

Technical note for post processing of jugular venous pulse, central venous pressure and velocity trace

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Abstract

In this paper an original reasoning about the post processing elaboration of medical studies is presented. The aim is to suggest a method to extrapolate numerical information from clinical images. The here described elaboration is referred to ultrasound examination of internal jugular veins and central venous pressure (CVP) measures. Firstly, the operator has to collect clinical images following precise indications, then specific techniques are applied to analyze the stored data and extrapolate quantifiable measures. Analyzing the studies with ImageJ software, jugular venous pulse, velocity, CVP and electrocardiogram traces can be drown in detail. Then, significant details can be highlighted using Matlab software. Finally, using R software, the traces can be cropped, aligned and synchronized together. The obtained results allow the operator to compare different kinds of traces of the same subject, or the same type of traces between a particular group of subjects. Before using these contents, everyone is invited to verify the accuracy of assumptions, calculations and conclusions.

Introduction

Since the last century, a lot of papers described the proper way to do venous ultrasound (US) scans and central venous pressure (CVP) measurements.¹⁻¹⁰ However, the literature about the post processing to obtain quantifiable measures is quite recent and poor.^{3,4,11,12} For this reason, it has developed a technical protocol for the analyses of venous US studies and CVP measures, with the aim of obtaining numerical results. In particular, the most interesting parameters are the variations over time of pressure, blood velocity and cross sectional area (CSA) of the Internal Jugular Veins (IJV). Hence, the final goal of this paper is to reconstruct, align and synchronize the traces of CVP, CSA and velocity collected for each analyzed subject.

Materials and Methods

The method here proposed needs morphological and hemodynamic measures, registered with US technology, and pressure measures, collected with analogue devices. With US technology, CSA measurements of IJV and blood velocity quantifications are obtained. The IJV CSA is examined recording a B-mode video clip, the velocity is studied collecting images of Doppler mode traces. On the other hand, CVP measures are collected using a central venous catheter (CVC) with a transducer connected to an analogue monitor.

For doing the examinations, specific measurement protocols are usually applied,¹⁻⁶ in order to guarantee a correct sequence and execution of measurements. These procedures should lead to objective, reproducible and accurate studies of patients, made as quickly as possible.

The subject is placed in supine position with three electrodes applied on its chest for simultaneously measuring the electrocardiogram (ECG) signal.

First of all, the operator focuses in B-mode with a transversal scan the IJV CSA and stores a video-clip of 10 sec (Figure 1).

This time is enough to record several cardiac cycles and two or three respiratory cycles. Subsequently, to quantify blood velocity in Doppler mode the operator studies the vessel with a longitudinal scan. Once the device graphs the velocity profile the operator can freeze and store the image (Figure 2).

At the same time, CVP measurements are collected with the CVC inserted into the Vena Cava. Once the CVP trace appears on the monitor, it is possible to store the images on a computer by using a video capture device and its software (for example Grabby, TerraTec, Alsdorf, Germany and Magix Video easy TerraTec Edition, Magix, Berlin, Germany) (Figure 3).

Once the studies are completed, stored images and video clips can be digitally elaborated off-line to obtain numerical dataset ready for analysis.

Analysis of cross sectional area images

Cross sectional area data sets are produced by processing transversal video clips.¹¹ Each acquired sonogram sequence is opened with ImageJ software.¹³ It allows to measure, frame per frame, area ($pixel^2$), perimeter ($pixel$) and grey level of a selected region of interest (ROI).

The procedure to obtain a CSA data set consists of several passages both manual and automatic. First of all the operator

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needs to know the dimension of the pixel in cm^2 , time duration and number of frames of the clip, in order to calibrate the system. Then, on the first sonogram, the operator manually traces a ROI including the IJV and launches a specific customized plug-in (Figure 4), which automatically detects the change in shape of the given ROI throughout the video clip.^{11,12}

The procedure provides the IJV CSA values in cm^2 versus sonogram acquisition time (Figure 5), that is the CSA(t) function, or ultrasound jugular diagram (USJD).

This function has been demonstrated as a way to deduce both a qualitative and a quantitative Jugular Venous Pulse (JVP) trace.^{11,12,14}

Analysis of central venous pressure and velocity images

The analysis of CVP and the one of Velocity images request the same steps, the only difference is the unit of measure (u.m.). The CVP is measured in cmH_2O , instead the u.m. of velocity is cm/s .

The data sets are produced by digitally identifying the position of each point of the trace on the acquired images. By using the ImageJ software, the operator draws a free-hand line overlapping the measured trace. With the function *List Selection Coordinates*, it is possible to obtain a vector

of coordinates (expressed in pixels) of every point of the line. To calibrate each position, with respect to the y scale with the proper u.m., it is necessary to rescale the measures knowing two coordinates of the y -axis (Figure 6), as follows:

$$Y(u.m.) = [Y(pixel) - \min(pixel)] \cdot \frac{\delta(u.m.)}{\delta(pixel)} + \min(u.m.), \quad (1)$$

where Y is the vertical position of one point of the trace, \min is the coordinate of the inferior point on y -axis, δ is the difference between the superior and inferior point on y -axis.

