Blood Pressure and Impedance Cardiography during Tilt Table Test

P Jurak[1], J Halamek[1], V Vondra[1], M Plachy[2],
P Frana[2], P Leinveber[1]

[1]Institute of Scientific Instruments of the ASCR, vvi, Brno, Czech Republic
[2]St Anne's University Hospital, Brno, Czech Republic

Abstract

The aim of this study was to evaluate and compare changes of arterial blood pressure, heart rate and thoracic impedance cardiography parameters during head-up tilt table test and to discuss possible negative-positive influence to diagnostic contribution. Results demonstrate that blood pressure parameters do not drop dramatically while tilting within healthy subjects. On the contrary, thoracic impedance cardiography parameters reflect supposed changes in hemodynamic system, primarily the decrease of stroke volume.

1. Introduction

A head-up tilt table test *(*HUT) is usually performed to evaluate the causes of syncope (loss of consciousness). Vasovagal syncope (the most frequent syncope type) is related to an abnormal nervous system reflex causing the blood vessels dilatation [1]. When this happens the heart rate decrease, lowering of blood pressure (BP) and reduced amount of blood to the brain occur [2]. In case of noninvasive blood pressure measurements (photo-plethysmography) [3] the blood pressure changes may reflect other artificial influences – blood perfusion, hydrostatic changes during tilting (unsuitable arm position), incorrect finger cuff application and device artifacts. All these factors can cause both dynamic and

Figure 1. Measured and computed signals, from top: 1- ECG, 2 -BP, 3- dBP/dt , 4- Abs dBP/dt , 5- heart sound, 6- TIC Zx, 7-dZx/dt, 8- Abs dZx/dt .

static blood pressure variations that don’t correctly reflect hemodynamic state and changes [4]. That’s why we simultaneously measured blood pressure and thoracic impedance cardiography (TIC) signal during HUT in healthy volunteers with exclusion of syncope symptoms to obtain comparable results reflecting normal hemodynamic change. Parameters separated both from BP and TIC records were analyzed.

2. Methods

The HUT protocol starts with 5 minutes measurement in supine position then continues with 8 minutes 75° head up tilting followed by 5 minutes in supine position. We used paced breathing 0.33 Hz during the whole measurement. We recorded ECG, BP (Finapres-2300, Ohmeda), heart sounds, breathing rate and depth (separated from TIC) and TIC (ISI BM1.2, UPT AVCR), see Fig. 1. Signals were digitized with sampling frequency of 500 Hz. Our data refer to 26 healthy subjects (19 male, average age 42±17 years, min 24, max 72 years). All measurements were completed in the Laboratory for Research of Circulation Control of St. Anne’s University Hospital. The study was approved by the Institutional Review Committee of St. Anne’s University Hospital. Each subject gave informed consent.

We used our custom-designed software ScopeWin to record analog data and to obtain the RR intervals from the digitally stored ECG signals. Within three intervals SP1 (1-4 min. in supine position), T1 (4-7 min. during tilting) and SP2 (2-5 min. in supine position after tilting) we detected and computed mean values from beat-to-beat obtained: systolic (SBP) and diastolic (DBP) blood pressure, pulse pressure ΔBP, maximum of derivative BP dBP/dt_{max} , difference $\Delta dBP = dBP/dt_{max} - dBP/dt_{min}$ and SAbs dBP/dt as sum of abs(dBP/dt) within R-R interval . From TIC signal we computed difference $\Delta Zx = Zx_{max} - Zx_{min}$, maximum of derivative Zx $-dZx/dt_{max}$ and difference $\Delta dZx = -dZx/dt_{max} + dZx/dt_{min}$ and SAbs dZx/dt as sum of abs(dZx/dt) within R-R interval. In case of derivative parameters BP and Zx were filtered in 0.5-15Hz pass band. Selected parameters are described in Fig. 2. All parameters were computed and statistics were performed in MATLAB.

.

