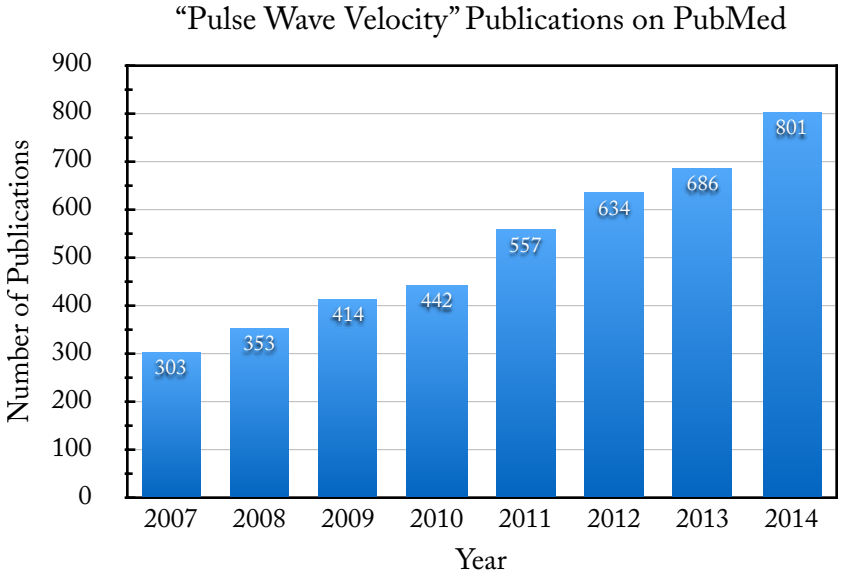
Predicting Cardiovascular Disease With Ease!

A Summary of Scientific Papers

1. What is pulse wave velocity and what does it do? Why is a device needed?

Pulse wave velocity (PWV) is a measure of arterial stiffness, or the rate at which pressure waves move down the vessels of the circulatory system. Pulse wave velocity, specifically cfPWV (carotid-femoral pulse wave velocity), is now considered the "gold standard" for measuring arterial stiffness.

The leading cause of death in the United States is cardiovascular disease. cfPWV is a valuable biomarker that can be measured non-invasively and accurately to improve risk prediction of cardiovascular events and mortality.



Pulse Wave Velocity and its merits are being recognized as it is becoming increasingly popular.

A Summary of Scientific Evidences:

1. Ben-Shlomo Y, Spears M, Boustred C et al. Aortic Pulse Wave Velocity Improves Cardiovascular Event Prediction. *Journal of the American College of Cardiology.* 2014;63(7):636-646.

   Summary:
   "Aortic stiffness can be assessed in a number of ways, but [PWV] is regarded as the current gold standard and has the and has the most evidence available linking it to cardiovascular risk." "The goal of this study was to determine whether aortic pulse wave velocity (aPWV) improves prediction of cardiovascular disease (CVD) events beyond conventional risk factors." "The main finding of the current study is that aortic stiffness, assessed by measurement of aPWV, can predict future cardiovascular events and mortality, even after accounting for other established cardiovascular risk factors."

2. Mozaffarian D, Benjamin EJ, Go et. al. Heart disease and stroke statistics—2015 update: a report from the American Heart Association [published online ahead of print December 17, 2014]. *Circulation*.

Summary:
"A few key statistics about heart disease, stroke, other cardiovascular diseases and their risk factors":
1."Cardiovascular disease is the leading global cause of death, accounting for 17.3 million deaths per year, a number that is expected to grow to more than 23.6 million by 2030."
2.About 85.6 million Americans are living with some form of cardiovascular disease or the after-effects of stroke.
3. "About 2,150 Americans die each day from these diseases, one every 40 seconds."

3. Steppan J, Barodka V, Berkowitz D, Nyhan D. Vascular Stiffness and Increased Pulse Pressure in the Aging Cardiovascular System. *Cardiology Research and Practice*. 2011;2011:1-8.

Summary:
Aging leads to many changes in the cardiovascular system, and (vascular stiffness) is a powerful predictor of adverse cardiovascular events. "Although systolic blood pressure and pulse pressure are surrogates for this process, vascular stiffness can be measured more precisely utilizing pulse wave velocity. Vascular stiffness, an index of vascular health, has been shown to confer additional independent predictive value for adverse cardiovascular outcomes."

4. Mitchell G, Hwang S, Vasan R et al. Arterial Stiffness and Cardiovascular Events: The Framingham Heart Study. *Circulation.* 2010;121(4):505-511.

