Specific frequency properties of renal and superior mesenteric arterial beds in rats

SHUENN T YOUNG,* WEI K WANG,† LUKE S CHANG,‡ TE S KUO§

*From the *Department of Electrical Engineering, National Taiwan University Institute of Biomedical Engineering, Yang-Ming Medical College; †Biophysics Laboratory, Institute of Physics, Academia Sinica Institute of Biomedical Engineering, Yang-Ming Medical College; ‡Department of Surgery, Yang-Ming Medical College and Department of Surgery, Veterans General Hospital; and §Department of Electrical Engineering, National Taiwan University Institute of Information Science, Academia Sinica, Republic of China*

ABSTRACT In order to investigate the effects of arterial beds on pressure waveforms in arteries, the pressure waves observed in the rat tail artery were resolved into their Fourier moduli before and during ligation of the left renal artery and the superior mesenteric artery. Consistently different patterns of waveform changes in the tail artery were seen on occlusion of these vessels. Ligation of the renal artery reduced, and of the superior mesenteric artery increased, the pressure harmonics over most of the spectra. These results imply that to study the changes in the pressure contours as the observation point is moved downstream, one may have to account separately for the contributions of individual arterial beds. This is relevant in considering the degree to which it is appropriate for data to be amalgamated in models of the systemic arterial bed.

Changes in the pressure contours provide a way to measure the characteristics of the arterial system.[1 2] In general, the pressure wave in an artery is considered to be the summation of an incident pressure wave and a series of reflected waves originating from peripheral systems.[3 4]

Many factors contribute to changes in pressure waves in arteries.[2 5] However, wave reflection is accepted as a main contributor.[1] O'Rourke et al[6] suggested a T tube model to explain this. The model amalgamates the effects of all arterial beds branching from the aorta into apparent reflecting sites in the terminal aorta. However, the origins of reflected waves are still uncertain, especially in the descending aorta.[1 4] The various arterial beds arising from the aorta below the diaphragm are rather complex and they each supply blood to organs or tissues which have different structures and geometry. These factors form a special characteristic for each arterial bed, and affect the wave reflection. Thus it is reasonable to predict that each arterial bed behaves differently. This will make the pressure waves have different reflection coefficients in each bed.

Our study is designed to investigate such specific properties of arterial beds and their effects on the pressure contours. It is encouraging to discover the existence of such a property in each arterial bed. This property causes a specific deformation pattern of the pressure waves when such an arterial bed is disturbed individually.

Address for correspondence and reprints: S T Young, MS, Institute of Biomedical Engineering, Yang-Ming Medical College, No 155, 2nd sec., Li-Nung Street, Shih-Pai, Taipei, Taiwan, Repubic of China.

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Methods

All experiments were performed on adult Sprague-Dawley rats, weighing 380-550 g. They were anaesthetised with intraperitoneal alpha-chloralose (48 $mg\cdot kg^{-1}$) and urethane (0.6 $g\cdot kg^{-1}$). Experiments were performed on the left renal artery, or on the superior mesenteric artery, or on both according to the experimental group. Arterial pressure waves were recorded from the tail artery. As little disturbance as possible was caused to the circulatory system. The frequency response of the entire recording assembly was uniform (+5%) to 45 Hz (about the eighth harmonic of normal physiological range in the rat).

Short records of the pressure waves, about 5-10 cycles, were taken before and during the ligation of an artery, giving paired data for each ligation. We obtained 5 to 18 data pairs for each rat. Records with minimal beat-to-beat variation over a respiratory cycle were selected. A total of 128 samples for each cycle were analysed. The contents of the first nine harmonics with their means were determined by Fourier transform. Beyond the ninth harmonic, the signal to noise ratios were too small and the variations between animals too large for them to be considered. In order to standardise the presentation of the data, harmonic moduli were normalised on the mean harmonic.

All comparisons were made between those pressure waves which corresponded to each other as closely as possible with regard to cycle length, mean blood pressure, and time in the respiratory cycle. The variations of each harmonic were calculated as the percentage change for each individual ligation.

Heart rate and the mean blood pressure were also monitored and recorded. All results are expressed as mean (SD).

