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Disclosures

None.

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高血圧診療のトピックス

家庭血圧・24時間血圧を実地臨床に活かす

Home blood pressure measurement and ambulatory blood pressure monitoring in general practice

河野雄平
Yuhei Kawano
国立循環器病センター内科高血圧腎臓部門

◎家庭血圧や24時間血圧の測定は，外来などでの随時血圧測定では得られない情報が多く得られることから高血圧の診断と治療において有用で，日本高血圧学会による“高血圧治療ガイドライン2009”(JSH2009)にも取り上げられている．家庭血圧測定は，日常生活における血圧を簡便に測れることから，ほとんどの高血圧患者に強く推奨される．また，家族全員の血圧測定を行えば，高血圧や仮面高血圧の早期発見に役立つであろう．24時間血圧測定は，夜間血圧を含む血圧日内変動の評価に優れている．保険適用となり普及すると考えられるが，再現性や忍容性などについて問題点もあり，高血圧の実地臨床においては適応を考慮して実施すべきであろう．

Key word：高血圧，家庭血圧，24時間血圧，白衣高血圧，仮面高血圧

家庭血圧や24時間血圧の測定は，外来などでの随時血圧測定では得られない情報が多く得られることから高血圧の診断と治療において有用で，日本高血圧学会による“高血圧治療ガイドライン2009”(JSH2009)にも取り上げられている[1]．家庭血圧計はすでに広く普及しており，血圧の自己測定を行っている高血圧患者は多い．一方，24時間血圧測定はおもに高血圧の専門施設において行われてきたが，保険適用となったことから普及してくると考えられる．

本稿では家庭血圧と24時間血圧について概説し，実地臨床に活かすための留意点について述べたい．

家庭血圧，24時間血圧とその測定意義

1．家庭血圧，24時間血圧の測定意義

家庭血圧や24時間血圧の測定は外来での随時血圧測定と比較して種々の利点があり，高血圧の診断と治療に大きな意義を有すると考えられる[2-6]．これらは測定回数が多く，日常生活における血圧値とその変動がわかり再現性もよい．また，白衣効果が除外され，白衣高血圧や仮面高血圧の診断に役立つ．さらに，降圧薬の薬効評価や持続時間の評価に有用であり，予後予測能が随時血圧より優れている．めまいや頭痛などの自覚症状と血圧との関係を評価できることも利点となる．家庭血圧測定では患者の血圧や高血圧治療に対する意識が高まり，コンプライアンスがよくなることも期待できる．

しかし，家庭血圧測定と自由行動下24時間血圧測定(ambulatory blood pressure monitoring：ABPM)は，異なった特性を有している(表1)．ABPMは夜間血圧の評価と血圧の短期変動性や日内変動の評価において家庭血圧測定に勝っているが，反復性や簡便性，忍容性，経済性では家庭血圧測定がABPMより優れている[1,6]．

2．家庭血圧，24時間血圧と診察室血圧

家庭血圧や24時間血圧は診察室や健診での随時血圧より低いことが多く，平均すると5〜10 mmHgほど低値である[7]．しかし，これらの血圧差は個人差が大きく，白衣高血圧や白衣現象を呈する人では外来血圧がかなり高く，仮面高血圧者は逆に家庭血圧や24時間血圧が外来血圧より高値である．また，血圧には日内変動があり，一般

表 1　各血圧測定法の特性1)

	診察室血圧	自由行動下血圧	家庭血圧
測定頻度	低	高	高
測定標準化	困難	不要	可
短期変動性の評価	不可	可	不可
概日変動性の評価(夜間血圧の評価)*	不可	可	可*
薬効評価	可	適	最適
薬効持続時間の評価	不可	可	最良
長期変動性の評価	不可	不可	可
再現性	不良	良	最良
白衣現象	有	無	無

*：夜間就眠時測定可能な家庭血圧計が入手可能である．

表 2　異なる測定法における高血圧基準1)

	収縮期血圧	拡張期血圧
診察室血圧(mmHg)	140	90
家庭血圧(mmHg)	135	85
24時間血圧(mmHg)	130	80
日中血圧(mmHg)	135	85
夜間血圧(mmHg)	120	70

には日中に高く夜間は低くなる．ただし，夜間降圧が減弱あるいは消失したnondipperや早朝の血圧上昇が著明なmorning surgeを示す人が少なくない．

したがって，家庭血圧や24時間血圧による高血圧の診断基準は，随時血圧の場合(140/90 mmHg以上)とは異なることに留意を要する．JSH2009による家庭血圧や24時間血圧での高血圧の診断基準を表2に示す1)．

3．家庭血圧，24時間血圧と臓器障害，予後

高血圧性の臓器障害や心血管予後については，家庭血圧や24時間血圧が随時血圧より強く関連していることが多くの研究において示されている8-11)．たとえば，イタリアのPIUMA研究での数年間の心血管イベントは，白衣高血圧者は正常血圧者と同等で，持続性高血圧のdipperはそれらより多く，nondipperがもっとも多かった8)．フランスのSHEAF研究では，治療中の高齢高血圧患者における心血管イベントは，外来，家庭血圧とも低い群に比べて白衣高血圧群は同等で，仮面高血圧群と両者とも高い群では多いことが示されている9)．著者らの研究でも，治療中の高血圧患者における左室重量係数や頸動脈内中膜厚，尿アルブミ