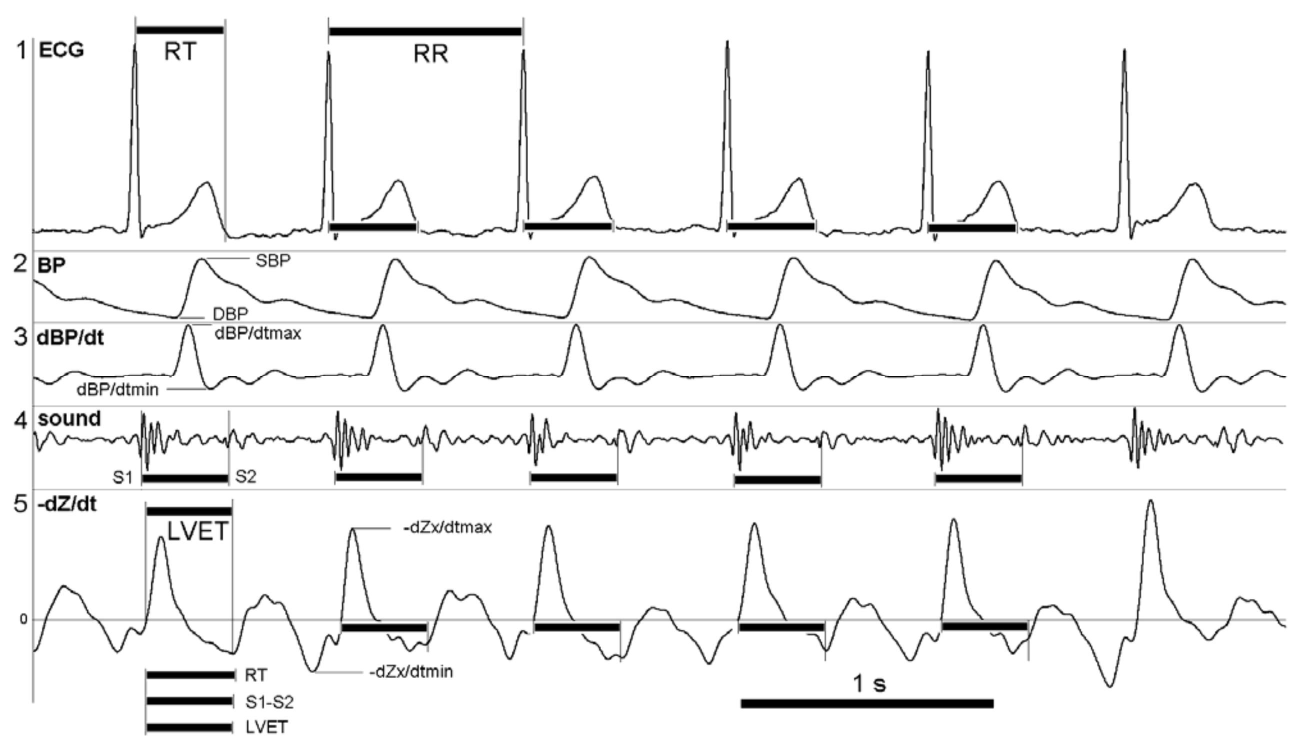

Figure 2. From top: 1- ECG, 2-BP, 3- dBP/dt, 4- heart sound, 5- -dZx/dt. Detected parameters: RR – heart beat intervals, SBP systolic blood pressure, DBP - diastolic blood pressure, ΔBP - pulse pressure, dBP/dt_{max} - maximum of derivative BP, ΔdBP - difference dBP/dt_{max} dBP/dt_{min}, $-dZx/dt_{max}$ - maximum of derivative TIC signal Zx and ΔdZx - difference $-dZx/dt_{max} + dZx/dt_{min}$. RT, S1-S2, LVET - black rectangles compare length of the first RT, S1-S2 and LVET interval in next beats (the same length as first interval) and demonstrate problematic LVET detection in -dZx/dt signal .

3. Results

Baseline relative changes during HUT and during supine position after HUT are shown in Table 1. We computed relative values to eliminate linear and additive "coefficients" which are used for absolute values computation [5]. Primarily the stroke volume computation from TIC signal is contaminated by many parameters which are indispensable for calibrated ml values. The relative changes complete eliminate influence of the coefficients and are related only to maximum of Zx derivation and LVET interval (left ventricular ejection time) [6].

In Table 1 there are also corrected values computed beat-to-beat. Parameters dBP/dt_{max}, ΔdBP, $-dZx/dt_{max}$, ΔdZx were corrected to R-T interval as $P_{corrected}=P*RT$. This correction corresponds to computation of stroke volume as $-dZx/dt_{max} * $ LVET interval. We didn't use LVET interval detection exactly from -dZx/dt because of its great inter-beat variability due to not sufficient -dZx/dt signal quality. Fig. 2 includes comparison of inter-beat variability of LVET and RT interval (detected from the first beat and compared with the next beats). Fig. 2 also compares length of LVET interval, RT interval and sounds S1-S2 interval. Generally, due to shortening RT interval during HUT, this correction increase differences and make it more significant.

