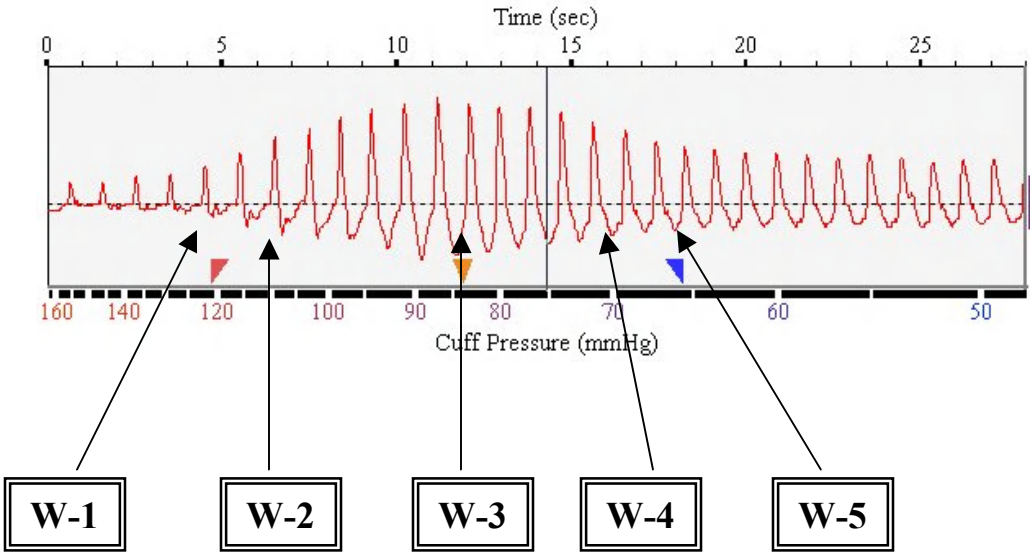
DynaPulse Korotkoff Sound Equivalent Blood pressures: Phase-1 (K1-eq.) Systolic, and Phase-4 (K4-eq.) and Phase-5 (K5-eq.) Diastolic

By, Shiu-Shin Chio, PhD
Inventor of Pulse Dynamics
Founder of DynaPulse/Pulse Metric, Inc.

In1988, the first DynaPulse cuff-sphygmomanometer was built and recorded the digitized pulse waveform during a blood pressure measurement. Since then, increasing interest has been directed to, not only the nature of bell-shaped oscillometric pulse signals, but also the gradually changing patterns of pulse waveform when cuff pressure decreases from higher than systolic to below diastolic. Figure 1 below illustrates this Pulse Dynamics phenomenon and the five-waveform types of interest, W-1 to W-5, that are observed.

Figure 1. The Oscillometric signals of DynaPulse cuff sphygmomanometer and the five pulse waveform patterns



Following are descriptions of these 5 waveforms and their most likely associations to the five phases of Korotkoff sounds.

W-1: The first pulse with its waveform displaying negative pressure at the bottom or beginning of the diastole cycle (the end of systole cycle). This indicates that a small amount of blood is flowing through the cuff-restricted brachial artery area, an effect of the Bernoulli principle. This point (W-1) at the cuff pressure is determined as the Systolic of Pulse Dynamics, or the **DynaPulse Systolic** blood pressure. It was compared and validated against **central aortic systolic** blood pressure measured by catheterization method **(146 +/- 4 vs. 145 +/- 5 mmHg, n=36, r=0.94)** at UCSD Medical Center with results published in American Journal of Cardiology, 1997; 80:323-330, Reference [1]. At point W-1, the amount of blood flowing through the brachial artery under the cuff is small, resulting in small pulse amplitude, and may not have strong enough force to generate Korotkoff phase-1 sound (K1).

