New algorithm for automatic determination of systolic and diastolic blood pressures in oscillometric measurements

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Introduction

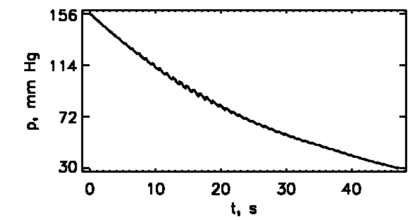
- Most **n**on-**i**nvasive **b**lood **p**ressure – (NIBP) measurements are based on either the auscultatory or the oscillometric technique
- Both techniques use and inflated cuff wrapped around the extremity and measure signal during cuff pressure deflation.

- The auscultatory technique uses the presence and absence of acoustic pulses (Korotkoff sounds) generated by blood flow through an occluded artery. These sounds are usually detected by a trained observer with a stethoscope. The pressure level in the cuff is manually controlled and observed by a mercury sphygmomanometer.
- This technique is still the method of choice for NIBP measurements in the office and represent a golden standard for NIBP measurements.

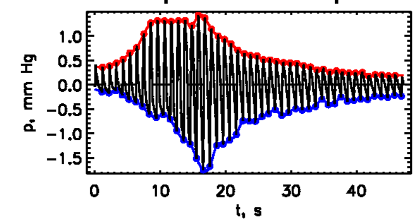
Introduction (Oscillometric technique)

- The oscillometric technique is based on arterial pressure pulses, called oscillometric pulses that are generated by arterial blood pressure (BP) pulsation in the cuff that occludes the artery during cuff pressure deflation.
- Algorithms for automatic determination of the systolic (SP) and the diastolic (DP) pressure values are based on some empirically derived criteria applied to the so-called oscillometric index, which is defined as certain characteristic physical properties (for example peak-to-peak values) plotted vs. the baseline cuff pressure.
- However, the algorithms used for detecting SP and DP are different from one device to another and are not revealed by the manufacturers.

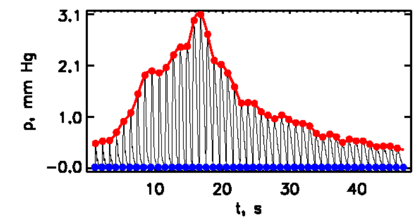
Measured pressure data



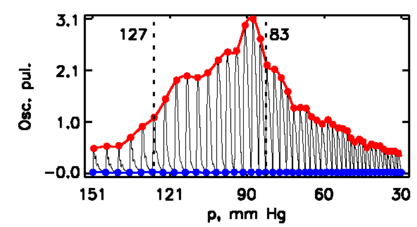
Filtered pressure pulses



Peak-to-peak pulses



Oscllometric index



Objective

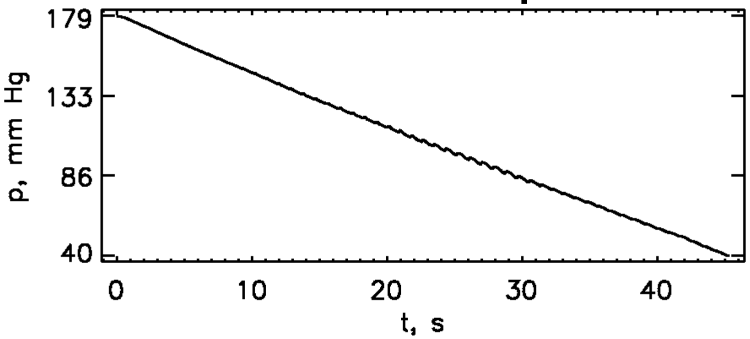
- The aim of this work is to find a possibly better method of oscillometric data analysis in NIBP measuring devices.
- We demonstrate a new presentation of an enhanced oscillometric index obtained by a powered short time variance (STV) of the oscillometric data.
- Such a presentation shows significant activity only below SP and above DP values, which like in the case of the auscultatory technique, simplifies the criteria for the automatic determination of blood pressure values.
- We introduce a new algorithm for automatic detection of SP and DP using our newly developed STV oscillometric index
- and compare it with known algorithms applied to oscillometric index based on peak-to-peak oscillation amplitudes,
- and finally evaluate these algorithms for 92 measurements performed on 23 healthy volunteers.

