-23.2)        | <0.001  |
| PRA [ng/ml/h]            | 0.51 (0.42-0.64)       | 0.88 (0.64-1.27)       | <0.001  |
| ARR [(ng/dl)/(ng/ml/h)]  | 74 (47-105)            | 18 (9-24)              | <0.001  |

PA – patients with primary hyperaldosteronism; EH – essential hypertension patients; eGFR – estimated glomerular filtration rate; CC – creatinine clearance corrected for body surface area; LDL – low density lipoprotein; HDL – high density lipoprotein; PRA – plasma renin activity; ARR – aldosterone-to-renin-ratio. Values are shown as means ± SD or medians (interquartile range) or absolute numbers and percentages. Variables are compared by unpaired t-test or Kruskal-Wallis test where appropriate.
Table 2. Hemodynamic parameters.

| Parameter                              | PA                        | EH                        | p-value    |
|----------------------------------------|---------------------------|---------------------------|------------|
| Clinical brachial SBP [mmHg]           | 154±18                    | 150±16                    | 0.317      |
| Clinical brachial DBP [mmHg]           | 89±11                     | 89±11                     | 0.703      |
| Brachial mean BP [mmHg]                | 111±13                    | 110±11                    | 0.481      |
| Brachial pulse pressure [mmHg]         | 64±12                     | 62±12                     | 0.289      |
| Heart rate [bpm]                       | 68±10                     | 68±12                     | 0.837      |
| 24-h BP [mmHg]                         | 146±15 / 88±10            | 139±13 / 84±11            | **0.021** / 0.057 |
| 24-h heart rate [bpm]                  | 68±8                      | 69±10                     | 0.633      |
| Day BP [mmHg]                          | 148±16 / 90±10            | 141±13 / 86±11            | **0.033** / 0.060 |
| Day heart rate [bpm]                   | 71±8                      | 72±10                     | 0.659      |
| Night BP [mmHg]                        | 141±16 / 82±9             | 132±16 / 78±12            | **0.009** / 0.054 |
| Night heart rate [bpm]                 | 61±8                      | 61±9                      | 0.851      |
| Central pulse wave velocity [m/s]      | 8.70±1.7                  | 8.00±1.3                  | **0.023**  |
| Peripheral pulse wave velocity [m/s]   | 11.59±1.4                 | 10.70±1.3                 | **0.002**  |

PA – patients with primary hyperaldosteronism; EH – essential hypertension patients; SBP – systolic blood pressure; DBP – diastolic blood pressure; BP – blood pressure. Values are shown as means ± SD. Variables are compared by unpaired t-test. A multivariate regression model was used to adjust for between-group central and peripheral pulse wave velocity comparisons.

![Fig. 1. Comparison of central and peripheral pulse wave velocity in primary aldosteronism and essential hypertension.](image)

Results

The basic clinical characteristics of studied groups are shown in Table 1. There were no significant differences in age, duration of hypertension, body mass index, lipid profile, fasting glucose levels, or creatinine levels between PA and EH groups. As expected, plasma potassium and PRA levels were significantly lower in PA participants and similarly, plasma aldosterone, ARR, and sodium levels were higher. Microalbuminuria was significantly higher in PA patients, however, there were no differences in creatinine clearance corrected for body surface area or estimated glomerular filtration (according to Cockcroft-Gault formula). Both groups were comparable in dyslipidemia, diabetes mellitus type 2 occurrence, as well as in statins and antidiabetic agents use. The differences in hemodynamic parameters and pulse wave indices are summarized in Table 2. Both peripheral (11.59 vs. 10.7 m/s, p<0.005) and central PWV (8.7 vs. 8.0 m/s, p=0.023) were significantly higher in PA when compared to EH patients, while clinical blood pressure was comparable (154/89 vs. 150/89 mm Hg, p>0.05). The results are illustrated in Figure 1 and Table 2. Despite the fact, that PA patients had significantly higher 24 hour ambulatory BP than EH, this difference remained significant after adjustments for age, clinical and 24 h mean blood pressure (p=0.018 for pPWV; p=0.026 for central PWV). After multiple regression analysis, aldosterone levels appeared to be the main predictor of pPWV, while age and clinical systolic BP were the main predictors of central PWV in PA. On the other hand, increased PRA with 24-hour diastolic BP and age with pulse pressure were the main predictors of pPWV and central PWV, respectively, in EH patients. Unlike EH patients, no relationship among 24 hour blood pressure indices and central/peripheral PWV was found.
in PA patients after multiple regression analysis. Table 3 summarizes the results of multiple regression analysis. Using logistic regression analysis for PA, central and peripheral PWV seem to be most important determinants of PA. See Table 4 for results.

**Table 3.** Multiple regression analysis results.

| β    | p-value |
|------|---------|
| Age [years] | 0.623 <0.001 |
| Pulse pressure [mmHg] | 0.308 0.004 |

Multiple regression analysis using PWV as dependent variable for PA

| Age [years] | 0.677 <0.001 |
| Systolic blood pressure [mmHg] | 0.455 <0.001 |

Multiple regression analysis using peripheral PWV as dependent variable for EH

| PRA [ng/ml/h] | 0.400 0.006 |
| 24-h diastolic blood pressure [mmHg] | 0.286 0.049 |

Multiple regression analysis using peripheral PWV as dependent variable for PA

| Aldosterone [ng/dl] | 0.321 0.030 |

PWV – pulse wave velocity; PA – patients with primary hyperaldosteronism; EH – essential hypertension patients; PRA – plasma renin activity. β – multiple regression analysis coefficient

**Table 4.** Logistic regression analysis for PA as dependent variable and age, brachial mean BP, PWV, peripheral PWV as independent variable.

| Odds ratio | p-value |
|------------|---------|
| Age [years] | 0.965 0.227 |
| Brachial mean BP [mmHg] | 0.973 0.205 |
| PWV [m/s] | 1.641 0.033 |
| Peripheral PWV [m/s] | 1.725 0.005 |

PA – primary aldosteronism; EH – essential hypertension; BP – blood pressure; PWV – pulse wave velocity

**Discussion**

The effect of aldosterone overproduction may contribute to increased aortic stiffness and to higher intima-media thickness of carotid arteries (Holaj et al. 2007, Štrauch et al. 2006). Furthermore, increased aortic stiffness might be reversible after successful treatment with adrenalectomy (Štrauch et al. 2008).

