Breakthrough in Clinical Cardiology:
In-Office Assessment with Pulse Wave Velocity (PWV) and Digital Pulse Analysis (DPA)

by Brian Scott Peskin, BSEE, with Robert Jay Rowen, MD

This article explores an exciting, noninvasive, easy-to-use, and economical method of assessing patients' cardiovascular physiologic status that is backed by more than 25 years of advanced research in medical physics. A 2007 *Clinical Medicine* article points the way to better clinical treatment of CVD, stating: "Arterial stiffness measured by pulse wave velocity (PWV) is an *accepted strong, independent predictor of cardiovascular events and mortality*."[1] Anesthesiologists are well aware of this technology, used for monitoring purposes. While pulse oximetry became standard in the operating room and in other critical care areas as a detector of hypoxemia – all pulse oximeters are fundamental photoelectric plethysmographs – PWV has been largely ignored. This is unfortunate, as PWV (plethysmographic) information itself may provide important clues regarding the CV condition of the patient.[2,3] With this advanced technology, cardiovascular science has moved forward, but many physicians have yet to appreciate these advances. As stated in the 1993 issue of the *Journal of Hypertension,* "Wave reflection is *not a subject with which most physicians are familiar* and only given mention in undergraduate physiology courses." Little has changed.

As this article was going to press, however, "Arterial Stiffness and Cardiovascular Events: The Framingham Heart Study," by Gary F. Mitchell, MD, et al. (*Circulation*. 2010;121:505–511) was published and featured on Medscape, stating: "In this study, we assessed the incremental value of *adding pulse wave velocity [PWV]* ... to a risk model that includes standard risk factors for a first cardiovascular event. ... Adding pulse wave velocity led to significant reclassification of risk and improvement in global risk prediction. ... [W]e need to focus our efforts on identifying and implementing interventions that can prevent or reverse abnormal aortic stiffness in order to prevent a marked increase in the burden of disease potentially attributable to aortic stiffness." The specific intervention/solution will be given later in this article.

Known in 1993: Blood pressure alone provides no information of the wave itself

"[T]he fallacy that there is a single 'systolic' and a single 'diastolic' blood pressure that is the same in all major arteries and can be measured in the brachial or radial artery is quite wrong, but few appreciate this fallacy, or its implications."[4]

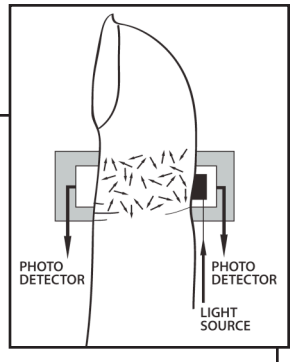
In 1996, Murray and Foster observed that pulse oximetry brought a major advance to patient monitoring in the 1980s, yet some of the most valuable data in the waveform signal were being overlooked.[5] Dorlas and Nijboer also make clear how this technology surpasses that used in the important (and complementary) ECG/EKG: "When displayed continuously on an oscilloscope, the plethysmograph indicates electro-mechanical dissociation. *The device is noninvasive, and can be applied easily and rapidly. However, despite these advantages, the method is not applied universally*. This may be because of unfamiliarity with the method. ..."[6]

Cohn et al., writing in 1995, make clear that when waveforms are compared between the invasive and noninvasive methods, computer analysis allows a very high degree of correlation and repeatability for successful use in clinical application across all populations (including diabetics): "In *hypertensive subjects*, *diabetics*, and in the *normal aging process* – and in *asymptotic individuals* – there was an abnormality in the oscillatory component of the diastolic waveform."[7] They also suggested that pulse wave analysis would be useful in screening subjects for early evidence of vascular disease and in monitoring the response to therapy.

The European Society of Hypertension (ESH) and the European Society of Cardiology (ESC) have added PWV measurement as an early index of large artery stiffening in their 2007 Guideline for the Management of Arterial Hypertension.[8]

Digital Pulse Analysis (DPA) is the next evolution in pulse wave velocity (PWV), and is based on the measurement of reflected infrared light (IR).