Electrocardiogram trace

The ECG trace, overlapped on each

recorded image, is introduced to find a temporal scale (x -axis) equal for every trace of a subject (Figures 1-3). The ECG is represented as a movable cursor tracing the line: since the acquisitions of the ECG and the main trace were simultaneous, the position of the ECG cursor determines the time value when each point of the main trace was acquired.

The ECG data set is created by identifying the coordinates (x,y) of every point of the trace, with the function *List Selection Coordinates* of ImageJ. To set a common temporal scale, it is requested to recognize and count the R peaks in the ECG trace, starting from 0, and rescale time in fractions of cardiac cycle (FCC). It is worth noting, however, that the number (N) of acquisitions between two R peaks could change, so

it is important to rescale the x position of each ECG point (k) in every cardiac cycle (i):

$$FCC_{ki} = \frac{k_i}{N_i}, \quad (2)$$

with $i = 0$ to (number of R peaks - 1) and $k = 1$ to N .

At this point, the x -axis of JVP, CVP and velocity functions are replaced with the respective vectors rescaled in FCC.

Cleaning of central venous pressure and cross sectional area traces

CSA(t), Velocity(t) and CVP(t) traces contain a lot of information due principally

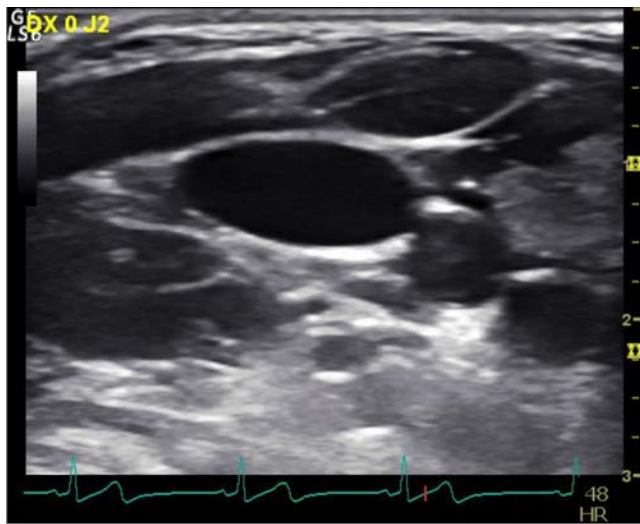


Figure 1. B-mode images of the cross sectional area of an internal jugular vein.



Figure 3. Image of a central venous pressure measurement: in blue the pressure trace, in green the electrocardiogram.

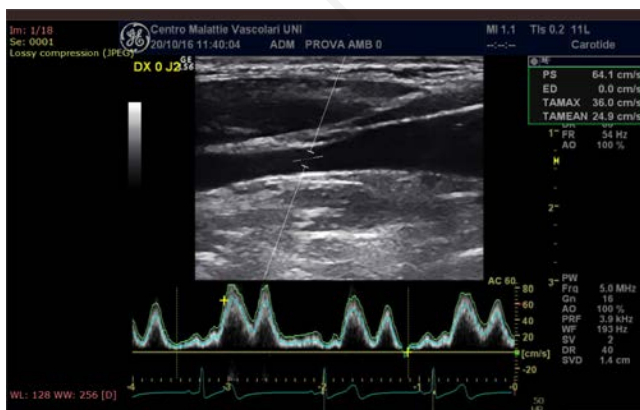


Figure 2. Doppler-mode image of a blood vessel.

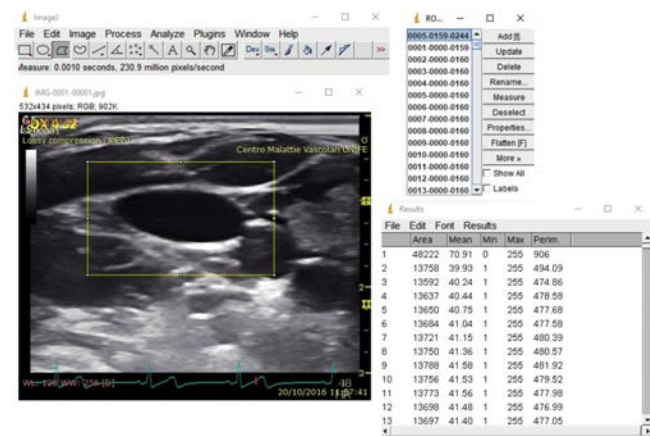


Figure 4. ImageJ custom plugin to detect area variations. In figure are visible an example of B-mode image with a rectangular Region of Interest (ROI), a list of ROI and the collected measurements.

to cardiac pulsations, respiratory cycles, muscular movements and noise. The main difference between these components is their frequency. The heart rate could range between 50 to 120 beats per minute, therefore the frequencies, widely above 2 Hz or below 0.8 Hz, could be noise or breathing contribution respectively.

