

Application Note 269 How CareTaker (NIBP-MRI) Works

The basic theory behind Pulse Decomposition analysis (PDA) is fully explained in a peer reviewed paper; see: <http://www.nonlinearbiomedphys.com/content/5/1/1>.

It is a fairly simple idea that the arterial pulse is not a single disturbance, but has internal structure and the structure has causes. The structure is composed of five individual pulses which sum to the familiar arterial pulse wave form. In many young people and some others these pulses are clearly observable in the raw data, see figure 1.

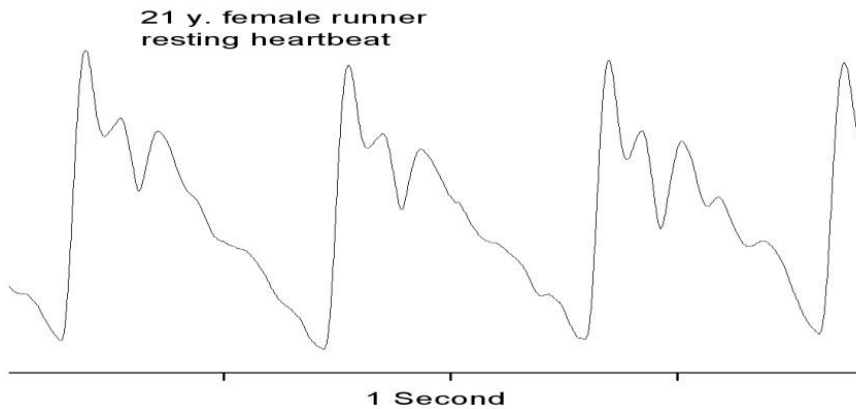


Figure 1

Raw data obtained from radial artery. Note that there are five distinct features, which are especially visible in the third pulse of the pulse train. In general, CareTaker (NIBP-MRI) can find the first three constituent pulses on almost all pulses of larger mammalian animals. The fourth and fifth are not used for the purposes of calculation of hemodynamic parameters and are often swallowed up by the faster heart rates of smaller animals. In equine species, all five constituent pulses are easy to obtain. In small monkeys, it is often difficult to obtain the first three. In humans, the first three are easily obtained, but no work has been done on children under ten.

These constituent pulses are also observable in the raw data obtained by central catheters in people with very short left ventricular ejection time because the narrowness of the pulses do not allow overlap which washes out the structure. At the hand, the inherent low frequency mechanical filtering of the arterial system smears out the separation of those individuals with short left ventricular ejection time periods. In PDA, all measurements concerning these pulses are made relative to the primary pulse that is ejected from the heart into the aorta. For reference, note that the pulse moves very fast (5 to 15 meters per second) and this is a temporal disturbance in the arteries. The blood, however, is flowing at a relatively slow rate of only about 2 cm/sec.

In the paper cited above, there are references to other papers that discuss the reflections or echoes that occur in the aorta. These reflections, like echoes, are due to hydrodynamic impedance mismatch, one at the transition of thoracic to abdominal aorta and one at the lower iliac artery, which is due more to the bifurcation. The hydrodynamic "smoothness" of the aorta and iliac allow for only two reflection sites. The only exception is in the case of some aortic aneurysms where a sixth pulse from a third reflection site has been observed. This third aberrant reflection site has also been observed to disappear after corrective surgery on the aorta leaving only the two normal reflection sites behind.

The structure of the pulse due to the main pulse and its reflections, sum to a pressure wave form that can be observed at the radial artery. Usually the observed pressure wave form has only bumps on it that show where the individual constituent pulses are. Almost always there is a large bump called the diastolic peak that is due to the powerful reflection in the iliac artery. Often, it is difficult or impossible to see any structure but the first and third pulse, especially in older adults. The second systolic pulse, however, is often visible as an inflection on the wave form. The PDA algorithm uses a number of spectroscopic techniques to locate the first three of the pulses, that is, it locates

- 1) the center of the Diastolic Peak 115 ms 0.2 Seconds 121 ms 193 ms 172 ms 168 ms Second Systolic Peak "Radial Reflection" (not visible) pulse which originates from the heart and establishes this as the zero of further measurements for both time and amplitude,
- 2) the center of the pulse and amplitude, that is, the echo from the thoracic/abdominal transition, and
- 3) the center of the pulse and amplitude that originates from the iliac artery due to the bifurcation.