Simple, easy-to-use, non-invasive finger probe



There has been an explosion of activity in pulse wave analysis, and the ability to identify premature vascular stiffening is of considerable value in the prevention of cardiovascular disease. "The PWV has been established as an important biophysical marker of arterial ageing, which is independently highly predictive of cardiovascular outcome. ..."[9,10]

Numerous independent confirmations show statistically significant CV parameters based on age, and how PWV is the ideal method for assessing *arterial stiffness* and *central aortic pressure*.[1,11,12] Measurements are highly reproducible in clinical application and apply to both male and female patients. [12,13]

Methodology

A photodiode detects changes in the amount of light absorbed by hemoglobin, and its output waveform is termed *photoplethysmography*, or PTG. PTG has been validated for calculating systemic arterial compliance (flexibility).[7] The application of this technique in population studies confirms the early detection and evidence of vascular disease, as well as patients' response to therapy.[10] The technique is underpublicized, and many physicians are not aware of the great clinical impact of this technology.

With advanced computer analysis of the waveforms, clinicians can now use this simple, insurance-reimbursable procedure to assess the coronary health of their patients, in detail – in the office – in less than 5 minutes. Simplicity, ease of use, and detailed cardiovascular analysis of the patient are key to clinical use. As part of the analysis, the physician is also given patients' CV "biological age" to compare with their actual age. This device is extremely responsive and can measure patient therapeutic improvement in as little as 3 to 6 months, if not earlier.

A New Successful Intervention

Even though atherosclerosis is a leading cause of CVD, age-related arterial stiffening receives little attention in everyday clinical practice, because until recently, there was no successful intervention that could be prescribed.[14] Although no single parameter of arterial compliance or stiffness can be expected to describe all clinically relevant arterial wall properties, the use of a DPA–integrated, multimeasurement approach, coupled with an effective protocol to stop and reverse arterial stiffening with plant-based, bioidentical parent essential oils (PEOs), will change this commonly held belief. This approach and the PEO protocol are being investigated in the IOWA study – Investigating Oils With Respect to Arterial blockages, which commenced in December 2009 (results reported later in article).

2010/2009 IOWA (Investigation Oils with Respect to Arterial Blockage) Study

IOWA's goal is to assess the intervention of plant-based, bioidentical PEOs and measure their effectiveness in both stopping progression of and reversing existing atherosclerosis; that is, reversing "hardening of the arteries" as evidenced not by hopeful but ineffective "surrogates," but by detailed DPA patient profiles, which are a much more direct measure of the physiologic CV state.[15] The study ultimately will include over 200 participants.

Many commonly used CVD surrogates are not indicative of the true state of the cardiovascular system; that is, patient markers may improve but the patient still ultimately suffers from CVD. Even coronary calcification (CA), once considered a possible "gold standard" in cardiovascular diagnostic measurement, has recently been called into question as an accurate diagnostic risk indicator.[15–17] Another deficiency of CA is that patients' soft plaque is not measured at all – a significant issue.

LDL-C Therapy Fails to Prevent CVD (an ineffective surrogate)

C-Reactive Protein Marker 'Called into Question'

There is now significant doubt that C-reactive protein is a dependable CVD surrogate.[19] Current DPA technology provides a much better way to both prevent and treat CV disease in the 21st century than merely "controlling cholesterol" via statins (with their ineffective NNT of 100), or hoping that CRP reductions will help.[15]