Summary:
"Higher aortic stiffness assessed by PWV is associated with increased risk for a first cardiovascular event. Aortic PWV improves risk prediction when added to standard risk factors and may represent a valuable biomarker of cardio-vascular risk in the community."

5. Khoshdel A, Carney S, Nair B, Gillies A. Better Management of Cardiovascular Diseases by Pulse Wave Velocity: Combining Clinical Practice with Clinical Research using Evidence-Based Medicine. *Clinical Medicine & Research*. 2007;5(1):45-52.

Summary:
"Measurement of aortic PWV is an established measurement of vascular damage, as well as a useful methodology to evaluate treatment benefits." Previous studies have allowed the development of a useful calculation of risk.

6. Laurent S, Cockcroft J, Van BL, et al. Expert consensus document on arterial stiffness: methodological issues and clinical applications. *European Heart Journal.* 2006;27:2588–605.

Summary:
"Carotid-femoral PWV is the 'gold standard' for arterial stiffness, has the largest amount of epidemiological evidence for its predictive value for CV events, and requires little technical expertise."

7. Blacher J, Safar M. Large-artery stiffness, hypertension and cardiovascular risk in older patients. *Nature Clinical Practice Cardiovascular Medicine*. 2005;2(9):450-455.

Summary:
"The measurement of arterial stiffness is clinically relevant not only for risk assessment but also to quantify reductions in cardiovascular risk."

8. Blacher J, Asmar R, Djane S, London G, Safar M. Aortic Pulse Wave Velocity as a Marker of Cardiovascular Risk in Hypertensive Patients. *Hypertension.* 1999;33(5):1111-1117.

Summary:
"Increased aortic PWV was strongly associated with the presence of atherosclerosis alterations and was even a strong predictor of cardiovascular risk. These results could have important clinical implications in risk assessment strategies."

2. Why is pulse wave velocity a useful indicator in comparison to other measures of cardiovascular risk?

Pulse Wave Velocity is an accurate predictor across a wide range of demographics, including children, the elderly, those at intermediate risk, and those at high risk (the obese).

1. Keehn L, Milne L, McNeill K, Chowienczyk P, Sinha M. Measurement of Pulse Wave velocity in Children. *Journal of Hypertension*. 2014;32(7):1464-1469.

   Summary:
   Pulse wave velocity (PWV) is strongly predictive of cardiovascular risk in adults. In a study that both measured carotid-femoral pulse wave velocity (cfPWV) and brachial-femoral (bfPWV) using a variety of methods, measurement is "well tolerated by children and gives excellent repeatability."

2. Vlachopoulos C, Aznaouridis K, Stefanadis C. Aortic Stiffness for Cardiovascular Risk Prediction. *Journal of the American College of Cardiology*. 2014;63(7):647-649.

   Summary:
   Aortic pulse wave velocity have been increasingly recognized as a valuable biomarker for cardiovascular risk prediction. "aPWV improves the overall 10-year risk classification for intermediate-risk subjects (i.e., those in particular need for potential reclassification) by an important percentage (13%)." Thus, aPWV is "justified to be included in clinical practice for risk prediction."

3. Joly L, Perret-Guillaume C, Kearney-Schwartz A et al. Pulse Wave Velocity Assessment by External Noninvasive Devices and Phase-Contrast Magnetic Resonance Imaging in the Obese. Hypertension. 2009;54(2):421-426.

   Summary:
   "Carotid-femoral pulse wave velocity (PWV) is considered the gold-standard measurement of arterial stiffness. Obesity, however, can render inaccurate the measurement of PWV by external noninvasive devices." The study tested aortic PWV values obtained by invasive (MRI) and non-invasive methods in a population of obese subjects. Results indicate that for obese subjects with high body mass index (27-35), "PWV measured externally validly reflect values obtained directly in the thoracic aorta through MRI."

4. Cruickshank K. Aortic Pulse-Wave Velocity and Its Relationship to Mortality in Diabetes and Glucose Intolerance: An Integrated Index of Vascular Function?. *Circulation.* 2002;106(16): 2085-2090.

   Summary:
   PWV is a powerful independent predictor of later mortality across the entire spectrum of glucose tolerance, with or without overt type 2 diabetes. Because PWV measurement is simple and relatively inexpensive, PWV may become a useful clinical method for assessing vascular and general risk of mortality.

Additionally, the selected studies demonstrate that pulse wave velocity measurement will provide more information than blood pressure measurement. Arterial stiffness (measured by

PWV) is a precursor of hypertension and more accurate predictor of adverse cardiovascular events.