Measurements

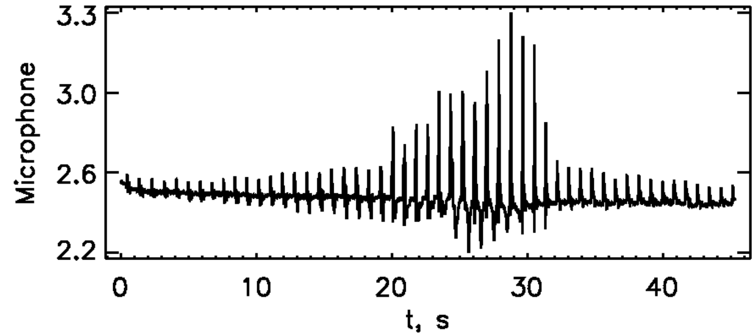
- EU-project “Simulator for NIBP”
- LODE (Groningen, NL)
- Compressor for the cuff inflation and a pressure sensor built in a personal computer
- Upper arm cuff (Accoson, UK) with implanted microphone
- Simultaneous measurements with commercial automated NIBP device OSZ4 (Welch Allyn)

Overview of data obtained with NIBP device

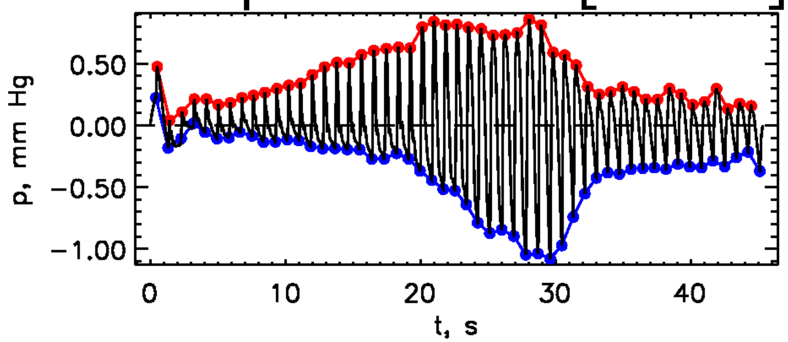
Measured data – pressure



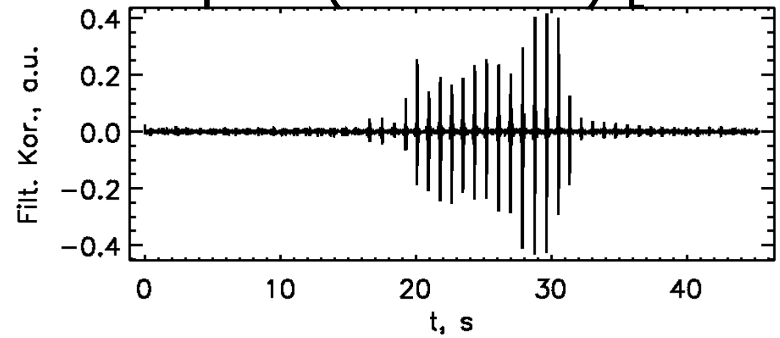
Measured data – microphone



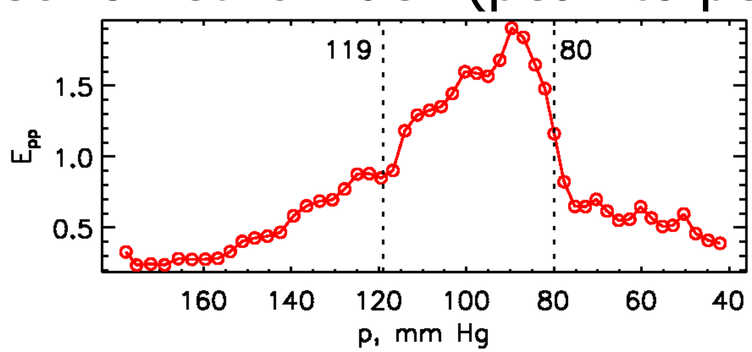
Pressure pulses - filter[0.3-40] Hz



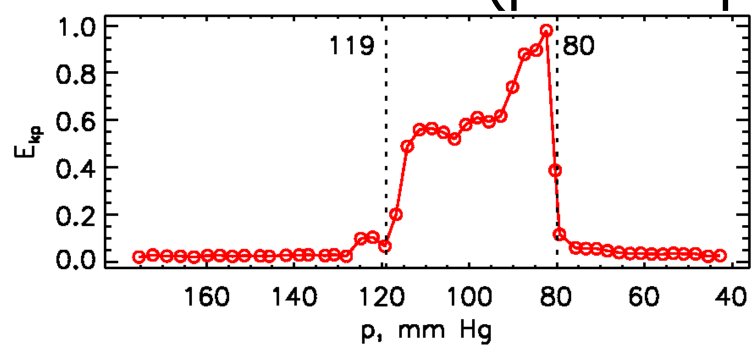
Audible part (Korotkoff) [10-40] Hz



Oscillometric index (peak to peak)