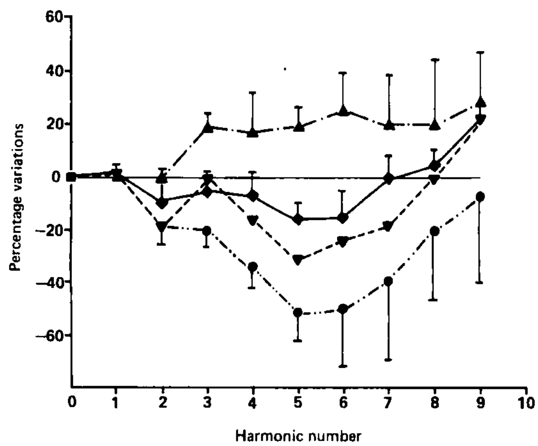

FIGURE *Harmonic moduli variation profiles of pressure wave due to ligation of arterial beds.*
● — · · — ● *(n=6): The variation profile with ligation of the left renal artery;* ▲ — · — ▲ *(n=6): The variation profile with ligation of superior mesenteric artery;* ⧫ —— ⧫ *(n=6): The variation profile with ligation of both left renal and superior arteries;* ▼ — — ▼ *: The variation profile directly obtained from the mathematic combination of* ● — · · — ● *and* ▲ — · — ▲ *profiles.*

Results

The left renal artery group had a heart rate of 6.37(0.37) Hz and 6.17(0.46) Hz before and during ligation. The variation induced by ligation was 0.16(0.12) Hz. The mean pressures were 104.7(2.6) mm Hg and 105.8(2.8) mm Hg, and the variaton was 3.5(1.21) mm Hg. These changes were not significant ($p>0.1$). Ligation of the superior mesenteric artery and both arteries together gave similar results.

The figure shows the variation profiles of the harmonic moduli of pressure waves. The left renal artery group had significant variations above the second harmonic modulus, the values varying from –7.16% to –51.0%. Superior mesenteric arterial ligation caused an entirely different profile. Its significant variations began at the third harmonic, and had positive values ranging from 17 to 28%. The ligation of both arteries caused another variation profile, which was similar to that obtained by simple combination of the individual occlusion profiles.

Discussion

A temporary ligation of an artery disturbs the intrinsic characteristic of the circulatory system and strongly affects the contours of the pressure waves. According to Fourier's analysis, a contour change of pressure wave in the time domain implies a redistribution of its moduli and phases in the frequency domain. There are several reports[1 3 7] that such changes are inconsistent when different arteries are occluded, and that such a redistribution is heavily dependent on the locations of pressure measurement in the aorta.

Theoretically, the arterial system might be arranged in such a manner that the pressure waves can transmit with a maximal efficiency and the heart work with minimum effort. Reflection and total occlusion methods[2 8 9] have been widely used to study the properties of the arterial system. Various studies[4 6 8] have shown the dependence of reflections on impedance mismatch at branch points and on frequency. O'Rourke et al[6] used this to depict the impedance patterns of the aorta at different locations and under different conditions. They clamped some arteries individually, and showed the effects on aortic impedance. The impedance patterns with different minimal points observed by O'Rourke strongly imply there must be different specific frequency properties in sections of the aorta and in arterial beds. Wang[10] has also suggested that the main organs, such as kidneys and spleen, seem to resonate with harmonics of the heart rate and might play a role in determining the characteristics of the circulatory system. All these experiments result in a picture of an arterial bed, consisting of the arteriolar bed in an organ and its supplying artery, which makes a specific frequency dependent contribution to the impedance at each section of the aorta.

In summary, in this study we observed strikingly different patterns with the occlusion of two different arterial beds. The changes in the pressure waves seemed to be quite consistent over the entire spectrum in each set of six rats. Ligation caused negative variations for the left renal artery and positive ones for the superior mesenteric artery over most of the spectrum. Ligation of both arterial beds at the same time caused a variation profile similar to the direct combination of the two individual profiles. The simple mathematic superimposition of waveforms is a good first approximation of what was seen.

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