The results of this investigation demonstrated higher central and peripheral arterial stiffness in PA patients in comparison to EH patients. Fibroproliferative effects of higher aldosterone levels might lead to alteration of central-elastic as well as peripheral-muscular arteries with subsequent increase in arterial stiffness. Total collagen and type III vascular collagen were found significantly higher in PA patients than in EH in small resistance arteries (Rizzoni et al. 2006). Similar changes might be expected in greater muscular and elastic arteries.

**In vitro** or animal studies proved fibroproliferative effects of aldosterone with accumulation of different types of collagen fibers and growth factors in vascular smooth muscle cell. However, there is lack of evidence of a direct relation between vascular stiffness and plasma aldosterone levels in humans and also no correlation between plasma aldosterone level and the morpho-functional parameters was found (Bernini et al. 2008, Joffe et al. 2005, Mahmud et al. 2005). Positive correlations were found between the ARR and parameters of pulse wave analysis (which represents systemic arterial stiffness) and its parameters, e.g. central blood pressure and augmentation index. These parameters are all related to cardiovascular diseases (CVD) to a similar extent as classic CVD risk factors. However PWV is considered to be a more precise marker of arterial stiffness (Mitchell et al. 2010), but there are no correlations between ARR and PWV (Mahmud et al. 2005). This might be explained by the hypothesis that aldosterone levels detected during the examination may not correspond to the chronic impact of aldosteronism prior to diagnosis of PA. Also, circulating aldosterone levels do not reflect local aldosterone effect on the vascular wall and plasma aldosterone levels may not reflect the local production of aldosterone in the vascular wall. In our study, multiple regression analysis showed, that plasma aldosterone level might be one of the most important predictors of peripheral PWV in PA. This fact and the finding of correlation of PRA after multiple regression analysis in EH suggest the importance of the role of RAAS in peripheral arterial stiffness. However, no similar correlations were found in central PWV, neither in PA, nor in EH. Age and clinical blood pressure parameters seem to be the most important predictors of aortic PWV. These results suggest possible different effect and different mechanisms of action of aldosterone...
overproduction on central and peripheral arteries. There are several explanations, but the exact mechanisms are not clear. Some vascular changes might be the result of aldosterone induced higher blood pressure load, but it seems that changes are independent of actions that can be attributed to blood pressure rise (Schiffrin 2006, Williams 2005). The results might be explained by different effects of aldosterone on different parts of arterial tree with different composition of vessel wall. Either delayed (genomic) or rapid (nongenomic) mechanisms of action of aldosterone might be involved as well.

As expected, higher serum sodium and lower serum potassium levels were found in PA group as a result of aldosterone overproduction. Similarly, higher excretion of urinary potassium was found. There is evidence, that high salt intake might be associated with an increased arterial stiffness in humans and positive correlation of plasma sodium level with central PWV was found (Safar and Benetos 2003, Štrauch et al. 2006). Changes in potassium balance may mediate some vascular effects of aldosterone, however aldosterone-mediated changes in potassium homeostasis do not appear to myocardial necrosis in experimental models (Martinez et al. 2002). Levels of urinary minerals excretion might be in relationship with central hemodynamics (Park et al. 2011). However, we found no correlation among plasma and urine minerals with PWV neither in PA, nor in EH group.

Significant differences in 24 hour ABPM indices might attenuate our results, but the difference in central and peripheral PWV remained significant after adjustment for mean 24 h BP. Furthermore, after multiple regression analysis, no relation among 24 hour blood pressure indices and central and peripheral PWV was found in PA patients.

There are few other possible limitations of our study. No ultrasound or angiography was performed to exclude the presence of femoral atherosclerosis or stenosis in studied patients. However, only patients with no signs of peripheral arterial disease according to history and physical examination were included. Men and women are not represented equally in PA group. Thus, we tried to maintain the same distribution in EH group. Furthermore, the prevalence of menopause in women was similar in both groups, and no women with hormone replacement therapy were involved. In the time of investigation and at least two weeks prior to investigation (spironolactone was stopped six weeks before) patients were on comparable antihypertensive treatment. However, we could not be able to exclude the effect of former therapy on arterial stiffness, because structural vascular alteration modify in longer periods. Nevertheless, the number of antihypertensive drugs used before switching was slightly higher in PA groups, and the amount of patients with history of spironolactone use was comparable in both groups. Other possible limitation of our study is the relatively small amount of studied subjects. As we published recently (Šomloová et al. 2010), different phenotype might be found in PA patients according to the subtype of PA (aldosterone producing adenoma / idiopathic bilateral hyperplasia), which was not distinguished in the current study. We would like to expand the number of subjects and continue to study certain subtypes of PA in the future and to evaluate the effects of treatment.

In conclusion, the present study demonstrates that aldosterone overproduction in PA does not preferentially affect the central arterial system. Both central and peripheral arterial stiffness were increased in PA compared to EH. Our data suggest that RAAS might play role in peripheral PWV and plasma aldosterone seems to be important predictor of peripheral PWV in PA.

Conflict of Interest
There is no conflict of interest.

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