Electrocardiogram based methodology for computing of Coronary Sinus Pressure

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Abstract

In this paper, a method based on pattern recognition and ECG technology is introduced as a means of calculating the optimum occlusion and release points within Pressure controlled intermittent coronary sinus occlusion (PICSO) cycles. There are favorable results that show PICSO can substantially salvage ischemic myocardium during medical surgery. These results are confirmed after studying groups of animals. The new method is a continuation of previous work on two other techniques using estimation and derivative calculations.

Keywords: *coronary sinus pressure (CSP), pressure controlled intermittent coronary sinus occlusion (PICSO), electrocardiogram (ECG).*

1. Introduction

Pressure Controlled Intermittent Coronary Sinus Occlusion (PICSO) is implemented by means of a block which is applied via a catheter that intermittently obstructs the outflow from the cardiac veins in the right atrium, Figure 1 shows a single PICSO cycle of approx 16-seconds. The technique leads to an increase of Coronary Sinus Pressure CSP (systolic as well as diastolic) in the course of a few heart beats; controlled pressure increase can result in better distribution of the blood flow through the ischemic area. In order to maximize the effect of the PICSO procedure, it is imperative that accurate Occlusion (Inflation) and Release (Deflation) points are identified within the PICSO cycle.

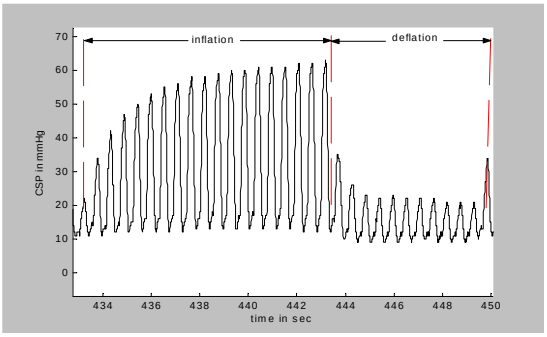

Figure 1 One PICSO with Inflation and Deflation time of 10/6 seconds respectively

Two techniques have been devised by the researchers to compute the Coronary Sinus Pressure (CSP) parameters (Systolic plateau, Diastolic plateau & the rise/release time) using a mathematical model which describes the increment and decrement of CSP in one PICSO cycle. The model consists of two parts that use 3-parameter double-exponential functions. This was fitted using the non-linear least square algorithms, as shown in Eq. 1 below:

$$P_{csp}(t)=\begin{cases} A*\exp\{B*[1-\exp(-C*t)]\}-1 & when \quad 0<t<T1 \\ D*\exp\{E*[1-\exp(-\frac{F}{t})]\}-1 & when \quad T1\le t<T2 \end{cases} \quad (1)$$

Where $P_{csp}(t)$ = Coronary sinus pressure, and A, D, B, E, C, F are fitting parameters.
The first part of the equation (1a) describes the rise of the CSP during the inflation (occlusion) period.

$$P_{csp}(t) = A*\exp\{B*[1-\exp(-C*t)]-1\} \qquad (1a)$$

The second part (1b) describes the release of the CSP during the deflation (release) period.

$$P_{csp}(t) = D*\exp\{E*[1-\exp(-\frac{F}{t})]-1\} \qquad (1b)$$

The systolic peaks increase with the time during the inflation period. These peaks were fitted with the nonlinear least-square algorithms.

a) T90 Method

The *T90* method, developed by Schriner and Alzubaidi [2], is the first technique for calculating the CSP parameters during a PISCO cycle; this method yielded an approximate calculation by taking 90% of the predicted height of the systolic plateau. $P_{CSP}(t)$ reaches the maximum value when $t \rightarrow \infty$ in (*Eq. 1a*) as shown below

$$P_{csp(t \rightarrow \infty)} = A^* \exp(B - 1) \qquad (2)$$

Because, in mathematical terms, a plateau is never actually reached, it is meaningful to consider the time taken to reach 90% of the predicted height of the plateau. Figure 2 shows the systolic plateau and its rise time (*RT*).

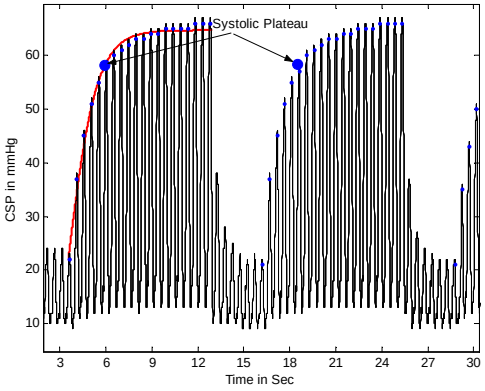

Figure 2 Systolic Plateau of CSP during the inflation period using T90 method

b) Time-Derivative Method

A new technique to describe the change of CSP parameters using the time-derivative method (dp/dt) was introduced by Alzubaidi L [1]. The new method is a more accurate means of calculating the systolic and diastolic plateau and the rise time of the PICSO cycle by determining the slope of CSP. The derived quantities serve as diagnostic parameters for a quantitative assessment of physiological condition and as predictors for an optimal adjustment of coronary sinus cycles.

