Quantitative analysis of jugular venous pulse obtained by using a general-purpose ultrasound scanner

Francesco Sisini
Department of Physics and Earth Sciences, University of Ferrara, Via Saragat 1, 44122 Ferrara, Italy

Published on 14 April 2016.

Ikken hissatsu (拳必殺) means something like to annihilate at one blow. This document is part of a series of notes each one targeting a single goal. Each note has to annihilate at one blow!

CONDITIONS OF USE

This is a self-published methodological note distributed under the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. The note contains an original reasoning of mine and the goal to share thoughts and methodologies, not results. Therefore before using the contents of these notes, everyone is invited to verify the accuracy of the assumptions and conclusions.

INTRODUCTION

Jugular venous pulse (JVP) examination dates back to more than a century ago [Mackenzie(1902), Mackay(1947), Applefeld(1990), Kalmanson et al. (1972)], but only recently it has been shown that the trace of the JVP can be obtained by means of an ultrasound scanner (US) equipped with a commercial linear probe. [Sisini et al.(2015), Sahani et al.(2015)] The method proposed needs a video clip of a few seconds obtained from the transverse scan of the neck, where the internal jugular vein (IJV) is clearly visible. [Sisini et al.(2015)]

The cross sectional area of the IJV (CSA) is measured on each picture (sonogram) of the video clip. The sequence of measurements (data sets) is the CSA trace. Moreover, in the same studies, it was shown that acquiring the video clip of the IJV simultaneously to the ECG trace, allows to identify relationship between the two ECG and JVP traces (see Fig. 1). The non-invasive techniques used up to now, are based on the use of a microphone or a motion sensor and produce a trace which qualitatively represents the pressure in the IJV. [Pyhel(1978), Applefeld(1990), Mackenzie(1902)]

This new technique is different from those used previously in that the JVP is the instantaneous value of the CSA of the IJV. The US technique for the JVP represents an improvement from qualitative to quantitative JVP. The importance of having a quantitative JVP trace had already emerged in the past when a calibrated JVP has been used. [Pyhel(1978)]

This new technique goes beyond the limit of calibration because it makes it possible to extrapolate the numeric parameters from the JVP that can be used for the clinical evaluation inter and intra-patient. This is a methodology-note that describes the innovative methods developed by the author to obtain quantitative parameters obtained by the JVP with ultrasound technique. The results reported here are only illustrative and are not produced by a dedicated experiment.
METHODOLOGY PRESENTATION

ECG analysis and P, R e T events detection

Over the past 30 years, several algorithms for the automatic detection of structures P, QRS and T in ECG, have been developed (Kohler (2002)). However, these can also be analyzed manually. In this work, the video clip of the IJV was analyzed frame by frame to find the sonograms in which the cursor of the ECG was at on of the events P, R or T (see Fig. 1). The time instants relating to each event were defined as \( t_{p_i} \), \( t_{R_i} \) and \( t_{T_i} \), where \( i \) indicates the \( i \)-th cardiac cycle between those traces.

\[
a_i = \max(CSA(t)) : t_{y_i-1} + \Delta t_y < t < t_{y_i} + \Delta t_y
\]

\[
c_i = \max(CSA(t)) : t_{a_i} + \Delta t_a < t < t_{a_i} + \Delta t_a + \gamma T_c
\]

\[
x_i = \min(CSA(t)) : t_{a_i} + \Delta t_a - \gamma T_c < t < t_{a_i} + \Delta t_a + \gamma T_c
\]

\[
v_i = \max(CSA(t)) : t_{v_i} + \Delta t_v < t < t_{v_i} + \Delta t_v + \gamma T_c
\]

\[
y_i = \min(CSA(t)) : t_{v_i} + \Delta t_v - \gamma T_c < t < t_{v_i} + \Delta t_v + \gamma T_c
\]

(1)

The waves \( a, c, x, v \) and \( y \) and the intervals \( \Delta a \) and \( \Delta v \) are the parameters that characterize the JVP (see Fig. 2). In this paper, these parameters are defined in terms of the values assumed by the CSA during the cardiac cycle. The values of the CSA of the IJV in correspondence of the waves \( a, c, x, v \) and \( y \), during the \( i \)-th cycle are indicated by the parameters \( a_i, c_i, x_i, v_i \) and \( y_i \). These parameters are detected on the JVP trace by means of an algorithm based on the following definitions:

The waves \( a, c, x, v \) and \( y \) are visible. The parameters \( a_i, c_i, x_i, v_i \) and \( y_i \) for each cardiac cycle \( i \) were identified by the algorithm. However, about 10% of the points are normally not properly detected by the algorithm, while it was possible to identify them manually (see Fig. 1). The parameters \( \Delta a_i, \Delta c_i, \Delta x_i, \Delta v_i, \Delta t_{ax_i}, \Delta t_{av_i} \) were calculated as in Eq. (2). The mean values and standard deviations of the parameters are presented in Table 1.

\[
\Delta a_i = a_i - x_i
\]

\[
\Delta v_i = v_i - y_i
\]

(2)

JVP and ECG time relationship

The time interval between the wave \( a \) and the events P and R and the wave \( x \) and the event T are calculated for each cardiac cycle. These intervals are defined as:

\[
\Delta t_{aR_i} = t_{a_i} - t_{R_i}
\]

\[
\Delta t_{aP_i} = t_{a_i} - t_{P_i}
\]

\[
\Delta t_{xT_i} = t_{x_i} - t_{T_i}
\]