Parameters SAbs dBP/dt and SAbs dZx/dt were corrected to RR interval as follows $P_{corrected}=P/RR$. This correction eliminates different number of samples per RR interval which may affect the sum. Impact of this correction is opposite of previous one.

4. Discussion and conclusions

The results provide clear message: TIC parameters reflect supposed changes in hemodynamic system during HUT, primarily the decrease of stroke volume and the increase of heart rate. RR intervals decrease to 77 percent of steady state, SBP remains unchanged and DBP slightly increase. These parameters are measured during HUT ordinarily and are used for clinical interpretation. RR shortening prompt hemodynamic reaction to reduced stroke volume. Unfortunately, this reaction is not adequately reflected in BP. The different situation is, when we compute pulse pressure ΔBP and derivative BP parameters. There we can find reduction and significant changes.

However, the reduction of TIC parameters is higher and more significant. In addition to that, the TIC parameters significantly correlate with changes of heart rate during tilting in individual subjects. This means that changes while tilting are not randomized (are pared to RR change individually in subjects) and are linked with actual hemodynamic state. This cannot be claimed about BP parameters.

Within healthy subjects, BP does not drop dramatically while tilting, because the body compensates decrease in BP flow with an increase in heart rate and constriction of the blood vessels in legs. Measured BP doesn't reflect hemodynamic changes correctly. Moreover, the continuously measured non-invasive photo-plethysmographic signal suffers from additive problems concerning blood circulation in finger with cuff and hydrostatic changes during tilting.

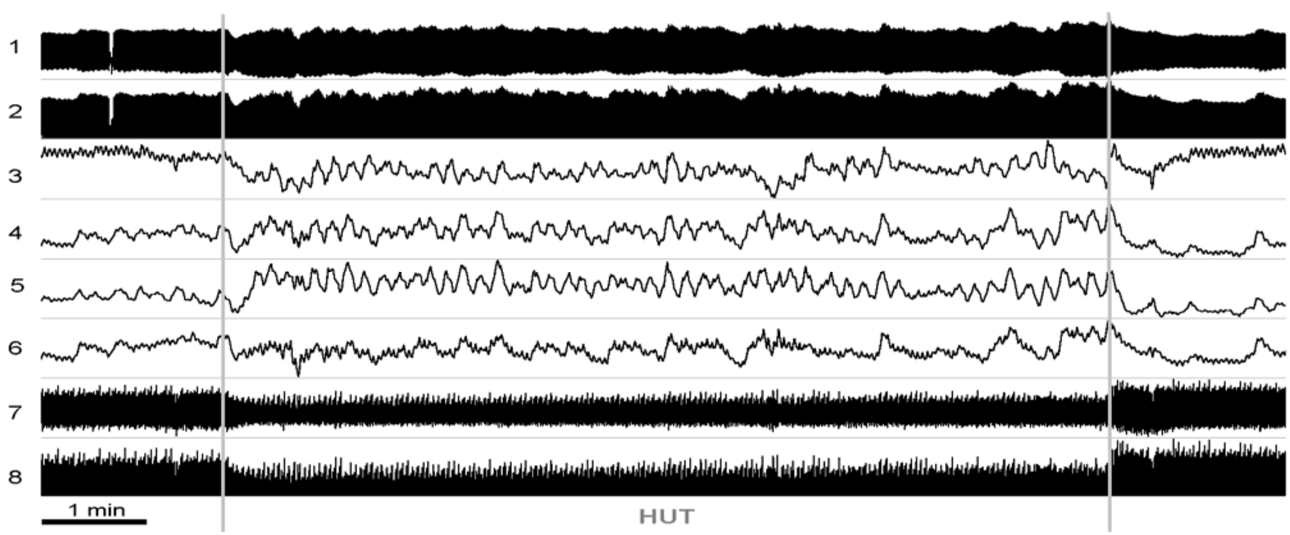

Figure 3. Change of beat-to beat computed values during HUT. From top: 1- dBP/dt , 2- SAbs dBP/dt , 3- RR , 4- SBP , 5- DBP, 6- ΔBP , 7- -dZx/dt , 8- SAbs dZx/dt

Table 1. Relative changes±SD in T1 and SP2 interval to SP1 baseline interval in percentage (values in SP1=100%). T1c and SP2c are corrected values to RT interval and RR interval. RRcorr column shows significant correlations with RR intervals. *p<0.05, **p<0.01, ***p<0.001, **** p<0.0001.