Aging and Decreased Arterial Flexibility

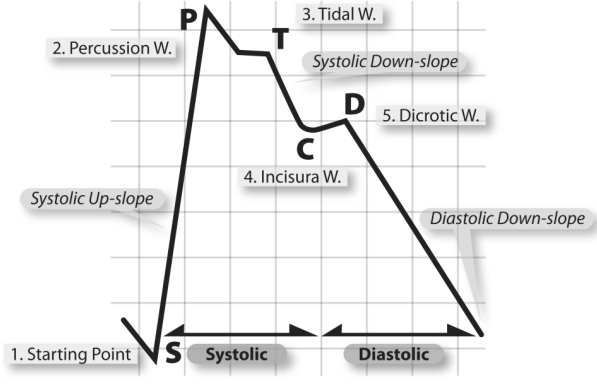
It is well known that aging is accompanied by increased stiffness of large elastic arteries, leading to an increase in PWV. Premature arterial aging, as determined by an elevated aortic PWV, is now recognized as a major risk factor for ischemic heart disease.[20–24] An influence of vascular aging on the contour of the peripheral pressure and volume pulse in the upper limb is also well recognized, and the aortic pulse wave velocity more than doubles between ages 17 and 70. [25,4]

Aortic / Large Artery Stiffness Measurements:

Millasseau et al. report: "*the stiffness of the aorta can be determined by measuring carotid-femoral pulse wave velocity* (PWVcf). PWV may also influence the contour of the peripheral pulse, suggesting that contour analysis might be used to assess large artery stiffness."[10] Because of difficulty in computing individual patient path lengths of these pulses, large artery stiffness (SI) cannot be considered a direct measure of the pulse wave velocity; however, SI is a *definitive index* of the stiffness of both the aorta and large arteries throughout the body. The systolic component arises from the pressure wave from the left ventricle to the finger; the diastolic pressure component arises from the reflected wave's traveling backward. Increased cardiovascular events are strongly correlated to arterial stiffness.[10]

Elements of PTG Waveforms

PTG (Plethysmogram) - derived from small artery of finger-tip by photoelectric method (unit mV/V) shows the dynamic changes of arterial blood volume at the finger-tip.



Note: Healthy CV patients have a well defined "dicrotic wave" in the diastolic phase at D, whereas 98% of overt arteriosclerotic patients had significant decrease or disappearance of the wave.[26]

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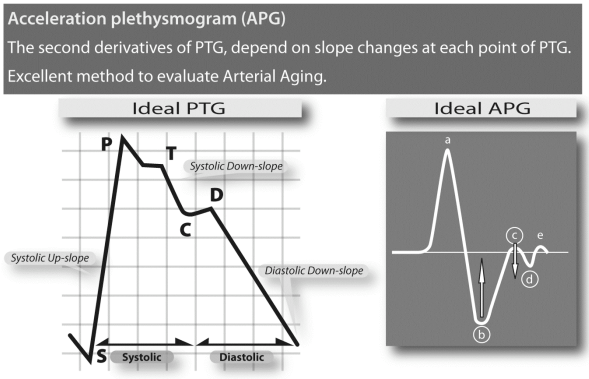
Elements of PTG (Systolic Phase)

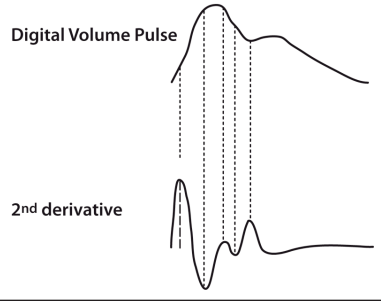
1. S (Starting Point)
   Starting point of systolic phase of arterial pulse-wave.
   Aortic valve opens and the blood of the LV is ejected into aorta.
2. P (Percussion Wave)
   Wave caused from LV ejection that increases the blood volume within artery.
   Higher point means stronger LV ejection and higher compliance of larger artery.
3. T (Tidal Wave)
   Reflected wave from the small artery.
   Higher point means contraction and stiffness of small artery.
4. C (Incisura)
   End-point of systolic phase, then aortic valve is closed.
   Less drop from pulse height (PH) means larger resistance (arterial contraction & tension).