There are different techniques for analyzing a signal and removing non-cardiac trends from measured data: some produce results localized only in frequencies, some others give results in both time and frequencies. This last type of methods, as the discrete wavelet transform (DWT), is the only one that allows to reconstruct the analyzed signal.¹⁵ Since DWT technique was already used in two different works to analyze JVP traces^{16,17} and previous studies demonstrated that Fourier- and Wavelet-based analysis yield equivalent results,¹⁸⁻²⁰ in the present note the DWT method already implemented in a Matlab Toolbox²¹ is used. In this type of analysis, the signal is convolved for a certain number of times with a filter, called wavelet. Using the function *Wavelet 1-D*, it is possible to choose the shape of the wave and decide how many times reiterate the division of the signal. After each step, the software shows the signal without the contribution of one range of frequencies (Approximation, ai) and the contribution itself (Detail, di). The most prominent components in the original signal appear as high amplitudes, on the contrary, the frequency bands less prominent have very low amplitudes, and their contributions can be discarded from the raw signal without any major loss of information. For similarity, the wavelet family that most describes the details of JVP cycles is the Symlet one.

An example of recorded trace with its DWT filtered curves is reported in Figure 7, the wavelet used is the Symlet7, choosing the maximum level of reiterations.

The lowest curves (*d1, d2, d3*) show the

highest frequencies of the signal (widely above 2 Hz), in the center are visible mean frequencies details (*d4, d5, d6*) and the lowest frequencies (widely below 0.8 Hz) contributions (*d7, d8, d9*). At the top there is the entire raw signal (*s*) and, just below, the signal without all the already mentioned components (*a9*). Knowing that video clip has on average a frame rate around 80-100 fps, the highest frequency components have a rate of several tens of Hertz, the lowest frequency components have a rate of few tenths of Hz, while mean details have a main frequency around a few Hz.

To reconstruct the signal highlighting the contribution due to the heartbeat, the mean frequencies details are summed to the mean value of the raw signal:

$$CSA(t) = MeanValue + d4(t) + d5(t) + d6(t), (3)$$

Using the resulted function, it is possible to build a vector of values for each trace.

Conformation of the traces

Finally, the last step of the off-line elaboration is the conformation of the traces of the same subject: each trace is divided in its cardiac cycles (*i*) and they are extended to the same number of frames ($\tilde{N} = \max N_i$). For doing this, a custom script is implemented with R software. The script is able to read a vector of values, draw the corresponding graph and perform a linear interpolation. Then, fixing the extreme points, it divides the curve in a certain number of values and creates a new vector for every cardiac cycle of each trace. The entire trace is reconstructed putting together every single vector. At the end of elaboration, the number of values per each trace is

$$M = (\text{numb. of R peaks} - 1) \cdot \tilde{N}. (4)$$

At the end of the elaboration JVP(t),

Velocity(t) and CVP(t) functions are synchronized using ECG and plotted in an amplitude vs time graph (Figure 8).

Mean time delay analysis

At this point the traces can be analyzed with several methods. For example it is possible to study for each *j*-detail that form JVP and CVP traces²²⁻²⁵ the amplitude and time-position in FCC. The time-position is useful to determine the mean time delay (MTD) between the two functions of the same subject. For evaluating this delay, it is preferable to study a minimum of 4 cycles per trace, in order to collect an acceptable number of values. For every *j*-details the mean difference between the position on x-axis of the detail and R peak of ECG is calculated in FCC. For example, the delay of *j*-detail is calculated as follows:

$$DelayJVP_j = Mean [JVP_{j,i} - R_i], (5)$$

and

$$DelayCVP_j = Mean [CVP_{j,i} - R_i], (6)$$

with *i*=1 to (number of cycles), *j*=a,c,x,v,y are the details that form the JVP and CVP traces.²²⁻²⁵

Then the CVP delay is arithmetically subtracted to the JVP one:

$$TimeDelay_{j-detail} = DelayJVP_j - DelayCVP_j, (7)$$

Finally, averaging time delays of every detail, the mean time delay is obtained:

$$MTD = Mean [TimeDelay_{j-detail}], (8)$$

with *j*=a,c,x,v,y.