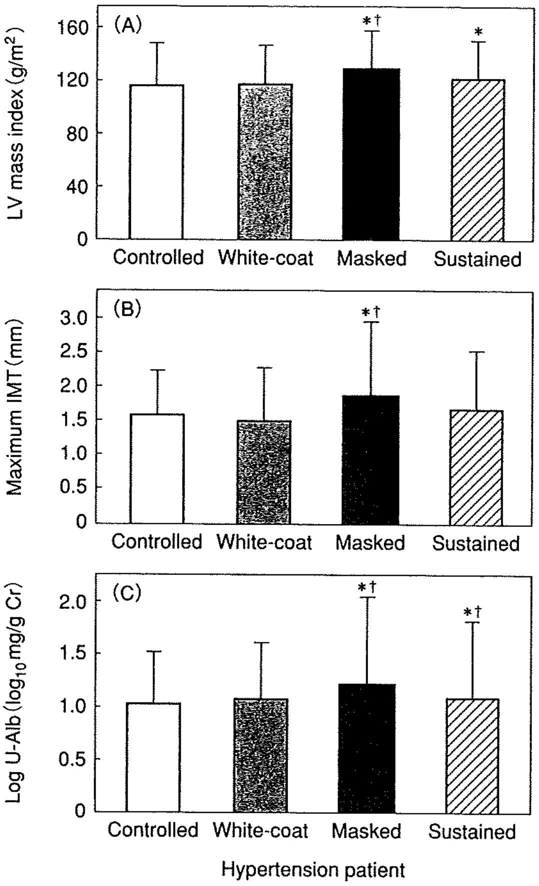

図 1　治療中の高血圧患者の左室重量係数(A)，頸動脈内中膜最大厚(B)，および尿アルブミン排泄量(C)10)

Contorolled：血圧がコントロールされている群(外来血圧：140/90 mmHg 未満，日中血圧：135/85 mmHg未満)，White-coat：白衣高血圧群，Masked：仮面高血圧群，Sustained：持続性高血圧群．

*：$p<0.05$ vs. controlled hypertension,
†：$p<0.05$ vs. white-coat hypertention.

表 3　家庭血圧の測定[1]

1．装置	上腕カフ・オシロメトリック法に基づく装置
2．測定時の条件	
必須条件	
a．朝	起床後 1 時間以内
	排尿後
	朝の服薬前
	朝食前
	座位 1〜2 分安静後
b．晩	就床前
	座位 1〜2 分安静後
選択条件	
a．指示により	夕食前，夕の服薬前，入浴前，飲酒前など
b．その他適宜	自覚症状のある時，休日昼間など，装置によっては深夜睡眠時測定も可
3．測定回数	1 機会 1 回以上(1〜3 回)*
4．測定時間	できるかぎり長期間
5．記録	すべての測定値を記録する

*：あまり多くの測定頻度を求めてはならない．
注 1：家庭血圧測定に対し不安をもつ人には測定させるべきではない．
注 2：測定値に一喜一憂する必要のないことを指導しなければならない．
注 3：測定値に基づき勝手に降圧薬を変更してはならない旨を指導しなければならない．

ン排泄量は，外来，日中血圧とも低い群に比較して白衣高血圧群は同等で，仮面高血圧群と持続性高血圧群は高値であった[10](図 1)．

家庭血圧，24時間血圧測定の実際と留意点

1．家庭血圧測定の実際と留意点

家庭血圧の測定には厳格な規定があるわけではないが，実地臨床に活かすには正確に測られる必要がある[2,11]．家庭用の血圧計には種々のものがあるが，市販の家庭用血圧計はオシロメトリック法による電子式のものが多く，血管の振動をとらえて収縮期および拡張期血圧を推定している．家庭用血圧計の精度については上腕用のものはほぼ正確で，手首用のものはすこし劣り，指用のものはかなり劣る．JSH2009 や，著者も委員を務めた日本高血圧学会家庭血圧測定条件設定作業部会による家庭血圧測定条件設定の指針では，オシロメトリック法に基づく上腕用カフ血圧計を用いることを推奨している[1,4](表 3)．手首用の血圧計はあまり勧められないが，精度検定で信頼されれば用いてもよいであろう．

家庭血圧は朝と夜に測定し，また，めまいや頭痛などの自覚症状があるときに測定することが勧められる．JSH2009 や家庭血圧測定条件設定の指針は，朝は起床後 1 時間以内で排尿後，朝食や服薬の前で，座位 1〜2 分の安静後に，夜は就床前に座位 1〜2 分の安静後に測ることを推奨している(表 3)．測定は 1 機会に 1 回でもよいが，初回と 2 回目の数値がかなり異なる場合もあり，2〜3 回測るほうがよいと考えられる．毎日測ることが望ましいが，厳密である必要はなく，時々でもよいので，患者の意向に合わせて測ってもらえればよいであろう．

家庭血圧における留意点としては，血圧はつねに変動しているので，数値にあまり神経質にならないよう指導する．また，家庭血圧は正しく測定されないとかえって誤った情報となる．カフを心臓の高さに保つこと，静かにして測定することが重要である．家庭血圧では 135/85 mmHg 以上が高血圧となることにも留意を要する．