With the PTG wave as a basis, its second derivative, termed the APG wave, provides an extremely useful measurement of the "biological age" of the patient's cardiovascular system.[9,27]

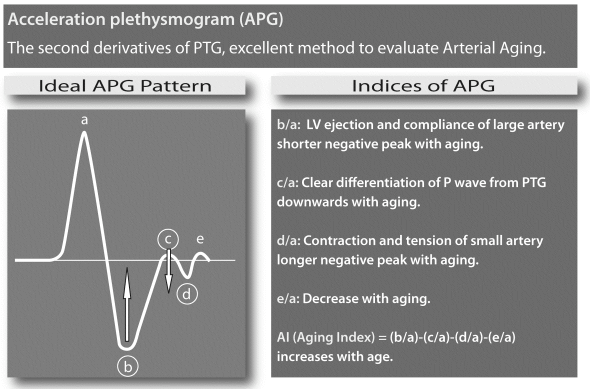
Elements of APG



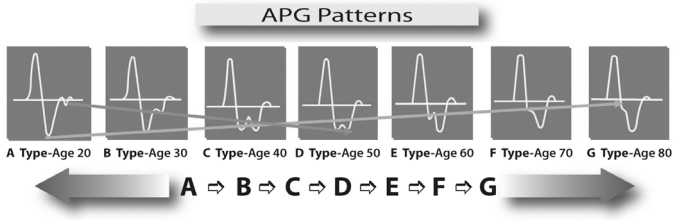
Inflection Points of APG



Interpretation of APG Indices

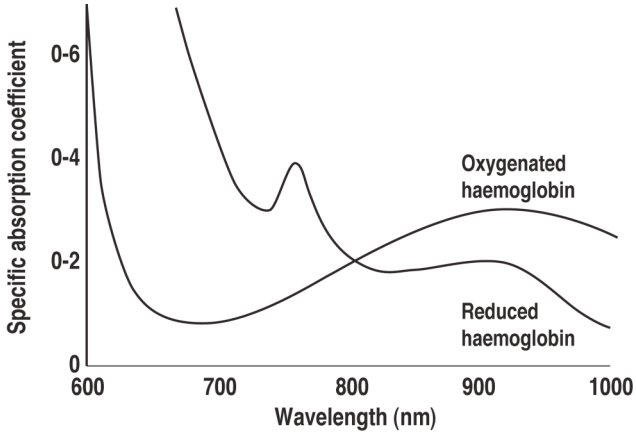


Note: A sophisticated approach to contour analysis of the PTG utilizes its second derivative, often referred to as the *acceleration photoplethysmograph*. This facilitates the distinction of 5 sequential waves, called a, b, c, d, and e waves. The relative heights of these waves (b/a, c/a, d/a, and e/a ratios) have been related to age, arterial blood pressure, large artery stiffness, and effects of vasoactive drugs. The b/a ratio has been related to aging and carotid distensibility. Following analysis of the correlation of the b/a, c/a, d/a, and e/a ratios with age, a more complex "aging index" was defined as [(b–c–d–e)/a]. In a study to assess arterial distensibility in adolescents, the d/a ratio identified individuals at increased risk of developing atherosclerosis. The second-derivative approach has also recently been applied to the study of the peripheral pressure pulse.[9,27]



A Short Summary of Operation

A short description of operation of the photoelectric plethysmograph has been provided by Challoner and Ramsay.[28] The fact that the absorption spectrum of the skin varies with oxygen content was known in 1943. Photoelectric plethysmography dates back to 1936, with the research conducted by Molitor and Kniazuk.[29] It was important that detection of oxygen content alone could not be the basis of measurement based on frequency; and it was found that at a frequency of 805 nm, both oxygenated and deoxygenated blood have the same absorption, thereby ensuring accuracy based on blood flow alone.



Absorptioin spectra of haemoglobin. From Horecker, B.L., 1943. J. Biol. Chem., 148, 173 (with permission).

Blood has a light absorption coefficient that is higher than surrounding tissue. This is a consequence of the Lambert-Beer law relating light absorption to optical density. Therefore, increases in the amount of blood give rise to decreased detected light. Erythrocytes and vessel walls also reflect light. However, reflection heavily dominates, and arterial pulses produce merely small reductions in detected light (1%–2%).