The results of this technique were shown to bear a close resemblance to the clinical effect of coronary sinus occlusion. Fig. 3 illustrates comparison of the systolic plateaus of T90 and time-derivative methods

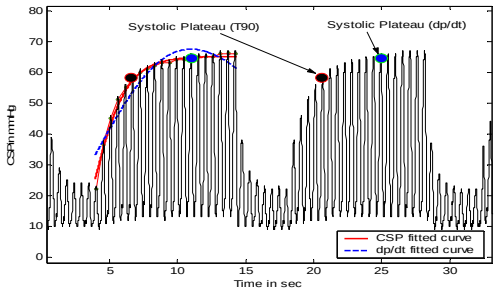

Figure 3 Systolic plateaus of CSP using the T90 and dp/dt methods

c) Weaknesses

There is room for improvement in both techniques above, as follows:

The T90 technique is fairly straight-forward, but the results are ultimately not as accurate as can be, this is due to the fact that the calculations are approximate.

Although the second (dp/dt) method is more accurate, it is also more complex and time-consuming. This is due to the extra overhead required for computing the slop of the CSP parameters using this approach.

What is needed, therefore, is an improvement in both accuracy and efficiency of the two algorithms above.

ECG Determines CSP Parameters

In this paper, we introduce a new technique to compute the rise and release of the CSP during the PICSO cycle. This technique can potentially yield more accurate figures using an ECG based calculation algorithm. The new technique is a pattern recognition technique that recognizes the heart beat with lowest differential between the QRST interval and PQ interval during PICSO cycle.

Electrocardiogram (ECG)

The Electrocardiogram (ECG) is a biological signal. It is a quasi-periodical, rhythmically repeating signal, synchronized by the function of the heart, which acts as the generator of bioelectrical events. ECG is recorded by attaching a set of electrodes on the body surface such as chest, neck, arms, and legs.

ECG is an accurate, electrical manifestation of the contractile activity of the heart. By graphically tracing the direction and magnitude of the electrical activity that is generated by depolarization and repolarization of the atria and ventricles, the ECG chart provides information about the heart rate, rhythm, and morphology.

Each heartbeat can be observed as a series of deflections away from the baseline on the ECG. These deflections represent the time evolution of electrical activity in the heart which initiates muscle contraction. A single sinus (normal) cycle of the ECG, corresponding to one heart beat, is labelled with the letters P, Q, R, S and T on each of its switching/turning points as in Figure 4.

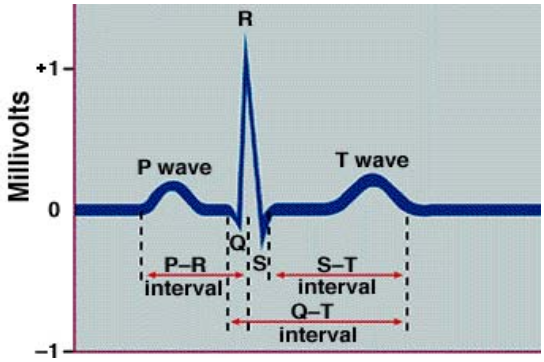

Figure 4 Morphology of PQRST for a single heartbeat

The ECG may be divided into the following sections:

- P-wave: a small low-voltage deflection away from the baseline caused by the depolarization of the atria prior to atrial contraction as the activation (depolarization) wave-front propagates through the atria.

- PQ-interval: the time between the start of atria depolarization and the start of ventricular depolarization.

- QRS-complex: the largest-amplitude portion of the ECG, caused by currents generated when the ventricles depolarize prior to their contraction. Although atria repolarization occurs before ventricular depolarization, the latter waveform (i.e. the QRS-complex) is of much greater amplitude and atria re-polarization is therefore not seen on the ECG.

- QRST-interval: the time between the onset of ventricular depolarization and the end of ventricular repolarization.

- ST-interval: the time between the end of S-wave and the beginning of T-wave. Significantly elevated or depressed amplitudes away from the baseline are often associated with cardiac illness.

- T-wave: ventricular repolarization, whereby the cardiac muscle is prepared for the next cycle of the ECG.