家庭血圧の測定は 24 時間血圧測定に比べて簡便で実施しやすく，実地臨床においてはほとんどの高血圧患者に強く勧められる．高血圧の治療においては外来血圧より家庭血圧に重きをおくべきであろう．しかし，神経質な患者は家庭血圧の数値に一喜一憂し，何度も血圧を測ったり血圧高値が不安を増強して種々の愁訴をもたらす場合がある．このような例では家庭での血圧測定は止めさせるほうがよいであろう．

家庭血圧の弱点は，睡眠中の血圧や血圧日内変

表 4　自由行動下24時間血圧モニタリング(ABPM)のよい適応となる病態3)

1）診察室あるいは家庭での血圧が大きく変動する場合
2）白衣高血圧が疑われる場合(外来血圧と臓器障害の程度が乖離)
3）薬物治療抵抗性の高血圧の場合
4）降圧薬投与中に低血圧を示唆する徴候がみられる場合
5）早朝に高血圧を示す場合

動の評価が困難なことである．しかし，最近はタイマー付きの家庭血圧計が市販され，夜間睡眠中の血圧測定も可能となってきた．このような装置が普及し夜間の血圧値が得られれば，家庭血圧測定の意義はさらに高まると考えられる．

2. 24時間血圧測定の実際と留意点

ABPMは，携帯式の血圧計により自由行動下に24時間の血圧を測定するものである2-12)．一般的には間接法による間欠測定が用いられ，オシロメトリック法がカフ位置の影響が少ないためおもに用いられている．いくつかの装置が市販されており，上腕に巻いたカフと本体をケーブルでつなぎ，定時的にバッテリー駆動の送気でカフを加圧して血圧を測定する．本体は肩からかけるか，腰に装着する．データは本体のメモリーに記録され，解析装置で解析，プリントアウトされる．

ABPMでの測定間隔については，著者も委員を務めた3学会の合同研究班による“24時間血圧計の使用(ABPM)基準に関するガイドライン”は15〜30分間隔を勧めている3)．測定時間は25〜26時間とし，最初の1時間のデータは高値を示すことが多いので用いないほうがよい3)．より長時間の測定も可能で，48時間血圧測定も行うことができる．また，血圧測定中は体動を抑えるように指導しておく．被験者に就眠と起床時間などの日常活動の記録をつけてもらうことも重要である．

ABPMは高血圧の診断と評価に大きな意義を有しており，とくに夜間血圧を含む血圧日内変動の評価に優れている1,2,12)．仮面高血圧の診断と病型分類にもきわめて有用である13)．これまでABPMはおもに高血圧の専門施設において行われていたが，最近ABPMは保険適用となったので，実地臨床においても普及することが期待される．

しかし，現時点ではABPMはルーチンの検査として行われるべきではない．保険の適用としては，ABPMは3学会の承認を得たガイドライン(表4)3)に沿って行われた場合に，1カ月に1回に限り算定すると定められている．仮面高血圧が疑われる場合もよい適応となろう．

ABPMには種々の利点があるが，問題点もある6,12)．血圧は精神身体活動などの影響によりつねに変化しており，日によっても平均値や日内変動がかなり異なることが少なくない．2日間のABPMによる夜間降圧の再現性は70％くらいであり，約30％は異なる区分になることが示されている14)．著者らの研究でも，飲酒によりnon-dipperの半分はdipperとなり，dipperの約半数はextreme-dipperへと変化した15)．また，ABPMによる夜間血圧測定はしばしばカフ加圧や音による覚醒やそれに伴う血圧上昇をきたす．したがって，同じ個人でも血圧日内変動や夜間降圧は条件によりかなり異なることに留意を要する．

実用性や忍容性については，ABPMは自由行動下血圧測定というものの，頻回のカフ加圧を伴う測定により行動が妨げられる場合が少なくない．また，睡眠がしばしば障害され，疼痛や皮膚刺激，不快感，仕事の支障などが起こりうる．被験者からみた忍容性を調べた研究では，診断手技や臨床検査のなかでABPMが最低であったとの報告もある16)．このようにABPMには問題点もあり，乱用すべきではない．

おわりに

家庭血圧および24時間血圧測定について意義や適応，問題点などを述べた．家庭血圧測定やABPMが高血圧の診療に有用であることは疑いなく，個々の高血圧患者の診療に活用すべきであろう．家庭血圧は簡便に測定できることから，ほとんどの高血圧患者に強く推奨される．また，家族全員の血圧測定を行えば，高血圧や仮面高血圧の

早期発見に役立つであろう．ABPM は保険適用となり普及すると考えられるが，再現性や忍容性などについて問題点もある．高血圧の実地臨床においては適応を考慮して実施されるべきであろう．

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Comparison between carotid-femoral and brachial-ankle pulse wave velocity as measures of arterial stiffness

Hirofumi Tanaka[a], Masanori Munakata[b], Yuhei Kawano[c], Mitsuru Ohishi[d], Tetsuo Shoji[e], Jun Sugawara[a], Hirofumi Tomiyama[f], Akira Yamashina[f], Hisayo Yasuda[c], Toshitami Sawayama[g] and Toshio Ozawa[h]

Background Arterial stiffness is an important risk factor for cardiovascular disease. Carotid-femoral pulse wave velocity (cfPWV) is the most recognized and established index of arterial stiffness. An emerging automatic measure of PWV primarily used in the Asian countries is brachial-ankle PWV (baPWV).

