Accurate methods of calculating the Coronary Sinus Pressure plateau

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Abstract

Salvage of ischemic myocardium during the intervention with Pressure Controlled Intermittent Coronary Sinus Occlusion (PICSO) has been described to be effective during experimental models of coronary artery occlusions but the standard calculation method of the CSP quantities in current use gives an approximate calculation. A novel computation method (dp/dt method) was introduced and evaluated to describe the rise/release of CSP. The new method is a more accurate way of calculating the systolic and diastolic plateau and the rise time by determining the slope of CSP. This method results in a time derivative that describes the changes in CSP measurements. The results are shown to bear a close resemblance to the clinical effect of coronary sinus occlusion. The Haemodynamic Quantities which calculated using the CSP method (T90 method) 'evaluated by Schreiner' will be compared with the Haemodynamic Quantities which calculated using the new method (dp/dt method).

Keywords: *coronary sinus pressure, PICSO, mathematical model, intermittent occlusion*

1. Introduction

Pressure controlled intermittent coronary Sinus occlusion (PICSO) is considered to be a physiological procedure for salvaging myocardium at risk after infarction or intra operative arrest of the heart. Intermittent occlusion of the coronary sinus by means of an inflatable balloon catheter temporarily obstructs the outflow from the cardiac veins in right atrium and thus leads to an increase of CSP (systolic as well as diastolic) in the course of a few heart beats. This back-pressure retrograde forces blood into regions deprived of regular perfusion after coronary artery infarction. After a few seconds CSP comes to a plateau (systolic higher than diastolic) the height of which is determined by the coronary artery input pressure as well as the myocardial power to squeeze blood into the coronary venous system. Because the beneficial effect of this intervention appears to be closely linked to exact application, mathematical models have been developed over many years in order to put the estimation of occlusion and release times on a quantitative basis.

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

Where

Pcsp (t) = Coronary sinus pressure (mmHg)

t = Time (s), measured from the start of occlusion

A, D =fitting parameter in (mmHg)

B, E = fitting parameter (dimensionless)

C, F= Fitting parameter (1/s)

T1 = Time that mark the end of the CSP occlusion phase (s)

T2 = Time that mark the end of the CSP release phase (s)

The first part (equation 1a) describes the rise of the CSP during the Inflation (occlusion) time.

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

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

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

The systolic and diastolic peaks were fitted with the nonlinear least least-square algorithms as shown in the Fig. (1)

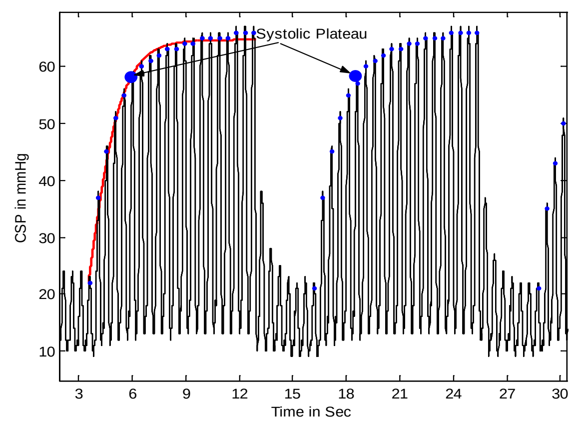

Fig. 1 Systolic Plateau of CSP using T90 method, the solid curve represents the fitted three parameter model functions, and the circle represents the systolic plateau

2. Method

The time derivative of CSP (dp/dt) describes the changing in the CSP quantities. The derivative of equation (1a) results in

$$dp/dt = A * B * C * \exp(-C * t) * \exp(B * (1 - \exp(-C * t)) - 1) \qquad (2)$$

The time derivative of CSP has two types of peaks, positive peaks (dp/dt Max) and negative peaks (dp/dt Min) as shown in the Fig. (2). These peaks were fitted separately with the least square algorithms using new fitting parameters α, β and γ

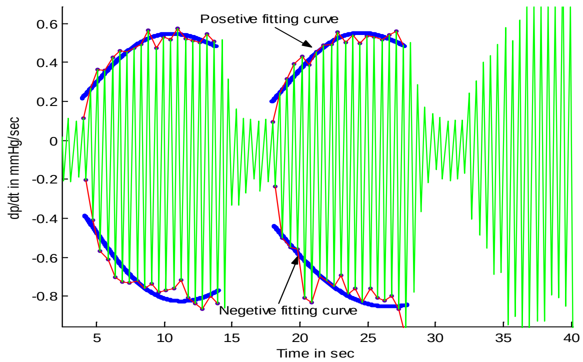

Fig. 2 Fitting of the dp/dt of CSP using the the least square algorithms

The first derivative equation (2) will be fitted with new fitting parameters α, β and γ using the non linear least square algorithms.

$$\mathrm{dp/dt} = \alpha * \beta * \gamma * \exp(-\gamma * t) * \exp(\beta * (1 - \exp(-\gamma * t)) - 1) \qquad (3)$$

Where

dP/dt = first derivative of CSP to time (mmHg/s)

α =fitting parameter in (mmHg)

β = fitting parameter (dimensionless)

γ = Fitting parameter (1/s)

Due to the intrinsic shape of the model for dp/dt rise there is an inflection point marking the steepest slope (represent the rise time). This inflection point can be calculated during algebraic manipulation by setting the 2nd derivative to zero

$$\frac{d^2 P_{csp}(tr)}{dt^2} = 0 \qquad (4)$$

The rise time (tr) will be calculated by solving equation (4), this leads to

$$tr = (1/\gamma) * lin(\beta) \qquad (5)$$

Fig. (3) Shows the inflection point and its relationship to the fitted curve of the CSP and the fitted curve of the dp/dt, this point represent the rise time, that the CSP needs to reach its systolic plateau.