Oscillometric index (peak to peak)

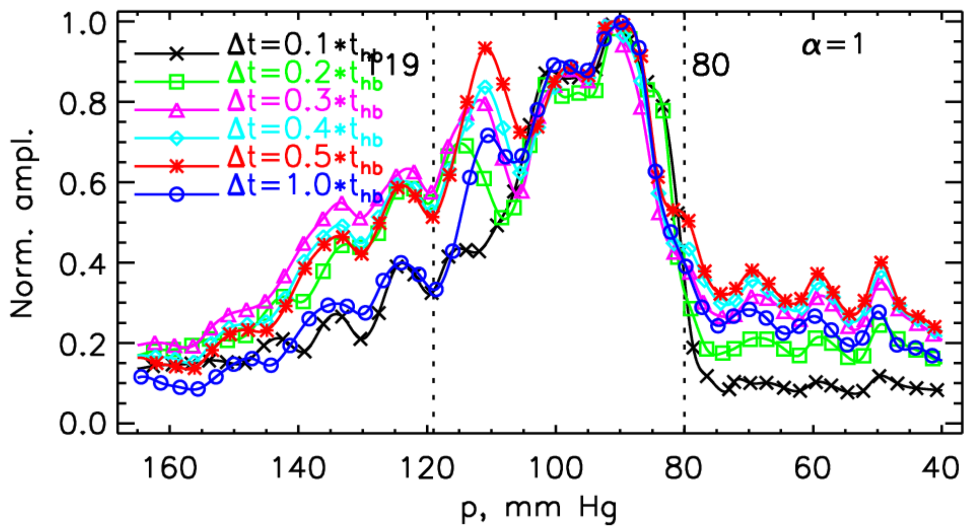


Enhanced oscilometric index

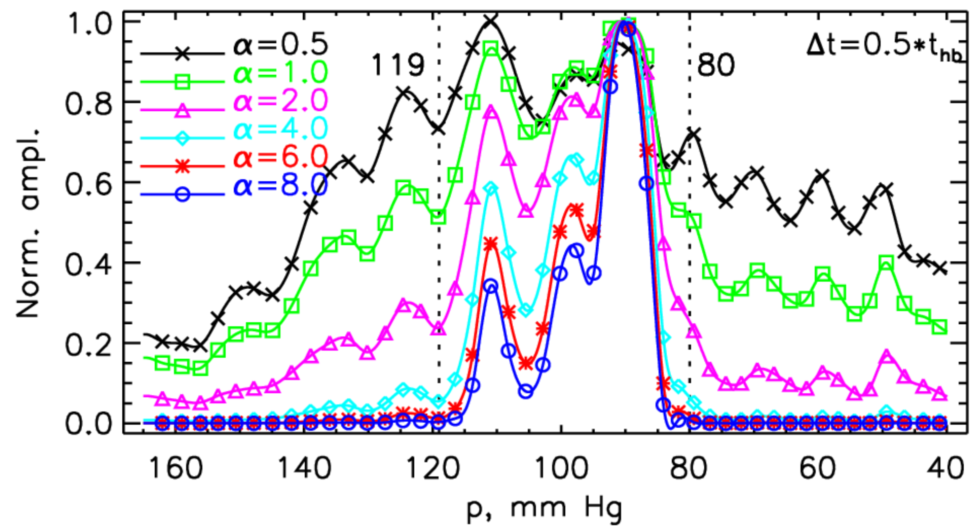
Power enhanced short-time normalized variance (STV) of NIBP data *p(t)* at the time subintrevals Δ*t*

$$V^{\alpha}(t_i) = V_i^{\alpha} = \left\| \sum_k \left(p(t_k) - \overline{p}_i \right)^2 \right\|^{\alpha}, \ \overline{p}_i = \frac{1}{N} \sum_k p(t_k), \quad t_k \in \left[t_i - \frac{\Delta t}{2}, t_i + \frac{\Delta t}{2} \right]$$

Influence of Δt (in units of heartbeat t_{HB})