Method To systematically compare these two methodologies, we conducted a multicenter study involving a total of 2287 patients.

Results There was a significant positive relation between baPWV and cfPWV ($r = 0.73$). Average baPWV was approximately 20% higher than cfPWV. Both cfPWV and baPWV were significantly and positively associated with age ($r = 0.56$ and 0.64), systolic blood pressure ($r = 0.49$ and 0.61), and the Framingham risk score ($r = 0.48$ and 0.63). The areas under the receiver operating curves (ROCs) of PWV to predict the presence of both stroke and coronary artery disease were comparable between cfPWV and baPWV.

Conclusion Collectively, these results indicate that cfPWV and baPWV are indices of arterial stiffness that exhibit similar extent of associations with cardiovascular disease risk factors and clinical events. *J Hypertens* 27:2022–2027 © 2009 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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Keywords: arterial distensibility, arterial elasticity, vascular assessment

Abbreviations: AUC, area under the curve; baPWV, brachial-ankle pulse wave velocity; CAD, coronary artery disease; cfPWV, carotid-femoral pulse wave velocity; CHD, coronary heart disease; eGFR, estimated glomerular filtration rate; PWV, pulse wave velocity; ROC, receiver operating characteristics

[a]University of Texas at Austin, Austin, Texas, USA, [b]Tohoku Rosai Hospital, [c]National Cardiovascular Center, [d]Osaka University, [e]Osaka City University, [f]Tokyo Medical University, [g]Sawayama Clinic and [h]Tokyo Metropolitan Geriatric Center, Japan

Correspondence to Hirofumi Tanaka, PhD, Department of Kinesiology and Health Education, The University of Texas at Austin, Austin, TX 78712, USA
Tel: +1 512 232 4801; fax: +1 512 471 0946; e-mail: htanaka@mail.utexas.edu

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See editorial commentary on page 1960

Introduction

Arterial stiffness is associated with a number of deleterious cardiovascular conditions [1–3] and has been identified as an independent risk factor for cardiovascular disease [4]. Because of its clinical importance, a number of indices have been developed and introduced to characterize arterial stiffness [5–8]. However, clinicians and researchers still report great difficulties in selecting the most appropriate methodology for their specific use [7]. Parenthetically, a measure of arterial stiffness has not been fully incorporated in routine clinical practice. Although no one methodology has been proved superior, pulse wave velocity (PWV) is the most recognized and established index of arterial stiffness [7]. The most frequently studied index to date among a variety of PWV measures is carotid-femoral PWV (cfPWV). cfPWV has been used in landmark studies of arterial stiffness conducted in Europe [2,9] and Australia [10] as well as in the Framingham Heart Study in the USA [11]. Despite the accumulating clinical evidence, this measure of PWV has not been fully included in routine clinical settings. An emerging measure of PWV that has been widely used in Japan and other east-Asian countries in the past 10 years is brachial-ankle PWV (baPWV) [8,12–15] (or some have referred to as brachial-ankle PWV index [14]). This automated measure of PWV is very unique in that it has been widely used in routine clinical settings, at least in Japan, with impressive number of machines (~10 000) already been incorporated in various clinics and hospitals.

Although these two PWV measures are widely used in the Western and Eastern societies, respectively, associations between the two are not clear. A few studies that have attempted to address this issue are small scale in nature [8,13]. Additionally, it is not known how each of the arterial stiffness measures are associated with coronary heart disease (CHD) risk factors. Moreover, how both techniques are comparatively related to clinical events is not currently known. In an attempt to systematically address these issues, we conducted a multicenter study to determine associations between cfPWV and baPWV.

Methods

Patients

Patients were participants in the community-based research studies from six different institutions in Japan and one in the USA. A total of 2287 adults (1265 men and 1022 women) were studied. All procedures were reviewed and approved by the local Human Research

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Committees. Each patient provided written consent to participate in the study.

Before the experiments, patients abstained from alcohol and caffeine and fasted for at least 3 h. Patients were studied under supine resting conditions in a quiet, temperature-controlled room.

Pulse wave velocity measurements

Electrocardiogram, bilateral brachial and ankle blood pressures, and carotid and femoral arterial pulse waves were simultaneously measured with a vascular testing device (VP-2000; Omron Healthcare) [12]. This machine was originally developed as a screening device for hypertension (via blood pressure), peripheral artery disease (via ankle brachial index), and arterial stiffness (via PWV), and this necessitated the use of four blood pressure cuffs on each limb. Carotid and femoral arterial pressure waveforms were stored for 30 s by applanation tonometry sensors attached to the left common carotid artery (via a neck collar) and left common femoral artery (via elastic tape around the waist). Bilateral brachial and post-tibial arterial pressure waveforms were stored for 10 s by extremities cuffs, connected to a plethysmographic sensor and an oscillometric pressure sensor, wrapped around both arms and ankles.

