# A Method for the Analysis of Systemic Circulatory System

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**Abstract: This paper proposes a new method, based on *cepstrum* , to get useful information of systemic circulatory system from the aortic pressure waveform . Using the proposed method, we can estimate the effective wave reflection sites of the arterial tree. To discuss the method ,an electric model of the systemic circulatory system is used. From experimental results obtained by the model, , it is concluded that the useful information of systemic circulatory system can be obtained by this method.**

## INTRODUCTION

It is well known that the wave of aortic pressure contains many useful hemodynamic information[1]. And from the measured pressure waveform, we can get useful information about the systemic circulatory system. One of the most useful hemodynamic information for the analysis of circulatory system is where is the effective wave reflection point of aortic tree. The pressure wave is formed by forward and backward pressure propagation waves. The backward propagation wave is reflected from the junctions of the arterial tree and is looked like to be reflected from an effective reflection point. Therefore,the time between the forward and backward waves is double propagation time between the measured point and effective reflection point. The time between the two waves can be measured by an autocorrelation method, but the measurement error of this method is too large to estimate the exact effective reflection point. Because the forward and backward waves overlap each other. In this paper, we propose a new analytic method based on the *cepstrum*.

## METHOD

A simplified transmission line model of systemic circulation is shown in Fig. 1. In this figure, s(t) is forcing function and x(t) is observed waveform at driving point

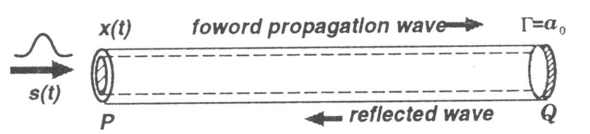



Fig.2 Simplified transmission line model with effective reflection site.

P. Γ is reflection coefficint at point Q. Then

$$x(t) = s(t) + a_0 s(t-\tau_0) + a_0^2 s(t-2\tau_0) + \cdots \quad (1)$$

$\tau_0$ the denote double propagation time from P to Q. Suppose that the higher order of Γ is negligible small , Power spectrum of x(t), $P(\omega)$ is

$$P(\omega) = F\{x(t)\} \cdot F^*\{x(t)\} = S(\omega)\{1 + 2a_0 \cos\omega\tau_0 + a_0^2\} \quad (2)$$

$S(\omega)$ denote power spectrum of forcing function. Inverce Fourier transform of logarythm power spectrum is called *cepstrum*. By logarithm , *cepstrum* separate into 2 terms. First term represents power spectrum of forcing function and second term depend on reflection coefficient Γ and propagation time $t_0$. Using expansion, we can get next equation.

$$\begin{aligned} cep(\tau)\} &= F^{-1}[\ln\{S(\omega)\}] + F^{-1}\{\ln(1+a_0^2)\} \\ &= F^{-1}[\ln\{S(\omega)\}] + -A_0\delta(\tau) + A_1\delta(\tau-\tau_0) \\ &= -A_2\delta(\tau - 2\tau_0) + \cdots \end{aligned} \quad (3)$$

The first term is the cepstrum of drive function and other cepstrum represent reflection phenomena and appear at $\tau = 0, \tau_0$, twice $\tau_0$ as a $\delta$ function. We apply this method for the analysis of circulatory system[2].

## THE CIRCULATORY SYSTEM MODEL

To discuss this method, an electric model of the systemic circulatory system is used.