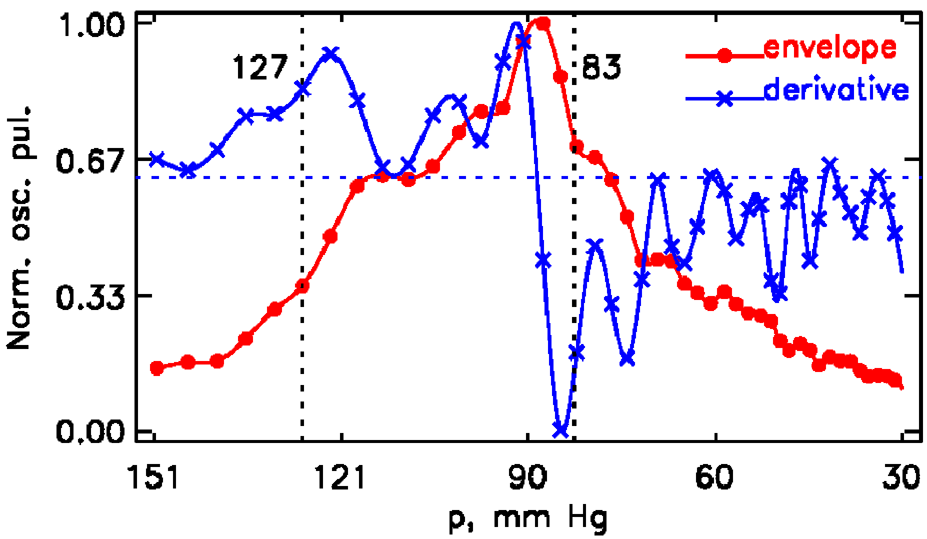
Influence of power α (Δt= t_{HB}/2)