2. Methodology

The technique, which is based on pattern recognition concepts, was used to calculate the systolic plateau and the rise time (RT) of CSP by identifying a significant heartbeat (the heartbeat with lowest QRST & PQ interval variation). The rise time (RT) is the time between the start of the PICSO cycle and our significant heartbeat; now that RT is identified, it can be used in Eq1 (above) as a parameter to calculate the systolic plateau.

The physiological implication of this relationship is illustrated in Figure 5 and Table 1 below. All values, apart from the RT time, are in milliseconds.

PQ + QRST = Heart Beat Interval

The minimum difference between QRST & PQ is 76.66 ms

$RT = 10.48 - 4.04 = 6.44$ sec

Hence, the systolic plateau can be calculated by substituting this *RT* value for the (t) parameter in Eq1 above.

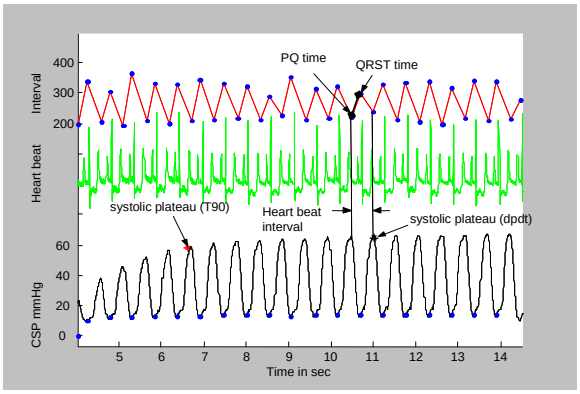

Figure 5 Relationship between CSP, ECG and the PQ & QRST intervals

Heartbeat Interval	PQ	QRST	QRST–PQ	*RT* (secs)
533.33	196.66	336.66	140	4.04
506.66	203.33	303.33	100	4.58
556.66	193.33	363.33	170	5.08
536.66	206.66	330	123.33	5.64
526.66	200	326.66	126.66	6.18
550	206.66	343.33	136.66	6.70
540	210	330	120	7.25
540	216.66	323.33	106.66	7.79
500	210	290	80	8.33
580	226.66	353.33	126.66	8.83
523.33	210	313.33	103.33	9.41
540	216.66	323.33	106.66	9.94
516.66	220	296.66	**76.66**	10.48
563.33	236.66	326.66	90	10.99
543.33	210	333.33	123.33	11.56
540	203.33	336.66	133.33	12.10
513.33	196.66	316.66	120	12.64
556.66	216.66	340	123.33	13.15

Table 1 Heartbeat interval, PQ time, QRST time and the CSP rise time RT for a 9-second inflation cycle

3. Results

All results were obtained by studying 3 groups of animals, namely sheep, pigs and dogs. The group size was 5, 5 and 3 respectively. All animals were pre-medicated with two ampoules atropine intramuscular and anesthetized before the catheters were placed into the right ear artery for arterial pressure monitoring and/or the right ear vein for intravenous infusions.

At each step of the experiment the animals were monitored online to avoid any unnecessary suffering and to ensure anesthesia was still effective. The experiment was terminated during complete anesthesia with a high dosage of potassium chloride injection. All measurements were recorded on a computerised data acquisition system (monitoring and long time storage) for biological signals.

The results comprise a preliminary investigation of the spread of the derived quantities observed during PICSO cycles. The systolic plateau and its rise time were calculated for 10 PICSO cycles of *approximately* 14-seconds each (10 inflation + 4 deflations).

The systolic plateau and its rise time were used to compare the calculations from T90 method and pattern recognition method. Figure 6 shows the results of both calculations; it is clear that the systolic plateau of pattern recognition method is higher than its T90 counterpart.

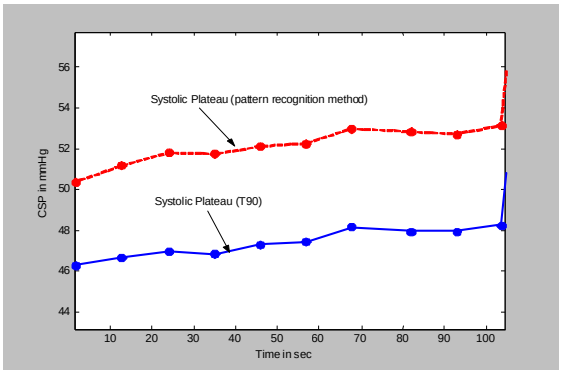

Figure 6 Comparison of Systolic Plateaus for 10 PICSO cycles using T90 and pattern recognition methods

The new technique can identify accurate occlusion and release points within PICSO cycles, thus helping to achieve an increase of Coronary Sinus Pressure CSP to yield higher blood pressure values resulting in better distribution of the blood flow through the ischemic area.

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