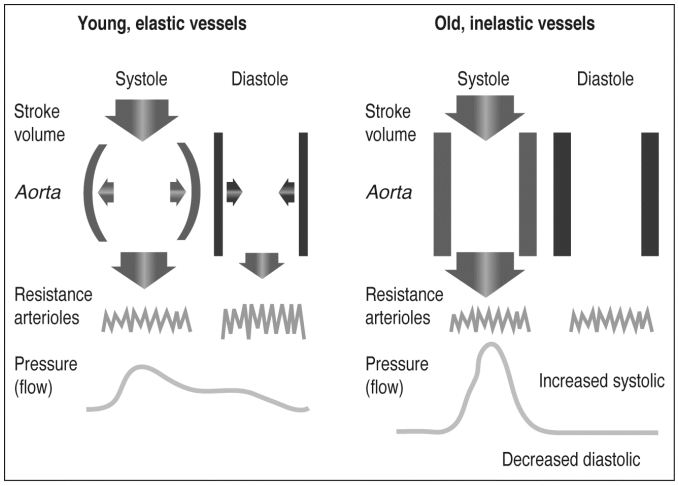
Detected light variation is amplified and converted to a voltage signal.[6] There are many factors involved in the attenuation of light, including absorption, multiple scattering, and reflection. But all technical issues have been resolved, and small changes in patient profile are easily detectable.

Blood Pressure Measurement Is Not Enough

For many reasons, blood pressure measurement, even measuring the central aortic systolic, is highly problematic and is not definitive in diagnosing CVD because patient blood pressure varies significantly throughout the day, depending on stress level and physical activity. O'Shea and Murphy make it clear: "Thus, inconsistency in the selection of arms for BP measurement, by different techniques, *may confound estimation of patients' cardiovascular morbidity risk*."[31] Also, as Izzo and Shykoff comment, BP is a late-stage diagnostic: "Because wide *pulse pressure* and *systolic hypertension* are *late manifestations of arteriosclerosis*, they are *only crude indicators of arterial wall disease*."[14]

Early DPA Detection in Diabetics – BP Measurement Failure

Increased large artery stiffness contributes directly to the observed age-related increase in systolic pressure as the following illustration details.[14]



In a rigid aorta (right panel), the absence of elastic recoil causes the full stroke volume to be delivered through the resistance arterioles during systole. There is minimal or no diastolic flow, resulting in increased systolic pressure, decreased diastolic pressure, and increased pulse pressure, all of which characterize the hypertension of old age.

As this article was going to press, papers presented at the 2010 annual meeting of the American College of Cardiology (details published online at www.sciencedaily.com/releases/2010/03/100314091130.htm) and scheduled to be published in the *New England Journal of Medicine* (April 29, 2010) made clear that "hopeful" CVD interventions for type 2 diabetics aren't effective: "ACCORD: Intensive BP, combined lipid therapies do not help adults with diabetes. Our results also showed a *higher risk of serious adverse events with more intensive blood pressure control*." Shockingly, pharmacologically lowering blood pressure to normal levels – below currently recommended levels – did not significantly reduce the combined risk of fatal or nonfatal cardiovascular disease events in adults with type 2 diabetes who were at especially high risk for cardiovascular disease events, according to new results from the landmark Action to Control Cardiovascular Risk in Diabetes (ACCORD) clinical trial. (Note: Lowering blood pressure to below the standard level significantly cut the risk of stroke by about 40% (relative risk). The researchers caution, however, that participants in the intensive blood pressure group were more likely to have complications such as abnormally low blood pressure or high levels of blood potassium.) "Our results provide *no conclusive evidence that targeting a normal systolic blood pressure compared with targeting a systolic blood pressure of less than 140 mmHg lowers the overall risk of major cardiovascular events* in high risk adults with type 2 diabetes." Clinician Dr Roger Blumenthal, referring to triglyceride-lowering fenofribrate, states in Medscape's Heartwire:

> But a lot of us in the cardiology community who manage high-risk diabetic patients thought we were doing patients a favor, thinking we were decreasing events at five years. So it was a bit of a surprise [pharmacologically lowering patient triglycerides failed].