W-2: Where cuff pressure further decreases, its restriction to brachial artery became less, and significant amount of blood flowed through, pulse amplitude increased, which interacted and applied enough force to brachial artery, and Korotkoff phase-1 sound (K1) can be detected by a stethoscope placed under the cuff and on the down-stream of the brachial artery. As described in the ANSI/AAMI 1987 guidelines [2], the Korotkoff phase-1 sound (K1) was described below:

Korotkoff Phase I (**K1** sound) - begins with the sudden appearance of a faint, clear, tapping or thumping sound that gradually increases in intensity.

Many medical text books and early publications indicated the difficulty of understanding the physics of how and why the Korotkoff sounds were generated, and previous studies found dependencies to age or brachial artery elasticity or stiffness, as well as the hearing ability of human ears [3]. Studies comparing DynaPulse Systolic to K1 systolic reading at mean ages of 47 (n=132, 38 male) [4] and 30 (n=803, 313 male) [5] resulted with DynaPulse systolic W-1 of 5 mmHg and 9 mmHg higher than K1 Korotkoff phase-1 readings respectively. Another study, applied DynaPulse to children as young as 2 years old. Results indicated that the W-1 systolic could be as high as 13 mmHg above the K1 reading [6]. For simpler comparison of **DynaPulse W-1 Systolic (W1)** to the Korotkoff phase-1 (K1) reading, and using them with the JNC-7 guideline for classifying and managing hypertension [7], **Table-1** provides a summary of our suggested **DynaPulse K1 equivalent systolic** (**DynaPulse K1-eq**.) reading for different age groups:

Table 1. Estimation of DynaPulse K1-eq. Systolic vs. Age*

Age range:	40 and up	18-39	17 and younger
DynaPulse K1-eq. Systolic (mmHg) =	W1 - 5	W1 - 9	W1 less (9 to 13)**

***Note**: The above DynaPulse K1-eq. estimation is intended for use as a reference only. It may vary from person-to-person depending on his/her cardiovascular conditions, where blood pressure waveform and phenotype are different and hemodynamic profiling is required.*
***** DynaPulse** is designed for use with small/medium/large adult size cuffs. Using DynaPulse on children with smaller cuff would require calibration and adjustment of the DynaPulse unit. DynaPulse monitor used in reference [6] study was not adjusted and calibrated for small children cuff by Pulse Metric.*

W-3: In this area, DynaPulse oscillometric pulses display peak amplitude and following pulse with its lower part of pulse waveform, known as the diastolic cycle, shows a balanced "V" shape. The associated cuff pressure at this point is applied to determine the mean arterial pressure (MAP). The DynaPulse MAP was compared and validated against invasive catheterization pressure at central aorta with results of (100 +/- 3 vs. 100 +/- 3 mmHg, r=0.95) [1]. In general clinical practice, MAP may be estimated from Korotkoff K1 systolic and K4 diastolic readings as MAP = 1/3*K1-SBP + 2/3*K4-DBP. Pulses around this W-3 area is most likely where the Korotkoff sounds phase-2 and phase-3, as described in ANSI/AAMI 1987 Guideline [2], would become detectable:

- ***Phase II** - phase I ends and phase II begins when the sounds change to a loud "swishing" murmur.*
- ***Phase III** - the beginning of Phase III occurs when the sounds assume a loud, distinct, knocking quality. These sounds are less intense than those of Phase I.*

W-4: While cuff pressure continues to drop, the pulse waveform, specifically the diastolic cycle or lower portion, changes shape significantly. This may associate closely to the "tone" change, or the "muffled" or "murmur-like swishing" of the Korotkoff phase-4 (K4) diastolic sound, as described at ANSI/AAMI 1987 Guideline [2]:

- ***Phase IV** - begins when the sounds suddenly become muffled and have a faint murmur-like or "swishing" quality.*

A study comparing the **Korotkoff phase-4 (K4)** and phase-5 (K5) **diastolic** readings, determined by the protocol of Bogalusa Heart Study [5], to

DynaPulse Diastolic (**W-5,** discussed below), indicated that **K4 diastolic was approximately 5 mmHg higher** (n=803, mean age=30, 313 male).