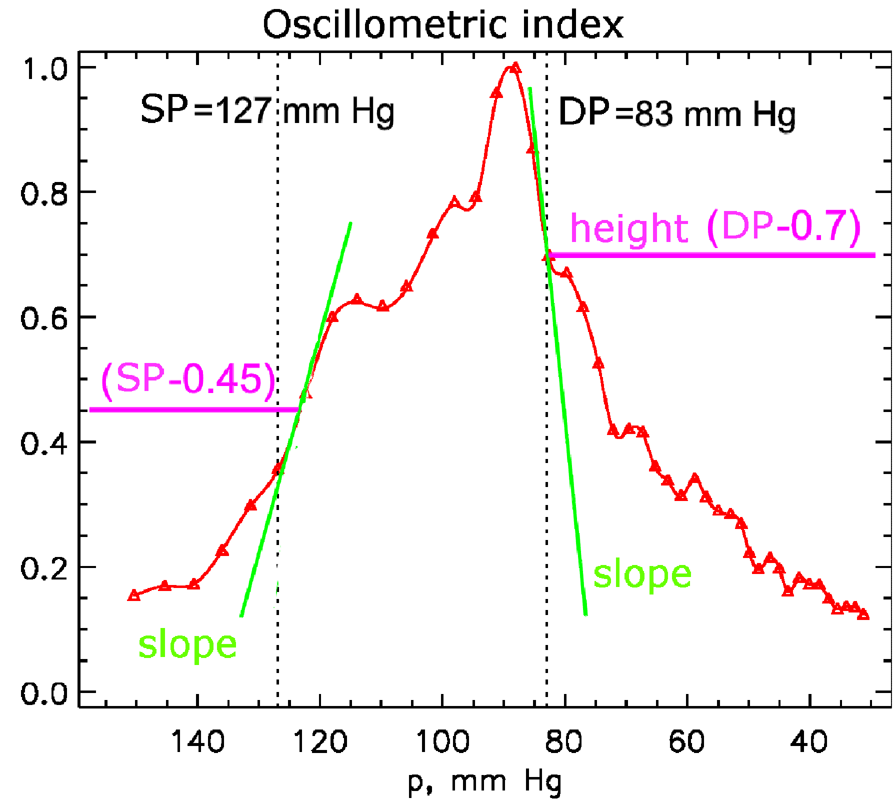


Known algorithms for SP and DP

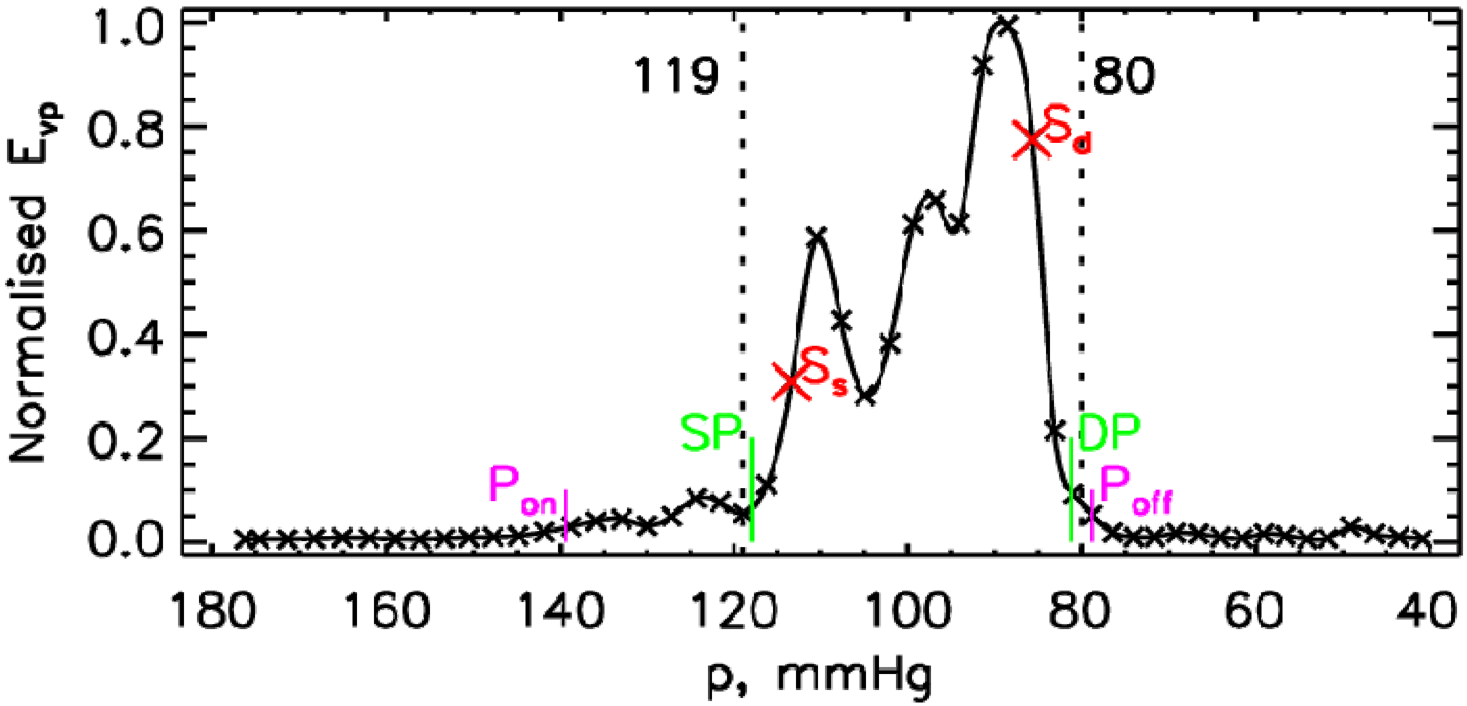
- Height based (HB) method
  uses characteristic height ratios
  (SP - 0.45, DP – 0.7)
- Slope based (BS) method
  uses maximum slope of the curve