The online CV News Digest for the American College of Cardiology stated: "According to studies presented at the American College of Cardiology meeting and to be published online March 18 by the *New England Journal of Medicine*:

> [A]ggressive treatment strategies doctors had expected would prevent heart attacks among people with type 2 diabetes and some who are the verge of developing it have proved to be ineffective or even harmful. ... Moreover, researchers found that Abbott's drug TriCor (fenofibrate), even though it did lower triglyceride levels, did not stop patients from having strokes and heart attacks.

If high-risk patients show no positive effect, it is unlikely that any patient will benefit with these interventions.

Pharmacologic (artificial) – not physiologic lowering of BP may sound good, but doesn't work. If you have followed my work you will understand why. For several years, I have been advocating an effective intervention to make patient arteries more compliant, which also positively affects lipid profiles without complications.

Unlike other surrogates, a critically important aspect of the PWV is that "diastolic variability [arterial flexibility/compliance] in the plethysmograph is *independent of arterial pressure*."[3] Furthermore, plethysmography is *extremely sensitive to small amounts of pulsatile blood flow*, and most importantly, the amplitude of the plethysmograph signal is *directly proportional to the vascular distensibility or flexibility*.[3] Therefore, DPA is significantly superior to mere blood pressure measurement.

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"Yet the *adverse consequences of age-related arterial stiffening still receive little attention in everyday clinical practice*, perhaps because *clinicians assume that nothing can be done about the process*."[14]

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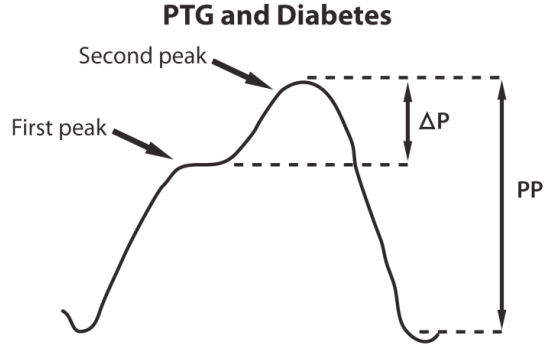
Fortunately, today there is an effective treatment with plant-based, bioidentical PEOs, as DPA measurement confirms.

PWV Analysis with DPA Bests Ultrasound

Ultrasound is insufficient to measure arterial compliance because arterial volume and the associated pressure cannot be simultaneously measured, and only a particular segment is scanned; DPA is significantly superior because it is a systemic measurement. The best method to estimate the distensibility and stiffness of the aorta and large arteries is PWV, because PWV is directly related to the stiffness of the large arteries. PWV directly correlates with aging, hypertension, renal failure, and other disorders affecting the cardiovascular system. To eliminate the need for central catheterization when measuring the central pulse contour, a transfer function was devised that reconstructs the central waveform from the peripheral.[33]

Aortic Stiffness (AI) Measurement

An extremely useful parameter from this technique is termed the (systolic) augmentation index (AI), relating the magnitude of the reflected peak to the magnitude of the incident systolic pressure surge from the left ventricle contraction. The amplitude of the pulsatile component of the DVP is influenced by respiration, sympathetic nervous system activity, and other factors that influence local perfusion. The shape or contour of the pulse, however, remains approximately constant.[9] This is a significant reason for the reliability of this measurement of the system circulation – it is uninfluenced by transitory conditions such as patient stress level.



A typical central aortic pressure wave from a middle-aged subject. The 2nd systolic peak becomes more prominent with age or as arteries stiffen, and is caused by wave reflection. The augmentation index (AI) is usually negative in young patients, approximately 0 at age 35, and positive in elderly patients.

