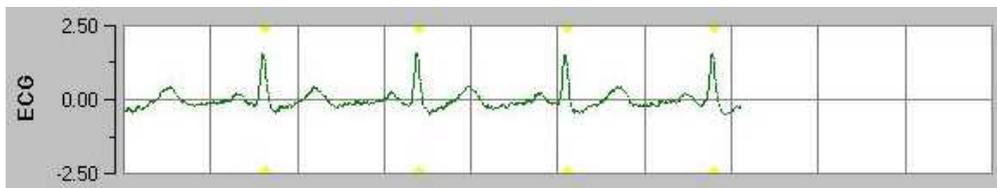


## From ECG to PTA<sup>1</sup>: principle of calculation

The analysis of heart rate variability (HRV) is a reliable way to measure the regulation of the cardiovascular system by the autonomous nervous system (ANS) [1].

The short-term variations of the heart rate are like reflection of sympathetic and parasympathetic (paraS) activity.

The adjustment of the instantaneous heart rate induced by the opposite effects of sympathetic and parasympathetic systems is measurable by spectrum analysis [2]: the high frequencies (HF) are only related to the parasympathetic system, whereas the low frequencies (LF) are influenced by both systems: sympathetic and parasympathetic. The thermoregulation and the baroreceptor reflex influence the LF and the very low frequencies. The respiratory movements represent the most part of HF modulation of heart rate, of which the effects on heart rate are described as “Respiratory sinus arrhythmia” [3]: the heart rate increases at each inspiration due to the temporary relaxation of the paraS tone.



**Figure 1:** lower sub-window displayed on the PTA monitor. Yellow triangles appear in regard of each R wave detected.

The R wave detection of the ECG signal (figure 1) allows calculating precisely the time interval between each cardiac contraction (RR interval) formulated in msec. The RR series are first filtered in real time thanks to detection algorithm in order to prevent any artifact to interfere with the ECG signal: the erroneous values are replaced by the most probable R-R samples computed by linear approximation using the two correct values on both sides of the disturbed period (figure 2) to provide the next most reliable calculations (figures 3 & 4) [4].

1: PTA means “Parasympathetic Tone Activity”. PTA is a trademark.

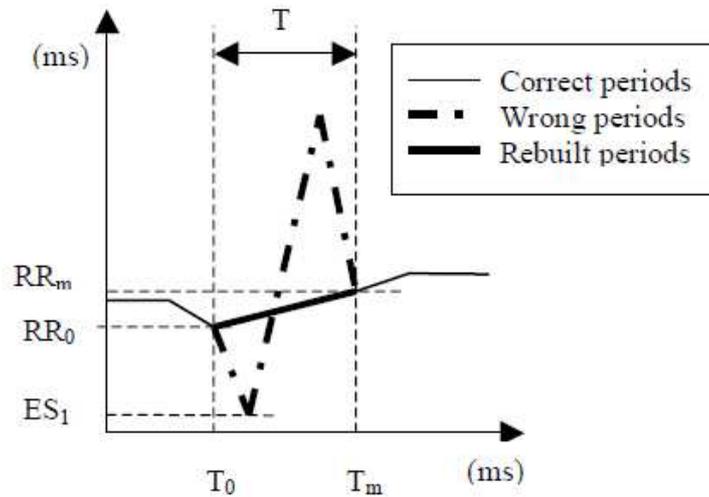


Figure 2: linear interpolation thanks to the detection algorithm

The RR interval means the instantaneous cardiac period and the next RR intervals allow following up the temporal evolution of the instantaneous cardiac period.

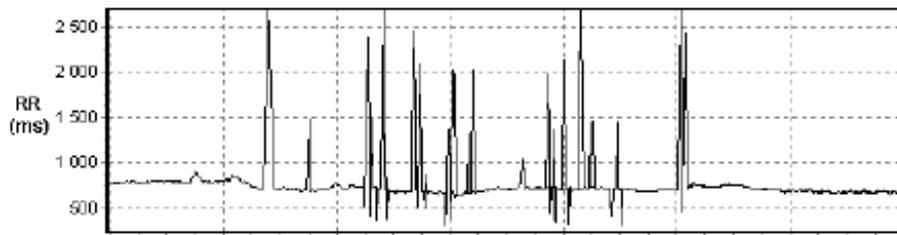


Figure 3: RR series before correcting the artifacts

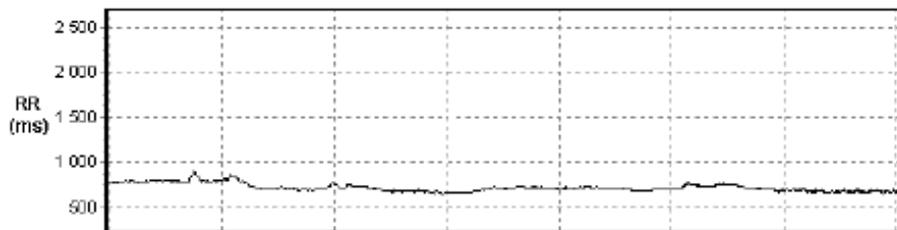


Figure 4: RR series after filtering

The filtered RR series are then re-sampled at 8 Hz, and then isolated into a 64 seconds moving window. To avoid the patient's basic heart rate influence, the mean ( $M$ ) value of the RR intervals within the window is computed and then the mean value  $M$  is subtracted from each sample of the window:  $RR_i = (RR_i - M)$ .

To be able to compare the RR series each other, the RR series ( $RR_i$ ) – considered like a vector of 512 points – is then normalized using the vectorial norm ( $S$ ) value.