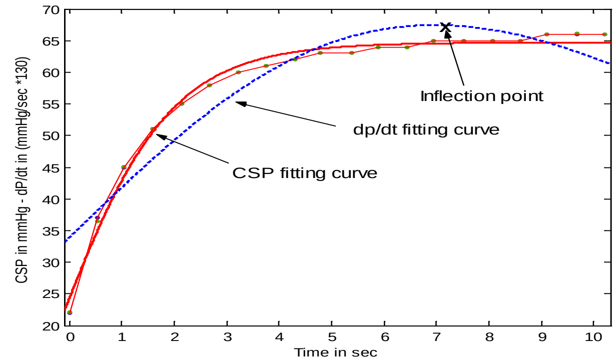

Fig. 3 Relationship between CSP and the dp/dt the solid curve represent the fitting of the CSP peaks during the inflation time, and the dash curve represents the fitting of the positive peaks of the dp/dt

The systolic plateau will be calculated by inserting tr into equation (1a), and it will be expressed in terms of two fitted parameters groups, this will gives

$$Pcsp(tr) = A * Exp\{B * [1 - Exp(-C * (1/\gamma) * \mathrm{lin}(\beta))] - 1\} \qquad (6)$$

Fig. (4) Shows systolic plateau and the rise time calculated from the mathematical model of the systolic rise using T90 method and dp/dt method. 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.

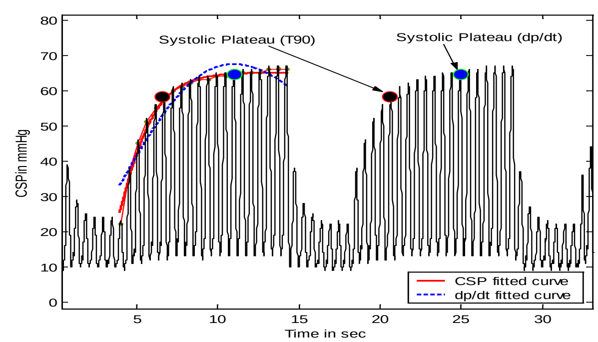

Fig. 4 The CSP rise fitted curve and the dp/dt positive peaks fitted curve with the Systolic plateau of T90 method

3. Results

The model parameters and the derived quantities will change with time. For any diagnostic value it is essential to establish ranges which can be used as reference intervals for the normal state. The following results comprise a preliminary investigation of the spread of the derived quantities observed during PICSO. Over 1000 PICSO was calculated using an automatic computation module, the Haemodynamic quantities was calculated for each PICSO.The rise time describes how long it takes to reach a pressure plateau after a prolonged occlusion cycle. The systolic plateau and its rise time were used to compare between T90 and dp/dt method. Fig. (5) shows the result of both calculations, it's very clear that the systolic plateau of dp/dt method higher then the T90 method.

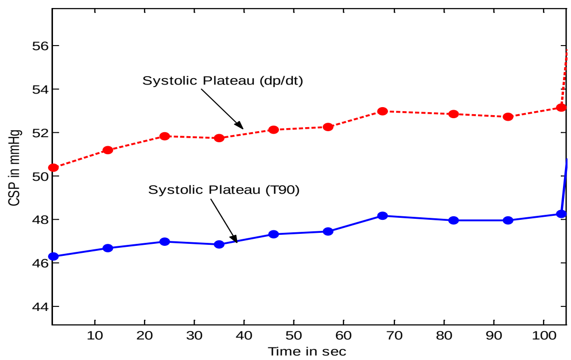

Fig. 5 Compare between the calculated systolic plateau of the coronary sinus pressure using T90 method and dp/dt method.

Fig. (6) Shows a part of the calculated data, it compare between the rise time of both methods, the rise time calculated using the dp/dt method is longer than the rise time of T90 method.

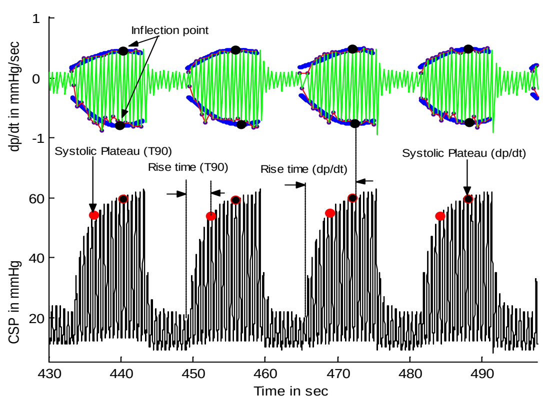

Fig. 6 Relation between systolic plateau and rise time of dp/dt and T90

4. Conclusion

The mathematical model equation (1) served as useful tool for describing the rise and the release of the coronary sinus pressure during the inflation and deflation periods. The CSP was expressed in the term of fitted parameters, three for inflation and three for deflation. Several hemodynamic quantities such as systolic and diastolic plateau, rise time, heart rate per PICSO and the mean integral of CSP were derived from this model using two methods, T90 method and dp/dt method. During the comparison of the results of both methods, we found that the results of dp/dt method are more exact and stable then the results of T90 method.

The physiological correlate of high systolic values is a good contractility of the myocardium and the systolic plateau can be seen as a monitoring parameter for myocardial strength. Myocardial strength is also reflected in the systolic rise time, the shorter is better. However, the rise time is also influenced by capillary and venous capacity as well as by the average coronary artery flow. The systolic rise time can be used as a calculated parameter for the closed loop regulation of PICSO.

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