(3)

Figure 1: The figure represents an illustrative sequence of three sonograms from a video-clip obtained by a transverse ultrasound scan of the IJV. In each picture it is visible the IJV (ellipses), the common carotid artery (circular) and the ECG trace (blue line). The active phase of the ECG is indicated by the red cursor. Below, it shows the IJV CSA trace obtained by measuring the CSA in cm\(^2\) on each sonogram of the video-clip.
Table 1: Example of mean value and standard deviation of main JVP parameters are presented.

| Parameter | Value     |
|-----------|-----------|
| a         | 1.57 ± 0.18 cm² |
| x         | 1.29 ± 0.16 cm² |
| v         | 1.33 ± 0.18 cm² |
| ∆a        | 0.29 ± 0.04 cm² |
| ∆v        | 0.04 ± 0.02 cm² |
| ∆t_a,x    | 0.33 ± 0.06 s   |
| ∆t_v,y    | 0.11 ± 0.05 s   |
| HR        | 61 Bpm         |

Table 2: Example of mean value and standard deviation of time intervals ∆t_a,R and ∆t_x,T averaged over several cardiac cycles.

| Parameter  | Value     |
|------------|-----------|
| ∆t_a,R     | 0.03 ± 0.02 s |
| ∆t_x,T     | 0.12 ± 0.06 s |
| ∆t_a,P     | 0.14 ± 0.05 s |

Figure 2: The figure shows an illustrative JVP trace during a cardiac cycle together with the ECG trace. The five waves "a", "c", "x", "v" and "y" of the JVP and the events P, R and T of the ECG are indicated.

The average and the standard deviation of these three parameters is calculated. The mean values and standard deviations of the parameters ∆t_a,R, ∆t_x,T and ∆t_a,P are presented in Table 2.

Figure 3: Examples of CSA and ECG trace are shown. The waves a, x, v, e y are correctly detected by an algorithm. The P, R and T events of the ECG trace are indicated.

Figure 4: Examples of CSA and ECG trace are shown. The x and v e y are not correctly detected. Correct waves are indicated. The P, R e T events of the ECG are indicated.
DISCUSSION

This note describes a methodology to extrapolate some interesting quantitative parameters from the IJV CSA trace, which is an analogue of the JVP. There are two important aspects that must be considered: i) the contouring of the IJV on each sonogram of the video-clip must be as accurate as possible. This means that the algorithm presented in [Sisini et al.(2015)] must be improved to achieve an accuracy close to 100%, while the current one is about 95%. ii) The wave detection algorithm must be improved. In fact it is not always sufficient to identify the waves, while they can be identified by the analysis of tracks performed by a human expert. This paper has not discussed the clinical use of these parameters.

ACKNOWLEDGEMENT

The author wants to thank Giacomo Gadda, Valentina Tavoni and Valentina Sisini to have kindly review the manuscript.

REFERENCES

[Applefeld(1990)] Applefeld MM. The Jugular Venous Pressure and Pulse Contour. In: SourceClinical Methods: The History, Physical, and Laboratory Examinations. Boston: Butterworths, 1990: Chapter 19.

[Beulen et al.(2011)] Beulen, B. et al. Toward noninvasive blood pressure assessment in arteries by using ultrasound. Ultrasound in Medicin, 2011:37(5), 788–797.

[Beulen et al.(2010)] Beulen, B., Verkaik, A. C., Bijnen, N., Rutten, M., Van De Vosse, F. (2010). Perpendicular ultrasound velocity measurement by 2D cross correlation of RF data. Part B: Volume flow estimation in curved vessels. Experiments in Fluids, 2010:49, 1219–1229.

[Chua Chiaco et al.(2013)] Chua Chiaco JM, Parikh NI, Ferguson DJ. The jugular venous pressure revisited. Cleve Clin J Med, 2013:80, 638-644.

[Kalmanson et al. (1972)] Kalmanson D, Veyrat C, Derai C, Savier CH, Berkman M, Chiche P. Non-invasive technique for diagnosing atrial septal defect and assessing shunt volume using directional Doppler ultrasound. Correlations with phasic flow velocity patterns of the shunt. British Heart Journal, 1972:34, 981-991.

[Kohler(2002)] Köhler, B. U., Hennig, C., Orglmeister, R. (2002). The principles of software QRS detection. IEEE Engineering in Medicine and Biology Magazine, 2002:21(1), 42–57. doi:10.1109/51.993193

[Mackenzie(1902)] Mackenzie J. The Study of the Pulse, Arterial, Venous, and of the Movements of the Heart. Edinburgh: Young J Pentland, 1902.

[Sisini et al.(2015)] Sisini F, Tessari M, Gadda G, Di Domenico G, Taibi A, Menegatti E, Gambaccini M, Zamboni P. An Ultrasonic Technique to Assess the Jugular Venous Pulse: a Proof of Concept. Ultrasound Med Biol, 2015:41, 1334-1341

[Sisini et al.(2015b)] Sisini F, Toro E, Gambaccini M, and Zamboni P, “The Oscillating Component of the Internal Jugular Vein Flow: The Overlooked Element of Cerebral Circulation,” Behavioural Neurology, 2015. [http://dx.doi.org/10.1155/2015/170756]