Pulse wave velocity was calculated from the distance between two arterial recording sites divided by transit time. Transit time was determined from the time delay between the proximal and distal 'foot' waveforms. The foot of the wave was identified as the commencement of the sharp systolic upstroke, which was automatically detected by a band-pass filter (5–30 Hz). Time delay between right brachial and tibial arteries (Tba), between carotid and femoral arteries (Tcf), and between femoral and tibial arteries (Tfa) were obtained. The path length from the carotid to the femoral artery (Dcf) was directly assessed in duplicate with a random zero length measurement over the surface of the body with a nonelastic tape measure [16]. For patients whose distance between the carotid and femoral artery was not available, Dcf was estimated using the equation [0.318 × height (cm) + 10.56] [17]. Agreement between cfPWV obtained using the estimated Dcf and directly measured Dcf was excellent ($r = 0.99$). The path lengths from the suprasternal notch to brachial artery (Dhb), from suprasternal notch to femur (Dhf), and from femur and ankle (Dfa) were calculated automatically by the machine using the following equations [13]:

$$\mathrm{Dhb} = (0.220 \times \mathrm{height}\{\mathrm{cm}\} - 2.07)$$

$$\mathrm{Dhf} = (0.564 \times \mathrm{height}\{\mathrm{cm}\} - 18.4)$$

$$\mathrm{Dfa} = (0.249 \times \mathrm{height}\{\mathrm{cm}\} + 30.7)$$

Pulse wave velocity was calculated by the following equations:

$$\text{Carotid–femoral PWV} = \frac{\mathrm{Dcf}}{\mathrm{Tcf}}$$

$$\text{Brachial–ankle PWV} = \frac{\mathrm{Dhf} + \mathrm{Dfa} - \mathrm{Dhb}}{\mathrm{Tba}}$$

The results obtained with right side and left side baPWV were identical ($r = 0.97$). As such, right baPWV is reported in the present study. The validity and reliability of the automatic device for measuring PWV have been established previously [12].

Blood samples

A blood sample was collected from the antecubital vein using venipuncture after an overnight fast. Plasma concentrations of glucose, lipids, and lipoproteins were determined by use of a standard enzymatic technique as previously described [16]. Glomerular filtration rate (eGFR) was calculated using the following equation introduced by the Japanese Society of Nephrology [18].

$$\text{Men}: \ \mathrm{eGFR}\,(\mathrm{ml/min\ per\ 1.73\,m^2}) = 194 \times \mathrm{Cr}^{-1.094} \times \mathrm{age}^{-0.287}$$

$$\text{Women}: \ \mathrm{eGFR}\,(\mathrm{ml/min\ per\ 1.73\,m^2}) = 194 \times \mathrm{Cr}^{-1.094} \times \mathrm{age}^{-0.287} \times 0.739$$

Statistical analyses

Univariate regression and correlation analyses were used to analyze the relations between variables of interest. Forward stepwise multiple-regression analyses were used to determine the influence of central and peripheral arterial stiffness on baPWV. To do so, only variables that had significant univariate correlations with cfPWV and/or baPWV were included in the model. Receiver operating characteristic (ROC) curves for both cfPWV and baPWV were constructed, and area under the curves (AUC) was calculated. This analysis was performed in a cohort of 814 patients [36 strokes and 40 coronary artery disease (CAD)] collected in three different institutions. Statistical significance was set *apriori* at $P < 0.05$. Data are expressed as means ± SEM.

Results

Table 1 shows the clinical and biochemical characteristics as well as PWV for the patients. On average, baPWV was approximately 20% higher than cfPWV.

As demonstrated in Fig. 1, there was a significant positive relation between baPWV and cfPWV ($r = 0.73$). Subgroup analyses revealed no systematic differences between men and women or between Japanese and

Table 1 Patient characteristics

Variable	Mean ± SD
n	2287
Age (years)	56 ± 16
Sex (%male)	56
CVD (%)	4.8
Height (cm)	162 ± 9
Body weight (kg)	61 ± 12
Systolic BP (mmHg)	128 ± 19
Diastolic BP (mmHg)	81 ± 13
Total cholesterol (mg/dl)	209 ± 36
LDL-cholesterol (mg/dl)	124 ± 33
HDL-cholesterol (mg/dl)	59 ± 16
Triglyceride (mg/dl)	127 ± 93
Plasma glucose (mg/dl)	103 ± 25
cfPWV (cm/s)	1256 ± 388
baPWV (cm/s)	1484 ± 342
eGFR (ml/min per 1.73 m^2)	79 ± 20

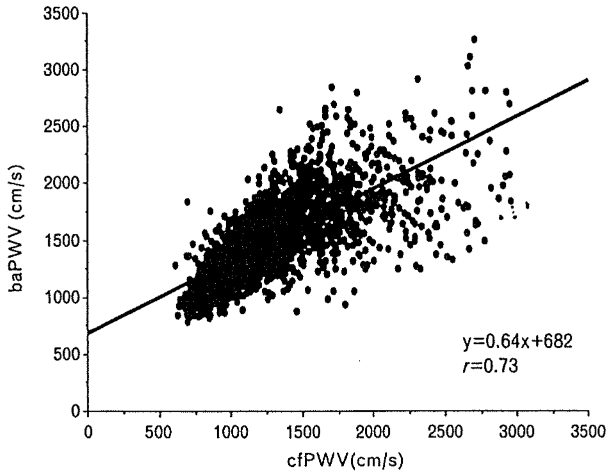
BP, blood pressure; CVD, cardiovascular disease; eGFR, estimated glomerular filtration rate; PWV, pulse wave velocity.