Diabetic Implications

Endothelial dysfunction and increased arterial stiffness are associated with type 1 diabetes mellitus, both of which contribute to excess cardiovascular mortality in these kinds of patients.

2010 Newsflash: AI Diagnoses Diabetic Arterial Stiffness
Increased Aortic Stiffness = Excess Oxygen Consumption = Increased Risk for Heart Attack

Increased aortic stiffness causes decreased cardiac efficiency (ratio of stroke work to oxygen consumption). If cardiac efficiency is decreased by just 16% from arterial stiffness, then for the heart to sustain the same systemic blood flow (stroke volume), myocardial oxygen consumption increases significantly by 30% to 50%.[4]

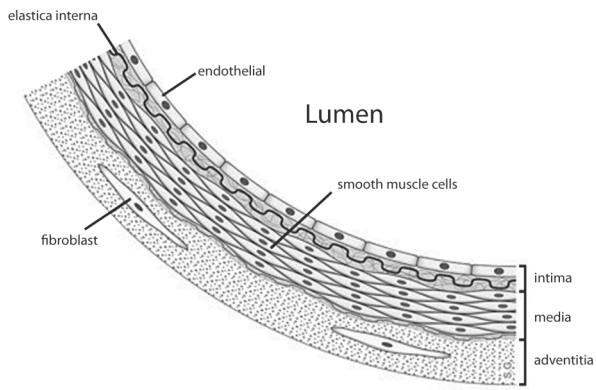
Arterial Stiffness: Arteriosclerosis and Atheromatosis

The physiology of the artery necessitates two separate pathologies, although they are typically combined into the single term *atherosclerosis*, which is nonspecific. *Arteriosclerosis* is typically referred to as a generalized thickening and stiffening of the media (see illustration below). *Atheromatosis* refers to the inflammatory occlusion response of the endothelial tissue (intima) in the lumen from oxidized lipid deposits, etc. These two processes often coexist. Over time, chronic inflammation makes vascular alterations irreversible. Therefore, early intervention is critical. In atheromatosis, lumen diameter is maintained until the final stage of the disorder. The process can be considered originating from the "inside out," whereas arteriosclerosis is best defined as an "outside-in" process. Wall thickness and the outer arterial diameter both increase. Unfortunately, there are often no clinical symptoms until sudden death, an outcome cardiologists know too well.

The pathologic hallmark of arteriosclerosis is thickening of the adventitia and media (see illustration) leading to excess arterial wall stiffness and systolic hypertension. There is also loss of and degradation of elastin fibers.

DPA Diagnoses Hypertrophy

It is important to note that "muscular arteries" are not equally affected by arterial hypertension, so "normal appearance" may be misleading, whereas DPA outputs are comprehensive and detect otherwise hidden arterial concerns.



Important note: The intima is 100% parent omega-6 (LA), not found in fish oil.

Treatment of CVD with PEOs

O'Rourke and Kelly commented: "Delay or reduction in wave reflection is a logical strategy to apply in the management of hypertension. Priority is given to ACE inhibitors (angiotensin-converting-enzyme inhibitors) and beta-blockers which reduce cardiac output, or to drugs which decrease arteriolar resistance."[4] While these drugs have garnered the spotlight, there is a new therapy that has direct physiologic and etiologic effect for arterial compliance – PEOs.

Because of its simplicity, DPA can be employed in large-scale epidemiological studies and be used to assess the effects

of these new interventions.[9] Both the aorta and large arteries have slow turnover of both cells and matrix proteins. A main therapeutic aim in preventing and reversing CVD is to reduce arterial stiffness; i.e., produce sustained reduction in arterial pressure.

Successful intervention: plant-based, bioidentical PEOs achieve this result naturally via numerous physiologic pathways.