W-5: At this cuff pressure, the DynaPulse oscillometric pulse waveform has its diastolic cycle, the wave's lower portion reach a steady state and remain unchanged for the following several pulses. The beginning of this phase is the determined point of **DynaPulse Diastolic pressure (W5)**. When compared with invasive catheterization **central aortic diastolic** measurement, we found **DynaPulse W-5 Diastolic** to be approximately 3 mmHg higher **(80 +/- 2 vs. 77 +/- 2 mmHg, n=36, r=0.91)** [1].

The study [5] at Bogalusa Heart Study, comparing **DynaPulse W-5 Diastolic** to the **Korotkoff phase-5 (K5) diastolic** reading, indicated that **DynaPulse W-5 Diastolic was less than 1 mmHg higher** (n=803, mean age=30, 313 male).

For reference, the Korotkoff phase-5 sound described in ANSI/AAMI 1987 Guideline [2] was: *"**Phase V** - begins when silence develops."*

Table-2 is our suggested DynaPulse K4 and K5 equivalent readings (K4-eq. and K5-eq.) vs. DynaPulse W-5 Diastolic (W5) value.

Table 2. Estimation of DynaPulse K4-eq. and K5-eq. Diastolic

Korotkoff Phase:	**K4-eq.**	**K5-eq.**
DynaPulse Diastolic K-sound equivalent (mmHg)* =	**W5+5**	**W5**

**** Note**: The above DynaPulse K4-eq. and K5-eq. estimations are intended for use as references only. They may vary from person-to-person depending on his/her cardiovascular conditions, where blood pressure waveform and phenotype are different and hemodynamic profiling is required.*

References:

[1] Brinton TJ, Cotter B, Kailasam MT, Brown DL, Chio SS, O'Connor DT, DeMaria AN. "Development and Validation of a Non-invasive Method to Determine Arterial Pressure and Vascular Compliance". Am J Cardiol 1997;80:323-330.

[2] American National Standard Institution/Association for the Advancement of Medical Instrumentation (ANSI/AAMI). "American national standard for eletronic or automated sphygmomanometer", Arlington, VA: 1987 Guideline.

[3] Ellestad MH. “Reliability of blood pressure recordings”. Am J Cardiol. 1989;63:983-985.
[4] Brinton TJ, Walls ED, Chio SS. “Validation of pulse dynamic blood pressure measurement by auscultation”. Blood Press Monit. 1998;3:121-124.
[5] Chio SS, Urbina EM, Berenson GS, et.al. “Korotkoff sound vs. oscillometric cuff sphygmomanometers: comparison between auscultatory and DynaPulse blood pressure measurements”. JASH 2011 (Jan.); 5(1): pages 12-20 (http://dx.doi.org/10.1016/j.jash.2010.10.005)
[6] Goonasekera CD, Wade AM, Slattery M, Brennan E, Dillon MJ. “Performance of a new blood pressure monitor in children and young adults: the difficulties in clinical validation”. Blood Press. 1998 Jul;7(4):231-7.
[7] “The Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure (The JNC-7 Report)”, By Chobanian AV, et. al., the National High Blood Pressure Education Program Coordinating Committee, J Am. Med. Asso. (JAMA) 2003; 289: 2560-2572; Links to JNC-7:
http://www.acpinternist.org/archives/2006/09/prehyp_chart.pdf
http://www.nhlbi.nih.gov/guidelines/hypertension/

NOTE to DynaPulse users: Applying DynaPulse K-sound equivalent systolic and diastolic to JNC-7 Hypertension Guideline - *Please note that JNC-7 guideline and many clinical studies published in the US measured K1 systolic and K5 diastolic readings of the Korotkoff sound phases. For comparison with JNC-7 and these studies, use of DynaPulse K1-eq. Systolic and K5-eq. Diastolic is recommended. For other studies and studies in Europe and overseas, Korotkoff sound phase-4 (K4) diastolic might be applied in their publications.*

For more information please contact:

Clinical Research Div.
DynaPulse/Pulse Metric, Inc.
2100 Hawley Dr.
Vista, CA 92084 USA
www.dynapulse.com