American populations. Both cfPWV and baPWV were significantly and positively associated with age ($r=0.56$ and 0.64; Fig. 2 and Table 2), systolic blood pressure (SBP) ($r=0.49$ and 0.61), and the Framingham risk score ($r=0.48$ and 0.63; Fig. 3). Stepwise multiple regression analyses indicated that the two primary determinants of both cfPWV and baPWV were age and SBP, explaining 43 and 60% of variances associated with cfPWV and baPWV, respectively. Figure 4 shows the results of the cross-sectional analyses involving the ROC of PWV to predict the presence of both stroke and CAD in a cohort of 814 patients (36 strokes and 40 CAD). The areas under the ROC curve for cfPWV and baPWV were comparable in stroke (0.62 and 0.63) and CAD (0.60 and 0.60).

Discussion

Pulse wave velocity is an established index of arterial stiffness and its first clinical use can be traced to Bramwell and the Nobel laureate, A.V. Hill [5]. In the present study, we performed comparative analyses of cfPWV and baPWV in a large number of patients who participated in the multicenter study. First, we demonstrated that baPWV was significantly and positively associated with cfPWV in the pooled population. Second, both PWV measures exhibit similar associations with various risk factors for CAD. Third, the areas under the ROC curve to predict the presence of CAD and stroke were comparable for cfPWV and baPWV. Collectively, these results indicate that cfPWV and baPWV are indices of arterial stiffness that are similarly related to CHD risk factors and predict clinical events to similar extents.

Fig. 1



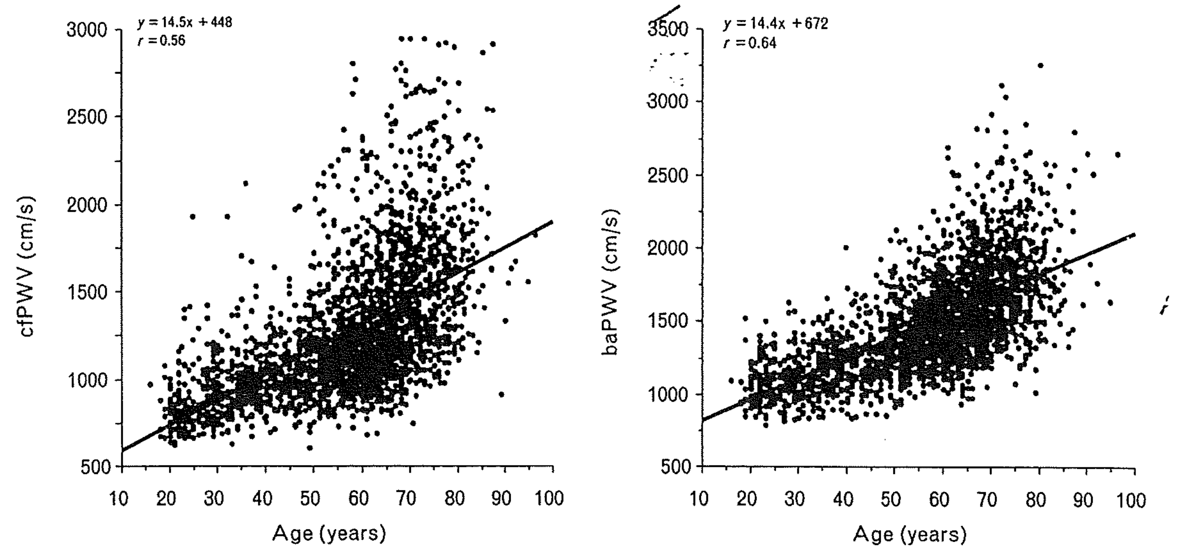
Association between carotid-femoral pulse wave velocity (cfPWV) and brachial-ankle pulse wave velocity (baPWV).

There was a strong positive association between cfPWV and baPWV, suggesting that both measures of PWV are indices of 'central' (or cardiothoracic) artery stiffness. These results are consistent with previous small-scale studies showing that baPWV is more closely associated with the index of central artery stiffness [8,13,19]. We have also previously reported that changes in central artery stiffness induced by a lifestyle modification are closely associated with the corresponding changes in baPWV [8]. Thus, in contrast to the prevailing notion, baPWV appears to reflect central arterial stiffness rather than peripheral artery stiffness. However, the regression line between cfPWV and baPWV deviated from the line of identity. On average, baPWV was approximately 20% higher than cfPWV. This finding indicates that some (albeit small) portions of baPWV may be determined by 'peripheral' (or muscular) arterial stiffness as suggested by a previous study [8].

The comparative assessment and analyses of different indices of arterial stiffness, particularly the comparisons with cfPWV, are becoming increasingly important given the recent European guidelines for the management of arterial hypertension proposing that a cfPWV value of more than 1200 cm/s be used as an index of subclinical organ damage [9]. The regression line obtained in the present study reveals that a baPWV value of 1450 cm/s is equivalent to the threshold value of 1200 cm/s proposed by the European Society of Hypertension and the European Society of Cardiology [9]. Such setting of a threshold PWV value may become a necessity if arterial stiffness measures were to be fully integrated into routine clinical settings.