5. Rhee M, Na S, Kim J et al. Elevation of Aortic Pulse Wave Velocity by High Sodium Intake in Individuals With Hypertension and Sodium Sensitivity. *Journal of Hypertension*. 2015;33:e150

Summary:
"High sodium intake elevated aortic stiffness, which was blood pressure independent in hypertensives with SS. The result suggests that increased aortic stiffness due to high sodium intake may contribute to enhanced cardiovascular risk beyond BP elevation."

6. Laskey W, Siddiqi S, Wells C, Lueker R. Improvement in Arterial Stiffness Following Cardiac Rehabilitation. *International Journal of Cardiology.* 2013;167(6):2734-2738.

Summary:
In a group of intensively treated patients with advanced coronary heart disease, "arterial PWV was noted to significantly decrease over 20 weeks of a cardiac rehabilitation program. This change occurred in the absence of detectable changes in peripheral blood pressure or heart rate." "Changes in PWV may serve as a sensitive measure of altered arterial stiffness in patients with advanced atherosclerotic arterial disease despite ongoing medical therapy. The improvement in PWV was linked to the number of cardiac rehabilitation sessions attended."

7. Kaess BM, Rong J, Larson MG, Hamburg NM, Vita JA, Levy D, et al. Aortic Stiffness, Blood Pressure Progression, and Incident Hypertension. *Journal of the American Medical Association[serial online].* 2012;308(9):875-81. Available at: http://jama.jamanetwork.com. Accessed Sep 07,2012.

Summary:
Aortic stiffness is "associated with future systolic blood pressure, pulse pressure, and incident hypertension. Our findings support the notion that vascular stiffness is a precursor rather than the result of hypertension."

3. Why is there potential for this device in today's market?

Today's market shows the increasing need for a device. Reasons include (but are not limited to): 1. Low availability for patients to accurately assess their risk of a cardiac event, 2. Inaccuracies in current pulse wave velocity measurements, 3. Faults in other pulse wave velocity measurement devices

1. Mancia G. The 2007 ESH/ESC Guidelines for the management of arterial hypertension. *Journal of Hypertension*. 2008;26(4):825-826.

   Summary:
   Page 1469 (8) Table 4 identifies Arterial Stiffness (PWV) as a high predictive value, very low availability to patients and slightly lower than normal cost in 2007.
   Page 1474 (13) Box 6 recommends PWV as a test in hypertensive patients.

2. Weber T, Ammer M, Rammer M et al. Noninvasive determination of carotid–femoral pulse wave velocity depends critically on assessment of travel distance: a comparison with invasive measurement. *Journal of Hypertension*. 2009;27(8):1624-1630.

   Summary:
   Carotid-femoral pulse wave velocity (cfPWV) is the "favored measure of aortic stiffness." "However, there is no consensus on the measurement of distance travelled by the pulse wave along the aorta to the femoral artery." After comparing cfPWV values measured invasively and noninvasively, findings supported that " for noninvasive assessment of cfPWV, estimation of pulse wave travel distance is critical."

3. van Leeuwen-Segarceanu E, Tromp W, Bos W, Vogels O, Groothoff J, van der Lee J. Comparison of two instruments measuring carotid-femoral pulse wave velocity: Vicorder versus SphygmoCor. *Journal of Hypertension*. 2010;28(8):1687-1691.

   Summary:
   In a comparison between the cfPWV values "measured by an extensively used device (SphygmoCor) and the Vicorder in adults initially", the "LoA of both instruments exceed a value of 1.5 m/s. The LoA of the Vicorder [cfPWV] measurements are considered too wide for using this technique reliably in adults or in children."

4. What are the future implications of this device?

Pulse wave velocity is a known predictor of Cardiovascular Diseases (Heart Attack, Stroke, etc.) and Hypertension. Furthermore, pulse wave velocity has the potential to predict: Coronary Artery Disease, Chronic Kidney Disease, Diabetes, Cognitive Impairment, and Sleep Apnea.

Coronary Artery Disease:

1. Tautu O, Chirila S, Dorobantu M. Young Patients With Acute ST-Elevated Myocardial Infarction: How Stiff Are Their Arteries?. *Journal of Hypertension*. 2015;33:e29.

   Summary:
   "Arterial stiffness is correlated with both atherosclerotic risk factors (such as smoking, dislipidemic, BMI) and with the severity of coronary artery disease."

2. Luo K. Study on the association between arterial stiffness and risk of coronary artery disease. *Pakistan Journal of Medical Sciences*. 2014;30(6).