- Non-monotonic curve –
  constraints in SB method





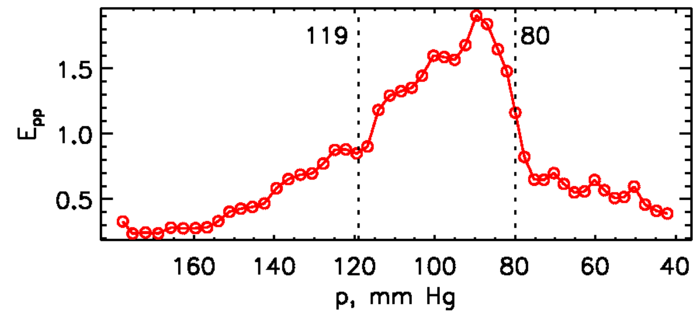
Presence/absence (PA) algorithm



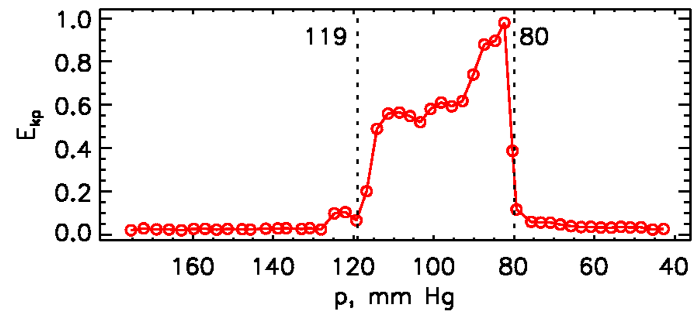
- The first estimates of SP Pon (onset) and DP Poff (offset) are defined as the deflation level at which threshold values ***Ts*** and ***Td*** for SP and DP are first reached, respectively. ***Ts*** and ***Td*** are determined from average background activities (mean value in time interval of 3 heartbeats)
- Then we found maximum slope (Ss) just after Pon and maximum slope (Sd) just before Poff.
- The final estimations of SP and DP are determined, when a rapid change of increasing and decreasing of signal activity occur. SP was determined as the first pressure below Pon where the envelope value increased by more than Ss/3, and DP as the first pressure above Poff where the amplitude increased by more than Sd/3 in the time interval of one heatbeat.

Example - reference: 119/80 mm Hg

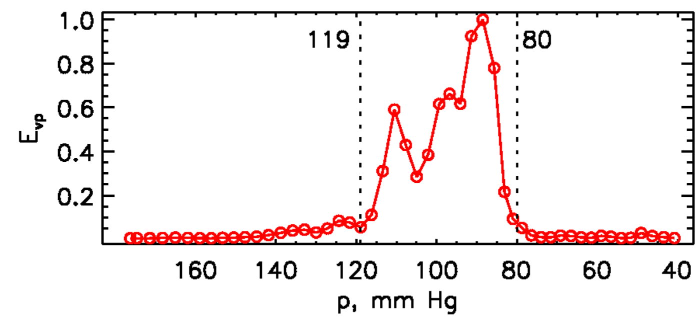
- Pressure pulses:
  HB: 121/81 mm Hg
  SB: 114/80 mm Hg



- Korotkoff sounds:
  PA: 120/77 mm Hg



- Short time variance:
  PA: 118/81 mm Hg



Evaluation of NIBP devices

Two standard protocols for evaluation of NIBP devices:

1. British Hypertension Society (BHS) – at least grade B

	Absolute difference between standard and test device		
Grade	≤ 5 mm Hg	≤ 10 mm Hg	≤ 15 mm Hg
A	60 %	85 %	95 %
B	50 %	75 %	90 %
C	40 %	65 %	85 %
D	otherwise		

2. American Association for the Advancement of Medical Instrumentation (AAMI):
   - Average absolute difference: $|\Delta p| \leq 5$ mm Hg
   - Standard deviation: SD ≤ 8 mm Hg

Evaluation protocol

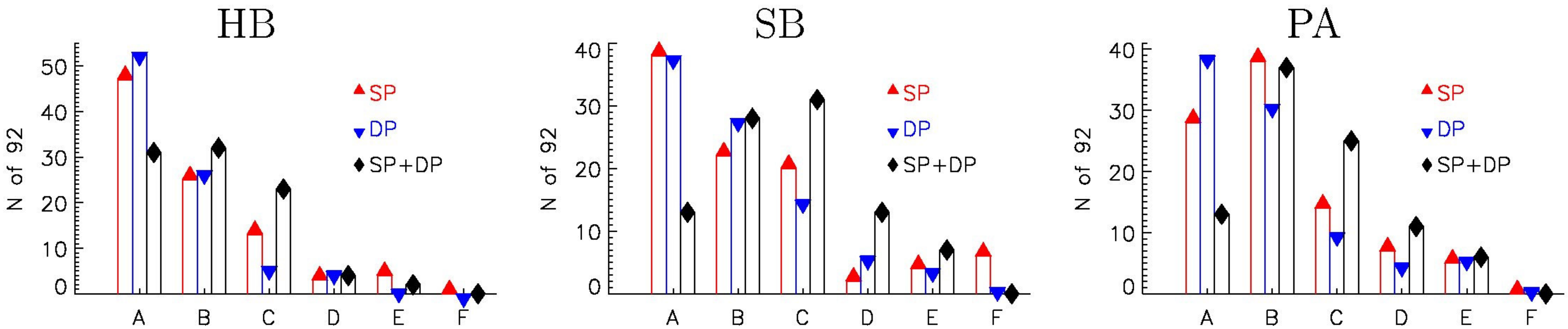
- Modified version of AAMI and BHS protocols
- Similar to BHS protocol, results were classified into grades (6)
- For every SP and DP, we found classification values V_{SP} and V_{DP}, and calculated combined value V_{SP+DP} (biased to the worse of the V_{SP} and V_{DP})