Carotid-femoral pulse wave velocity has been shown to be accurate, reliable, and relatively simple to use and has been strongly linked with cardiovascular disease [1,2,14]. However, this methodology has not been widely incorporated in the routine clinical settings. The use of pressure transducers or Doppler probes on target arteries may be perceived as somewhat difficult to clinical staff. Additionally, some patients may feel uncomfortable exposing the inguinal area during the acquisition of

Fig. 2



Relation between age and pulse wave velocity (PWV) measures.

femoral pressure waveforms. These trends were particularly evident in generally demure Japanese population and required a development of a novel arterial stiffness index. baPWV has a procedural advantage of being very simple to use, only requiring the wrapping of blood pressure cuffs on four extremities. As a result, it has become a very popular modality to assess arterial stiffness in Japan [13], and it has been incorporated in thousands of local (i.e. nonresearch-oriented) clinics and hospitals.

Brachial-ankle pulse wave velocity has been criticized that the pulse wave does not travel directly from the brachial arteries to the post-tibial arteries in the same arterial tree and that the nomenclature of PWV is inappropriate. However, the same argument can be made for the well established cfPWV. cfPWV measures the velocity of pulse wave from carotid to femoral arteries, and these two arteries are not connected directly in the same arterial tree. Another issue pertaining to cfPWV is that there has been no consensus in terms of how the arterial path length should be measured. In large epidemiological studies from France that yielded the most clinically significant findings on cfPWV [1,20,21], the straight distance between the carotid and femoral arteries was applied. On the contrary, different investigations, including the Framingham Heart Study, employed the subtraction of the carotid artery length from the carotid to femoral straight distance in order to account for the pulse traveling in the opposite direction [22]. Rajzer *et al.* [23] recently compared the values of aortic PWV obtained with different arterial path length measurement: the carotid to femoral straight distance vs. the subtraction of the carotid artery length from the suprasternal notch to femoral straight distance. They reported that PWV measured with the former method was 25% higher compared with that using the latter method. We recently measured the aortic path lengths directly by the three-dimensional transverse magnetic resonance image arterial tracing in 256 apparently healthy adults and found that PWV calculated with the straight distance between carotid and femoral sites 26% overestimated the actual arterial path length [24]. Thus, it should be acknowledged that both cfPWV and baPWV have inherent problems with regard to the measurement of arterial path length.

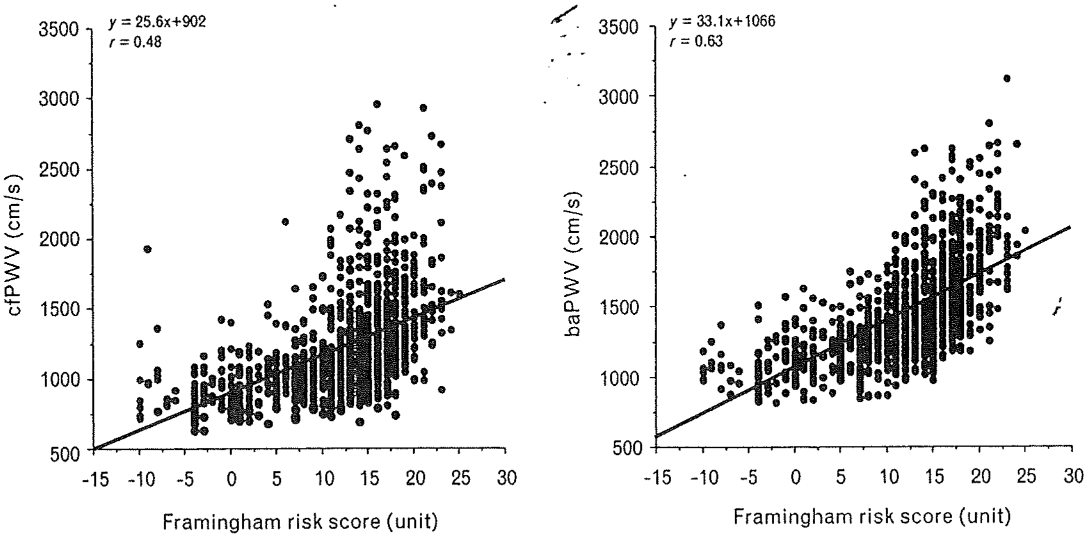
Table 2 Associations between pulse wave velocity (PWV) and risk factors for coronary heart disease

Variable	cfPWV	baPWV
Age	0.56	0.64
Systolic BP	0.49	0.61
Diastolic BP	0.13	0.23
Mean BP	0.48	0.58
Pulse pressure	0.50	0.56
FRS	0.48	0.63
eGFR	−0.32	−0.25

BP, blood pressure; eGFR, estimated glomerular filtration rate; FRS, Framingham risk score; PWV, pulse wave velocity. Values are Pearson correlation coefficients. All are significant at $P < 0.001$.