	T1	T1c	RRcorr	SP2	SP2c
RR	77.1±7.4 ****	-	-	107.9±5.5 ****	-
RT	90.8±8.8 ****	-	-	104.3±6.1 ****	-
SBP	96.4±12.8	-	-	100.1±11.7	-
DBP	113.7±22.8 *	-	-	100.2±10.2	-
ΔBP	79.1±14.2 ****	-		100.5±8.1	
dBP/dt_{max}	97.6±28.8	88.7±25.9	-	88.1±30.7 *	91.7±31.3 *
ΔdBP	86.1±27.1 ***	78.4±25.0 ****	-	91.5±33.1 ***	95.5±34.1 *
SAbs dBP/dt	82.3±14.4 ****	107.4±21.1	-	97.2±18.8	90.6±19.7 **
ΔZx	68.0±12.7 ****	-	0.63 *	104.6±8.1	-
$-dZx/dt_{max}$	76.0±19.2 ***	69.2±18.2 ****	0.52 **	107.2±11.5	111.8±13.0 **
ΔdZx	74.7±13.9 ****	68.0±13.2 ****	-	102.6±8.7	107.0±10.2 *
SAbs dZx/dt	61.8±13.5 ****	79.8±13.6 ***	0.61 ***	103.9±8.3	96.6±8.1

IC is commonly used for stroke volume computation. There are many papers [7,8] comparing TIC results with other both invasive and non-invasive methods (Doppler, thermodilution). Conclusions are not identical but mostly positive. This paper demonstrate easy test which neglect typical stroke volume computation procedure (absolute values in ml) which uses detection of LVET interval from derivative TIC signal. Beat-to-beat LVET detection brings irregularities and is strongly depended on TIC signal quality. -dZx/dt corrected to R-T interval (beat-to-beat) represents the best way how to analyze relative SV changes.

The blood pressure recording together with non-invasive and cheap TIC during tilting physiologic maneuver represent a compact set to test hemodynamic parameters. Moreover, TIC brings important additional information connected with real decrease of stroke volume.

Acknowledgement

The work was supported by Grant No. IAA200650801 of the Grant Agency of the Academy of Sciences of the Czech Republic.

References

[1] Shen WK, Low PA, Rea RF, Lohse CM, Hodge DO, Hammill SC. Distinct hemodynamic profiles in patients with vasovagal syncope: a heterogeneous population. JACC 2000; 35(6):1470-1477

[2] Zaidi A, Benitez D, Gaydecki PA, Vohra A, Fitzpatrick AP. Haemodynamic effects of increasing angle of head up tilt. Heart 2000;83:181-184.

[3] Penaz J. Photoelectric measurement of blood pressure, volume and flow in the finger, in *Digest of the 10th International Conference on Medical and Biological Engineering*, Dresden, 1973, p. 104.

[4] Bogert J, van Lieshout JJ. Non-invasive pulsatile arterial pressure and stroke volume changes from the human finger. *Experimental Physiology* 2005;90-4:437-446.

[5] Wang DJ, Gottlieb SS. Impedance cardiography: more questions than answers. Current Heart Fail Report 2006:3 (3);107-13.

[6] Faddy S, Boland J. Accuracy and reliability of non-invasive cardiac output: The Future in cardiology? *Computers in Cardiology*. 2003;30:251-3.

[7] Koobi T, Kahonen M, Iivainen T, Turjanmaa V. Simultaneous non-invasive assessment of arterial stiffness and haemodynamics - a validation study. Clinical Physiology & Functional Imaging 2003; 23(1):31-36.

[8] Van De Water JM, Miller TW. Impedance cardiography: The next vital sign technology? *Chest* 2003;123(6): 2028-2033.

Address for correspondence

Pavel Jurak
Institute of Scientific Instruments ASCR, v.v.i,
Kralovopolska 147,
61264, Brno
Czech Republic

e-mail: jurak@isibrno.cz