The algorithm thus determines the arrival time of the second and third pulse relative to the first and the peak heights relative to the first. The fourth and fifth pulses are not used in the analysis and are often swallowed by the next heartbeat if the heart rate is fast. The fourth and fifth occur because of re-reflections.

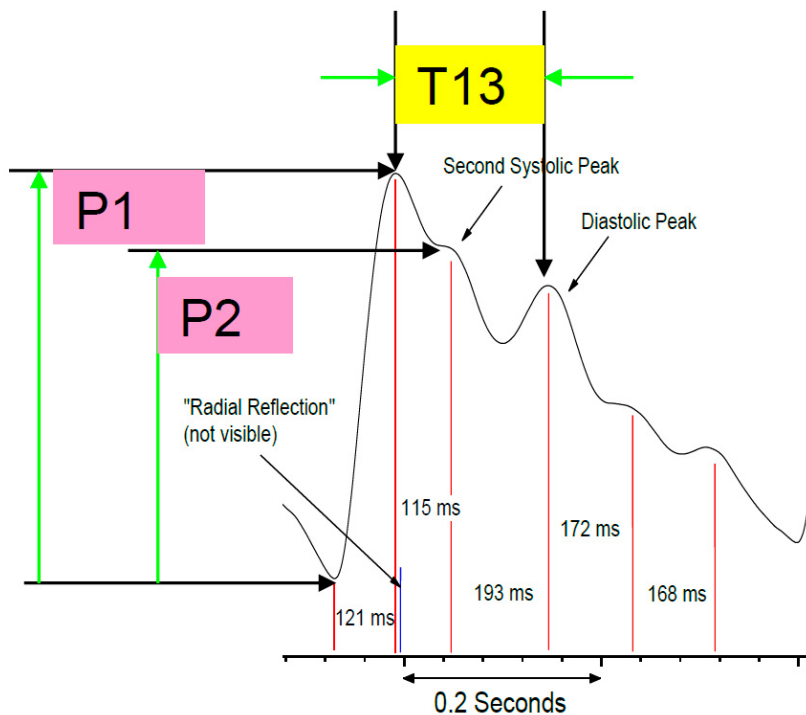


Figure 2

This figure shows an actual raw data pulse that happens to exhibit the five constituent pulses. P2 rises and falls linearly with systolic blood pressure. T13 lengthens or shortens in time linearly with pulse pressure. Loss of blood volume, say due to a routine blood donation is observed in the shortening of the T13 time because hemorrhaging is directly related to pulse pressure. Diastolic blood pressure is calculated by subtracting the pulse pressure from the systolic blood pressure. All measurements are done on each detected pulse and are therefore beat by beat.

The amplitude of the second systolic peak (the second pulse of the five or also the first echo) tracks or follows the **systolic blood pressure** linearly. In other words, the relation between SBP and P2 (the amplitude of the second pulse) can be stated as

$$Y = mx + b$$

where $Y = \text{SBP (systolic blood pressure)}$

$m = \text{gain factor (mostly the same in humans from around the ages of ten to adult, but set for the individual during the calibration period)}$

$x = \text{P2 (amplitude of the second pulse)}$

$b = \text{the offset (determined by calibrating to a known absolute BP)}$

This is not unlike a thermometer that reads Celsius degrees. The zero of a Celsius temperature scale does not start at the absolute zero, but the thermometer is linear, but relative. CareTaker (NIBP-MRI) (NIBP-MRI) can measure differences in blood pressure between heart beats, but, unless calibrated, cannot measure the absolute blood pressure. Like a Celsius thermometer, CareTaker (NIBP-MRI) (NIBP-MRI) is measuring relative changes.

Similarly, the time between the third pulse or iliac reflection and the first pulse, T13, linearly tracks the pulse pressure. So, the CareTaker (NIBP-MRI) (NIBP-MRI) 1) detects the time varying pressure in the artery, 2) converts this time varying pressure to a time varying voltage (which also time differentiated the signal and prevents long settling times), 3) digitizes the arterial pulse voltage signal, 4) uses PDA to find the peaks and arrival times, and 5) computes P2/P1 and T13. This happens for every heartbeat.

The **diastolic blood pressure** equals the systolic blood pressure minus the pulse pressure.

The **heart rate** is calculated by counting the time between the primary peaks and is called the interbeat interval. Its inverse is the pulse rate.

Empirical Technologies Corporation, PO BOX 8175, Charlottesville, Virginia 22906-8175