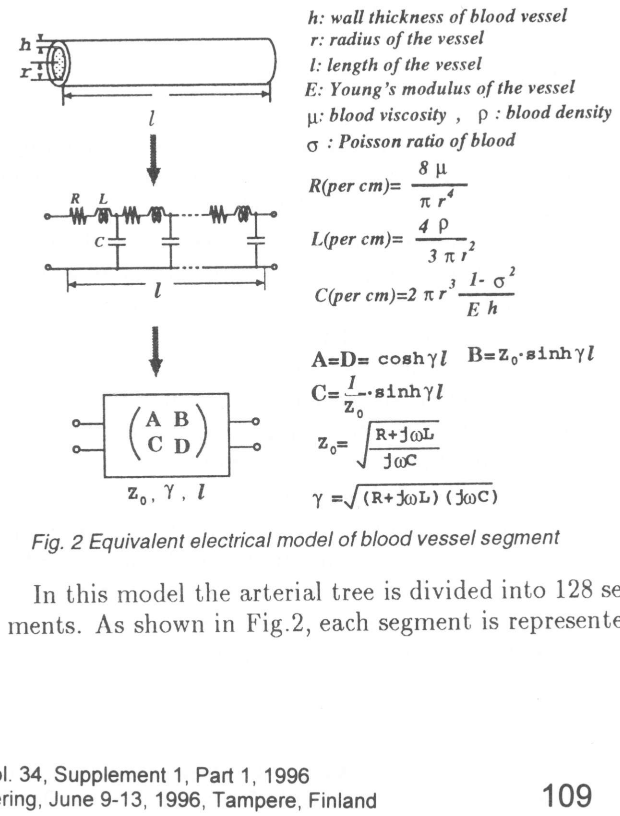
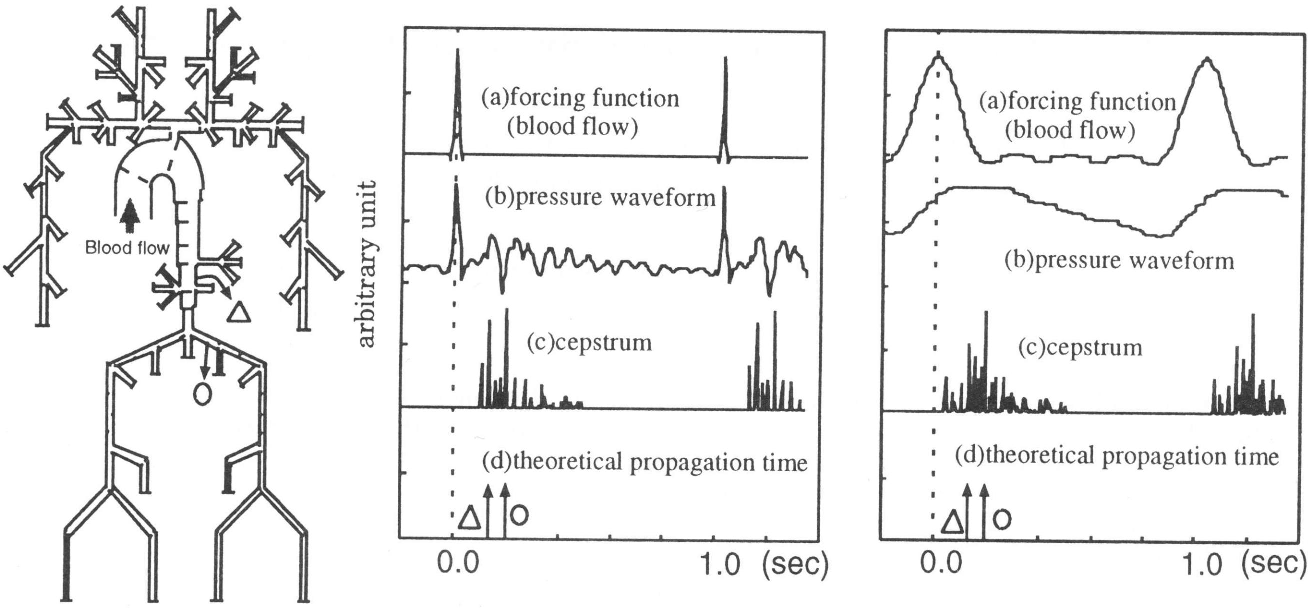



*Fig. 2 Equivalent electrical model of blood vessel segment*

In this model the arterial tree is divided into 128 segments. As shown in Fig.2, each segment is represented




A : 128 segments model of a human systemic arterial tree

B: short driving function

C: wide driving function

( O Common illiac △ Abdominal aorta)

Fig. 3 Results obtained from Systemic circulation model

by the physical parameter of the corresponding vessel, such as wall thickness, radius and length of vessel and Young's modulus are needed. And parameter of blood such as viscosity and density are also needed. Each segments represented by a lumped circuit. Those physical parameter are changed to corresponding electrical element R,L,C. The relation between physical data and lumped constants, such as, inductance, capacitance and resistance are shown in those equations. To easily calculate the characteristics of arterial tree, the four terminal network are derived from the lumped constants circuit. The four terminal parameters, A,B,C and D are shown by these equations using characteristic impedance $Z_0$ and propagation constant $\gamma$. On this model, blood flow and pressure are represented by electric current and voltage respectively.

RESULT

Fig. 3 shows the calculation results obtained by aplying this method for human systemic arterial tree model. Fig. 3A: shows the model which is represented by 128 vessel segments. The physical data of each segment is referred from the paper[3]. And all distal segment are terminated by resistance, so as the reflection coefficient to be 0.7 In this model, abdominal aorta which denoted △ and common illiac which denoted ○, are relatively large reflection sites. Then we assume that these position are effective reflection points. In these example, the two forcing function as blood flow wave, are used . One is short pulse and another is wide time duration similar to normal human cardiac output. For short pulse , the results can be easily discussed, because the forward and backward wave are clearly separated even in time domain and we can easily check the time position of reflected wave. In Fig. 3, (a) shows driving function ( blood flow waveform), (b) shows blood preesure waveform meassured at aortic root , (c) shows short pulse as shown the cepstrum of (b), and (d) shows the propagation time calculated from propagation constant $\gamma$ and total distance. Fig. 3B: shows the results for short pulse forcing simulation. Though there are various reflection sites, we can recognize the larger reflection sites as effective reflection points from the pressure waveform . And from *cepstrum*, shown in third diagram(c), we can estimate the reflection sites. And these positions coincide with abdominal aorta and common illiac .

CONCLUSION

We propose a new method,based on *cepstrum*,for analising the aortic pressure waveform. In the human circulatory system, there are many wave reflection site . Nevertheless ,with our method, one can identify the main reflection point as an effective reflection point. By simulation for systemic circulatory system model,derived from anatomical data of human arterial segments. we confirmed the validity of this method, and believe that the method offers some effective information about the cardiac condition

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