   Summary:
   Carotid-femoral PWV (cfWV) is an important way to measure the stiffness of the thoracic and abdominal aorta. In a study that compared cfPWV and baPWV in patients with and without Coronary Artery Disease, it was found that "baPWV and cfPWV are two independent factors for the risk of Coronary artery disease" and "can be explained by several mechanisms."

3. Tarnoki A, Tarnoki D, Godor E et al. Relationship of Coronoary Atherosclerosis with Arterial Stiffness and Central Systolic Blood Pressure. *Journal of Hypertension*. 2015;33:e29.

   Summary:
   Because "arterial stiffness, an independent predictor of cardiovascular disease, has been associated with the presence and extent of coronary artery calcification (CAC)", the study sought to assess the relationship between stiffness and presence of coronary atherosclerotic plaques. It was found that "Patients with coronary atherosclerosis have a higher arterial stiffness."

Chronic Kidney Disease:

4. Townsend R. Arterial stiffness and chronic kidney disease: lessons from the Chronic Renal Insufficiency Cohort Study. *Current Opinion in Nephrology and Hypertension*. 2015;24(1):47-53.

   Summary:
   The Chronic Renal Insufficiency Cohort Study measured the pulse wave velocity of over 2800 participants in order to analyze the relationship between PWV and kidney function, protein excretion, cardiovascular disease prevalence, and incident cardiovascular events such as heart failure. Recent findings from the CRIC study assert that "Pulse wave velocity is a robust, reproducible measure of arterial stiffness which adds important information to standard clinical assessments such as SBP and DBP in a population with chronic kidney disease."

5. Baumann M, Wassertheurer S, Suttmann Y et al. Aortic pulse wave velocity predicts mortality in chronic kidney disease stages 2-4. *Journal of Hypertension*. 2014;32(5):1115-1120.

Summary:
In end-stage renal disease, aortic stiffness predicts mortality, whereas this role remains uncertain in mild-to-moderate CKD. The study concluded that "results provide the first direct evidence that in patients with CKD stage 2–4, increased aortic stiffness determined by aPWV is a strong independent predictor of all-cause mortality."

Diabetes:

6. Stehouwer C, Henry R, Ferreira I. Arterial stiffness in diabetes and the metabolic syndrome: a pathway to cardiovascular disease. *Diabetologia.* 2008;51(4):527-539.

Summary:
"There is convincing evidence that diabetes and the metabolic syndrome are associated with greater arterial stiffness." There is a marker of greater arterial stiffening "in middle-aged and older individuals but even in relatively young type 1 diabetic individuals."

Cognitive Impairment:

7. Karasavvidou D, Pappas K, Stagikas D, Makridis D, Katsinas C, Kalaitzidis R. PWV is an Independent Determinant of Cognitive Dysfunction in CKD Patients. *Journal of Hypertension*. 2015;33:e57.

Summary:
Cognitive dysfunction is a complication of chronic kidney disease (CKD). "Carotid-femoral PWV may be a more sensitive marker of cognitive dysfunction than other parameters of central blood pressure. In clinical practice, measuring aortic stiffness may help predicting the cognitive decline."

8. Watfa G, Benetos A, Kearney-Schwartz A et al. Do Arterial Hemodynamic Parameters Predict Cognitive Decline Over a Period of 2 Years in Individuals Older Than 80 Years Living in Nursing Homes? The PARTAGE Study. *Journal of the American Medical Directors Association*. 2015;16(7): 598-602.

Summary:
Arterial stiffness (evaluated by carotid-femoral pulse wave velocity or cfPWV) "enabled to identify subjects at higher risk of cognitive decline, while blood pressure alone did not appear to have a significant predictive value." The findings also highlight "the contribution of vascular determinants in cognitive decline even in this very old population."

9. Subclinical Brain Damage Gasecki D, Kwarciany M, Kowalczyk K et al. Aortic Stiffness is an Independent Biomarker of Subclinical Brain Damage in Acute Ischemic Stroke. *Journal of Hypertension*. 2015;33:e58.

Summary:

"Increased aortic stiffness is associated with brain microvascular disease in patients with acute ischemic stroke, beyond and above classical risk factors. PWV provides a useful new tool for identification of subclinical brain damage in AIS."

Sleep Apnea:

10. Seetho I, Parker R, Craig S, Duffy N, Hardy K, Wilding J. Obstructive sleep apnea is associated with increased arterial stiffness in severe obesity. *Journal of Sleep Research*. 2014;23(6):700-708.

Summary:
"Patients with obstructive sleep apnea with severe obesity have increased arterial stiffness that may potentially influence cardiovascular risk independently of metabolic abnormalities."