Prostacyclin (PGI_2) production to ensure platelets are free-flowing (natural blood-thinners), production of the body's most potent anti-inflammatory – PGE_1 – that both prevents and reverses thrombosis, incorporation of parent omega-6 into the epithelial tissue (intima) itself, along with incorporation directly into the media and adventitia, allowing maximum flexibility. PEOs, parent essential oils (plant-based) – *not fish oils* – in a ratio 1:1-2.5:1 LA/ALA, with more parent omega-6 than parent omega-3, provide profound cardiovascular protection as evidenced by IOWA with 34 subjects, and the results are unprecedented:

IOWA: Investigating Oils With respect to Arterial Blockage
Significant differences in biological age compared to physical age
Brian Peskin, BSEE: Founder: Life-Systems Engineering Science with David Sim, M.D., Interventional Cardiologist
(Based on 34 patients using the PEOs over 3 month and as long as 144 months)

Age: 35-75	**Median age: 62**	22 females, 13 males

Paired t-test. Median: 24 months PEO use / Mean: 90 months PEO use

Significant differences (**p 0.0015**) with standard error of the mean +-5 years.
Subject's **biological age being (average of) 8.8 years lower than their actual physical age.**

Note: This experiment has a 99.85% accuracy—30 times more accurate than the 5% standard error used in most clinical trials. Therefore, this result is *not* due to possible error and is *highly* significant with patient CV health 8.8 years better than physical age predicts.

Analysis by Alex Kiss, Ph.D. (statistics) — January 21, 2010
Analysis Variable : agediff

N	Minimum	Maximum	Mean	Std Dev	Pr > |t|
34	-39.00	22.00	-8.82	14.84	0.0015

Study Summary

The above numbers, based on APG, mean as follows: There were 34 people who completed the study, using PEOs from 3 to 144 months. There was no baseline (the weakness of the study). Half were under two-year users, and half were over two years, double females to males. The subjects had their arteries studied and compared with accepted waveforms for age. The best subject was 39 years less than chronological age. The worst was 22 years over, and the only subject greater than chronological age. Overall, the mean age of arteries (flexibility) was 8.82 years less than chronological age. The p value (chance of this being chance only) was 15 in 1,000, indicating extremely significant results.

Special thanks to renowned interventional cardiologist David Sim, MD, for his invaluable technical expertise, and to Michael Czajka (Australia) for introducing us to PWV and DPA technology.

Notes

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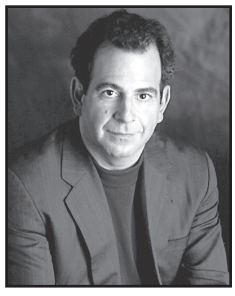

Brian Scott Peskin, BSEE, is available to discuss how you can incorporate 21st-century DPA, anti-CVD technology into your practice. Brian earned his bachelor of science degree in electrical engineering from Massachusetts Institute of Technology (MIT) in 1979. He founded the field of Life-Systems Engineering Science in 1995, and was appointed adjunct professor at Texas Southern University in the Department of Pharmacy and Health Science from 1998 to 1999. He is chief research scientist at Cambridge International Institute for Medical Science (www.CambridgeMedScience.org). Peskin integrates theory into practical applications – enhancing and extending the quality of life. He readily acknowledges his role as the messenger of critically important but overlooked information published in leading medical textbooks and medical journals. His medical insights and often-unique ability to "connect the dots" have given him an international following of leading physicians demanding state-of-the-art medical science in treating their patients. For more information, visit **www.peskinpharma.com** or contact **prof-peskin@peskinpharma.com**.

Robert Jay Rowen, MD, is editor-in-chief of Second Opinion Newsletter (www.secondopinionnewsletter.co m). He is affectionately known as the "father of medical freedom" and was instrumental as an Alaskan physician in drafting legislation making Alaska the first state to provide statutory protection to alternative physicians (medical freedom law). While he continues to treat patients for conditions like heart disease and cancer, Dr. Rowen's greatest desire is to help people avoid these diseases in the first place. He has nearly 30 years' experience practicing alternative medicine, and is considered one of America's foremost physicians practicing state-of-the-art, evidence-based medicine.

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