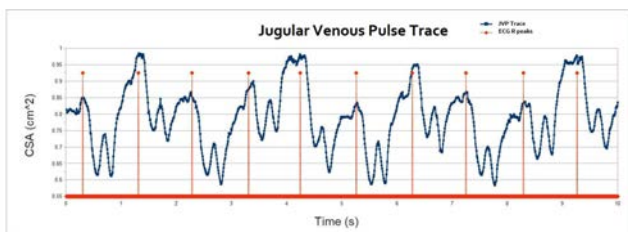


Figure 5. Plot of the jugular venous pulse (JVP) trace over time obtained with the ImageJ custom plugin in blue, the R peaks of the electrocardiogram in red.



Figure 6. Calibration of the y scale: 1 and 2 are the inferior and superior points on y axis, 3 is one point Y on the trace.

Discussion and Conclusions

This paper describes a methodology to analyze the traces extrapolated from the post processing of medical images and video-clip. The goals of the analysis are the reconstruction, the synchronization, the conformation and the alignment of different traces: JVP(t), velocity(t) of blood and CVP(t).

Once obtained these results, several statistical analysis can be done. A comparison

between all the traces of the same subject can be applied in order to find possible correlations. Otherwise, a transversal study between different subjects can be done, comparing the same kind of trace collected for different targets of population: for example JVP trace of healthy subjects and JVP trace of pathological patients.

There are several important aspects that must be considered before to apply the described protocol: i) JVP, CVP and velocity traces have to be stored with the ECG

trace recorded simultaneously; ii) the JVP trace needs a frame rate around 80-100 fps; iii) to compare JVP, Velocity and CVP traces, they have to be recorded almost in the same time, or at least with a very short delay.

This paper has not discussed the clinical use of these parameters.

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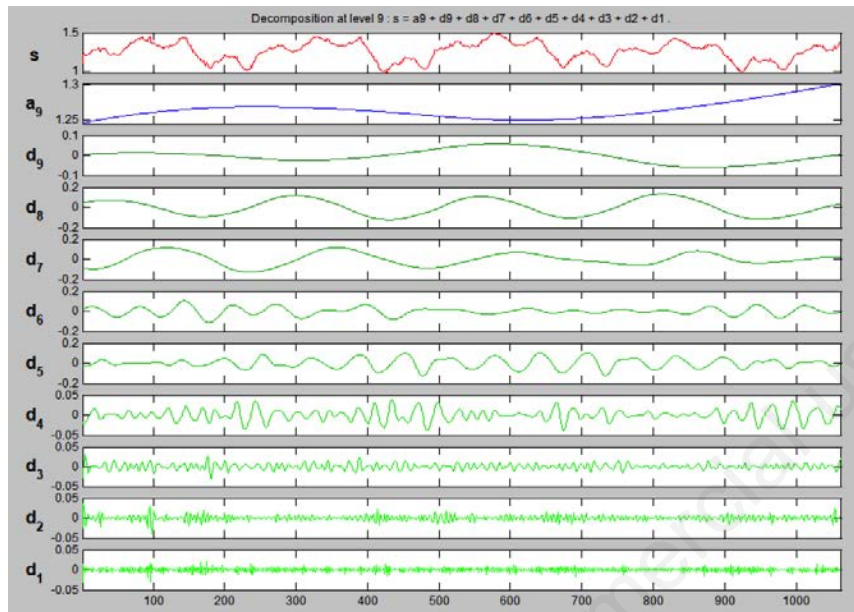


Figure 7. Wavelet analysis of the signal with Matlab toolbox. *s* is the original signal, *d1*, *d2* and *d3* the details at higher frequencies than cardiac cycle, *d4*, *d5* and *d6* the details at frequencies close to cardiac cycle, *d7*, *d8* and *d9* the details at lower frequencies than cardiac cycle, *a9* the signal without the details.

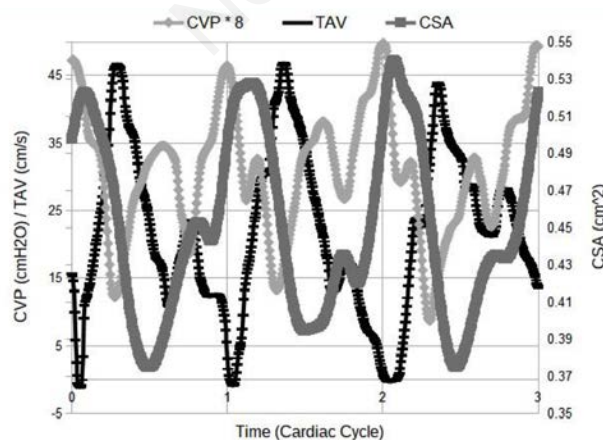


Figure 8. Plot of jugular venous pulse, central venous pressure and time average velocity vs time in number of cardiac cycles. The traces are synchronized using electrocardiogram. Central venous pressure trace is multiplied by eight for an easier comprehension of the graph.

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