Grade	Value	description	absolute difference
A	1	excellent	0 or 1 mm Hg
B	2	very good	2 or 3 mm Hg
C	3	good	4 to 5 mm Hg
D	4	approximate	6 to 7 mm Hg
E	5	bad	8 to 10 mm Hg
F	6	fail	more than 10 mm Hg

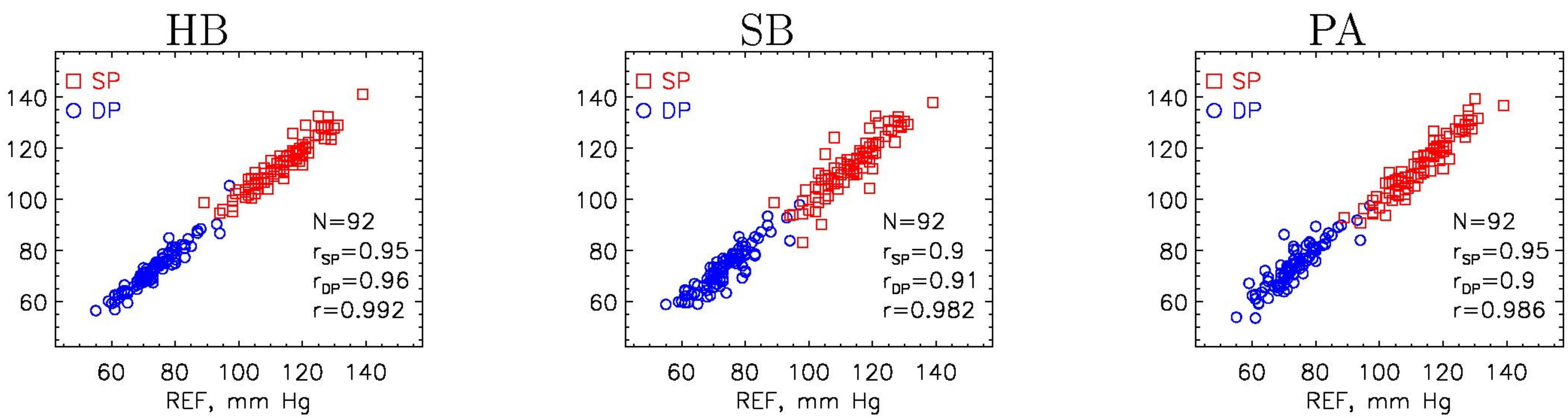
$$V_{SP+DP} = \mathrm{round}\left(\frac{\min(V_{SP},V_{DP}) + 4 \cdot \max(V_{SP},V_{DP})}{5}\right).$$

- Like in AAMI protocol, we calculated $|\Delta p| \pm SD$ (average absolute difference).
- In addition, we have also calculated $\Delta p \pm SD$ (average difference),
- linear regression correlation coefficient r,
- and maximum difference Δp_m

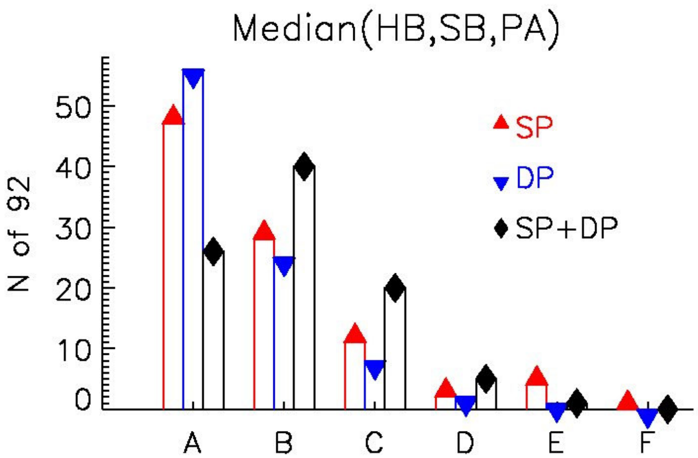
Results (92 measurements on 23 volunteers)