Many studies showed the pain and/or the anxiety lead a sympathetic activation which could measure by using the HRV analysis: there is an increase of the LF spectral content (sympathetic and paraS) and a decrease of the HF content (paraS). The filtering of the RR series in the frequency range allows displaying the surface of respiratory influence in the RR series which corresponds to the relative paraS tone of the patient.

In order to be independent from the respiratory rate variations, our index is based on the surfaces of the RR series (figure 6) [5, 6]: automatic detection of the local maxima and minima, delimitation of the upper and lower envelope outlines and then calculation of the area of A1, A2, A3 and A4 between the upper and lower envelopes in 4 subdivided windows of 16 seconds each (figure 5).

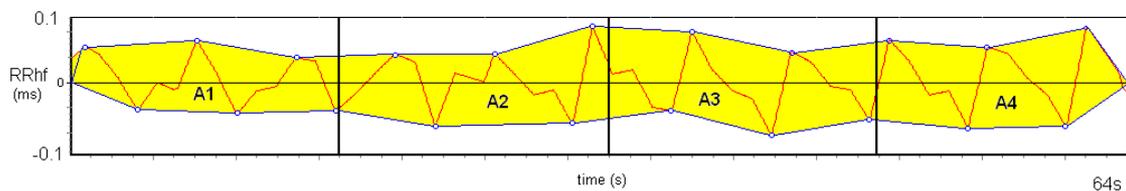


Figure 5: calculation of the surfaces A1, A2, A3 and A4 of the RR series

We define AUCmin (the minimal Area Under the Curve) as the smallest among the 4 surfaces A1, A2, A3 and A4. The parasympathetic tone activity (PTA) is then calculated to express a fraction of the surface influenced by the respiration and provide a value:

$$ANI = 100 * [\alpha * AUCmin + \beta] / 12.8$$

$\alpha = 5.1$  et  $\beta = 1.2$  have been determined to keep the appropriateness between the visual effect of the respiration influence on the RR serie and the PTA index.

The equivalent PTA calculation in the literature is the normalized HF contents (HFnu) [7].

The maximum possible total surface (equal to 12.8 corresponding to length\*width of the figure 6 thus  $64 * 0.2$ ) which is the reference for the PTA index, is understandable because the normalized series are displayed in a window whereof the vertical axis is set (thanks to the normalization).

The averaging of the signal is done within 2 moving windows: one minute for the instantaneous PTA<sub>i</sub> (blue curve) and four minutes for the averaged PTA<sub>m</sub> (orange curve). Both are displayed in the upper subwindow on the screen (figure 6) and the numeric value of each is displayed in the same real time on the right (figure 8).

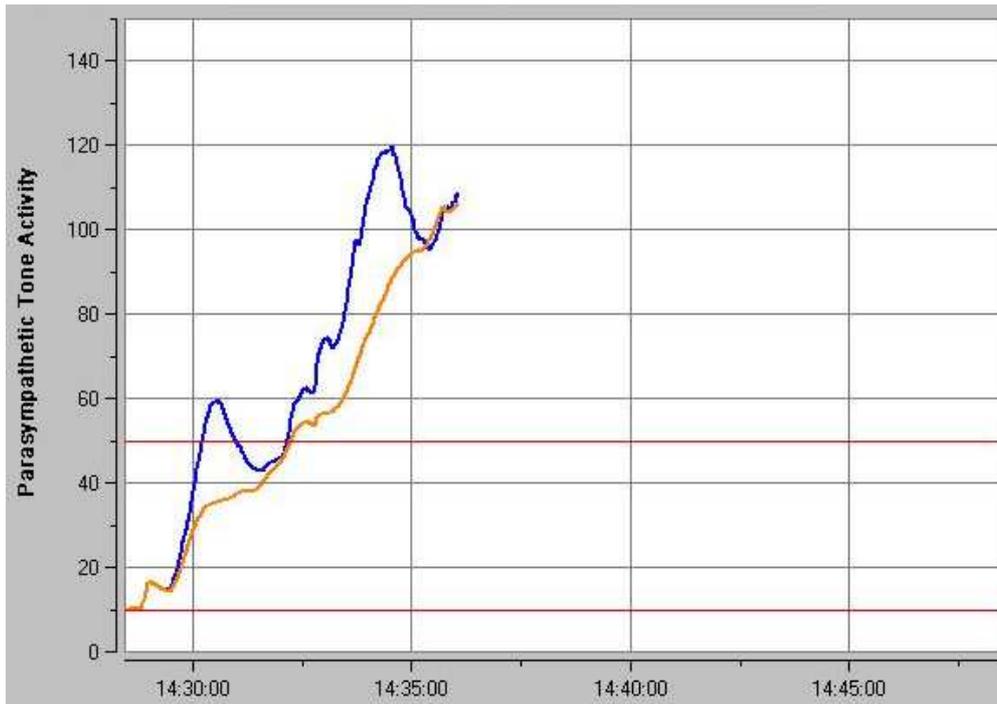


Figure 7: PTAi and PTAm curves in the upper subwindow of the display

An acute nociceptive stimulus leads a flattening almost instantaneous of the RR series due to the drop of the paraS tone but this variation is reflected with a delay from 20 to 30 seconds for the instantaneous PTA displayed (blue curve and numeric value).



Figure 8: display of the PTA monitor during monitoring

The PTA monitoring limits are essentially related to the heart sinus rhythm and to the good quality of the ECG signal acquired. The influences of all different medicines used during surgery have to be determined. Especially the interpretation of the PTA in case of anticholinergic administration has to be really cautious during all effect long on the sinus node.

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