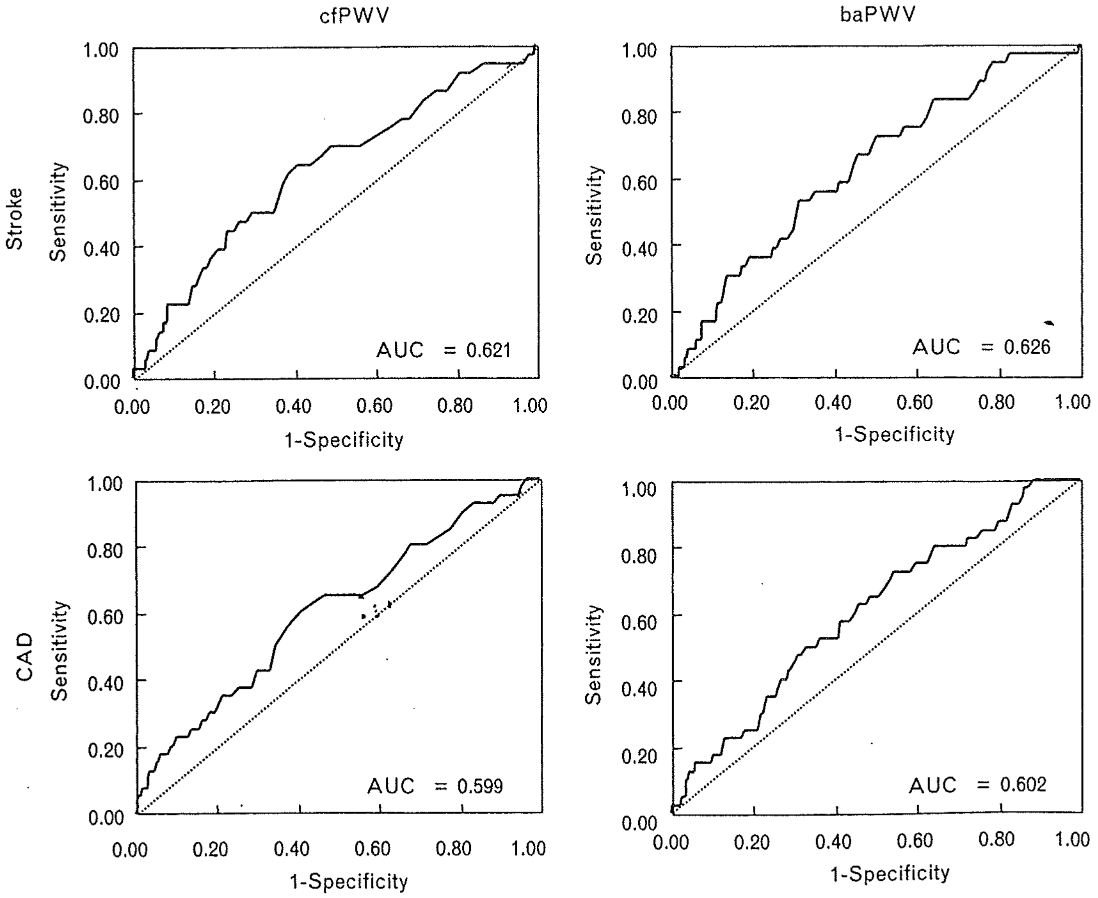
Both cfPWV and baPWV were significantly and similarly associated with various risk factors for CAD in the present study. Multiple regression analyses revealed that the two primary determinants of cfPWV and baPWV were the same (age and SBP). Interestingly, the strength of associations was somewhat greater for baPWV. These results are consistent with a recent epidemiological study [14] showing that both cfPWV and baPWV were significantly associated with the presence and severity of coronary calcification among overweight postmenopausal women. Interestingly, baPWV displayed stronger associations with the presence of coronary calcium than cfPWV

Fig. 3



Relation between the Framingham risk scores and pulse wave velocity (PWV) measures.

Fig. 4



Receiver operating characteristic (ROC) curves for incidences of stroke and coronary artery disease (CAD). AUC, area under the curve.

[14]. A similar finding that baPWV is more strongly related to left ventricular mass than cfPWV has also been reported [15]. Although baPWV is predominantly a measure of central artery stiffness [8], it also displays a modest correlation with peripheral artery stiffness (e.g. leg PWV) [8]. Thus, baPWV may be affected by more peripheral or systemic disease processes.

The areas under the ROC curve were also similar for baPWV and cfPWV. The results from this cross-sectional analysis indicate that both cfPWV and baPWV have similar abilities to associate with the presence of CAD and stroke. However, the values depicting the areas under the ROC curve were somewhat lower than what have been reported in the literature. This may be related to a lower cardiovascular risk in the Japanese population. Future prospective longitudinal studies are warranted to properly address this issue.

Carotid-femoral pulse wave velocity values reported in the present study appear high compared with some of the previously published studies [3,11] but are consistent with other studies [1,25]. The divergent cfPWV values are attributed to a different method used to measure the arterial path length (20% differences in mean values). In the latter studies, the arterial path length is the distance between the carotid and femoral recording sites, whereas the distance between carotid and femoral recording sites minus the distance from the carotid location to the supersternal notch is used in the former studies. Although this choice of methodology would produce approximately 20% differences in cfPWV values [24], it is still a matter of debate which arterial path length should be measured for the calculation of cfPWV. However, Sugawara *et al.* [24] have recently demonstrated that subtraction of the distance from the carotid location to the supersternal notch is the closest to the actual aortic length directly measured by the three-dimensional MRI. In baPWV, arterial path length is automatically estimated from one's height.

In summary, the newer automated measure of PWV (baPWV) was strongly associated with the gold standard measure of PWV (cfPWV). Additionally, both cfPWV and baPWV exhibit similar association with established risk factors for CAD and provide similar areas under the ROC curve for both stroke and CAD. Given the simplicity of the technique, baPWV is a promising new technique that is ideal for large-scale population studies and for incorporation into routine clinical settings. However, a more thorough analysis against a conventional technique is desirable.

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