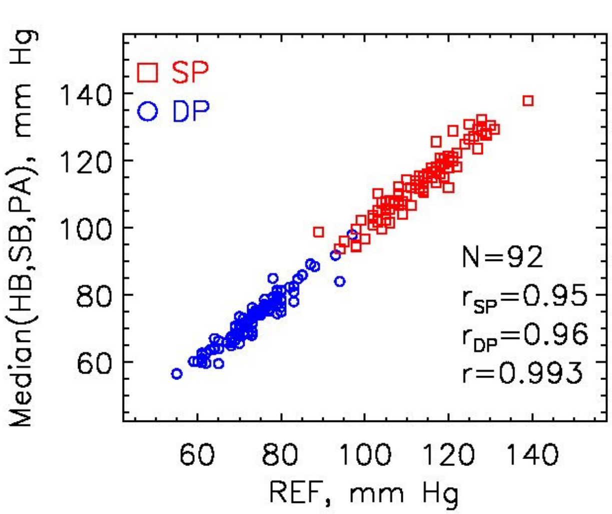
BP	Height based (HB)					Slope based (SB)					Presence/Absence (PA)				
	F	C	$\Delta p \pm \mathrm{SD}$	$\lvert\Delta p\rvert \pm \mathrm{SD}$	Δp_m	F	C	$\Delta p \pm \mathrm{SD}$	$\lvert\Delta p\rvert \pm \mathrm{SD}$	Δp_m	F	C	$\Delta p \pm \mathrm{SD}$	$\lvert\Delta p\rvert \pm \mathrm{SD}$	Δp_m
SP	0	87	0.13 ± 3.0	2.2 ± 1.9	10	5	82	-0.67 ± 4.6	3.0 ± 3.6	-18	0	80	0.18 ± 3.6	2.9 ± 2.2	10
DP	0	86	-0.56 ± 2.5	1.8 ± 1.8	8	2	79	-0.68 ± 3.6	2.7 ± 2.5	-11	1	80	0.50 ± 3.8	2.6 ± 2.7	16
SP+DP	0	85	-0.22 ± 2.8	2.0 ± 1.9	10	1	74	-0.68 ± 4.2	2.8 ± 3.1	-18	0	75	0.34 ± 3.7	2.7 ± 2.5	16

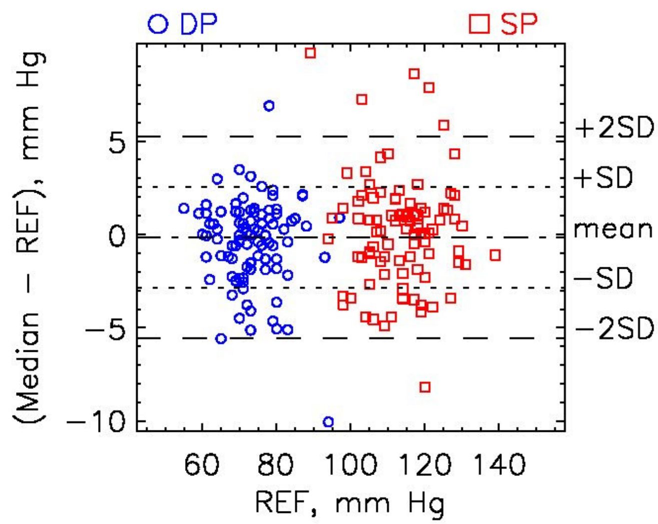


Median results



BP	Height based (HB)				
	F	C	$\Delta p \pm \mathrm{SD}$	$\lvert\Delta p\rvert \pm \mathrm{SD}$	Δp_m
SP	0	87	-0.09 ± 2.7	2.0 ± 1.8	9
DP	0	89	-0.43 ± 2.4	1.8 ± 1.7	-10
SP+DP	0	87	-0.26 ± 2.6	1.9 ± 1.8	-10





Detailed statistics of the median values show that in total most of them are selected from HB method (39 SP, 51 DP), followed by SB method (34 SP, 26 DP), and PA (15 SP, 15 DP).

Conclusions

- We proposed a new presentation of the oscillometric index based on the power enhanced STV of measured pressure data,
- which like in the case of Korotkoff sounds in conventional auscultatory method showed significant signal activity only in the region below SP and above DP values.
- We developed the presence/absence (PA) algorithm for automatic determination of SP and DP values.
- Evaluation studies performed on 92 recordings measured on 23 healthy volunteers showed that the proposed PA algorithm gave results comparable to results of the two known algorithms, height based (HB) and slope based (SB) applied to oscillometric index constructed form pressure pulses.
- Median values of SP and DP estimated by the HB, SB and PA methods gave the best match with the corresponding measured SP and DP.

Thank you for your attention