30th Annual International IEEE EMBS Conference
Vancouver, British Columbia, Canada, August 20-24, 2008

The Benefit of Stretching Along the Artery

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Abstract—**Many rehabilitation exercises involve the stretching of bodies. We point out the necessity of the longitudinal stretching in arteries. The efficiency of an arterial system is closely related to the condition of the transverse vibration of the arterial walls or to the magnitudes of the area oscillation in all blood vessels. For a given blood pressure wave, a more elastic arterial wall has larger area oscillation, and therefore a higher efficiency in circulation. Elastic properties of the artery depend on the longitudinal stretching. In vitro experiment on pig aorta confirms that proper longitudinal stretching increases its elasticity and benefits to the circulatory system.**

I. INTRODUCTION

There are many exercises: such as yoga, Chinese tai-chi-chain and rehabilitation exercises after heart surgery, involve the stretching of the various parts of the body. What is the benefit of the stretching? Is there a precise effect of the stretching from scientific point of view?

In this study, we will find out the benefit of longitudinal stretching based on some basic theories in arterial system. We also perform an in-vitro experiment on hog aorta to find how the arterial stiffness is associated with the longitudinal stretching.

II. THEORY

Bergel [1] and McDonald [2] found that if arteries were taken outside the body, their natural length are never reached, and a considerable amount of force is needed to stretch them out to their in vivo length. Han *et al.* [3] showed that axial extension promotes cell proliferation.

We have proposed a wave model, the radial vibration model [4], [5]. The periodic ejection of blood from the heart produces a pulsatile pressure wave P which drives the vibration of the arterial wall, and therefore causes an oscillation of the cross-sectional area S of the artery. We called this vibration mode the PS wave mode [5]. The blood acts more as a mediator to pass the pressure than as a medium to transmit the ventricular energy output.

Once the ventricular- arterial system reaches a steady state, the whole arterial system will execute a distributed stationary vibration [6], [7]. Most of the side branch arteries and the organs connecting the main artery are perpendicular to the main artery [8]; maximal transverse vibration will drive maximal pulsatile blood flow to the side branches [6].
We also described the arterial system as a special drum with the elastic arterial wall as its drumhead [7]. The high static pressure assures the necessary tension in the circumferential direction. However, proper tension in the longitudinal direction is also required.

In a local artery, we define the area cross section of the artery as S, the radius as r and the local blood pressure oscillation amplitude as P. Peterson et al [9] defined the pressure–strain elastic modulus as $E_p=r_0\Delta P/\Delta r_0$. Here ΔP is the variation of the pressure and Δr_0 is the associated change in the radius.

It can be shown that the power offered from large arteries to their side branches for delivering blood to the peripheral arteries is inversely proportional to Peterson's elastic modulus. This means that a lower E_P in the arterial wall will have a higher efficiency for blood circulation.

III. MATERIAL AND METHOD

To investigate how the Peterson's elastic modulus of artery varies with longitudinal stretching, we set up an in vitro experiment on pig aorta. The pig aorta was dissected from the animal immediately after it was sacrificed. The outside fat and the connective tissue were cleaned, and only the cylindrical shaped tube was kept. Although the intima and probably a large portion of the media were retained, most of the adventitia was removed. In order to isolate a cylindrical tube, the cutting points on the branches were very close to the aorta tube and the holes generated by the cut branches were sealed by heat. The entire aorta was filled with and immersed in Ringer's solution at room temperature and gas (CO_2 5% $O_2$95%) was bubbled constantly to the solution to maintain the pH7.4 and the oxygen content immediately after the aorta was dissected. The experimental setup is similar to Fig. 2 of reference [10]. All pig aorta experiments were performed within 24 h after the death of the animals.

Pressures in the pig aorta were measured by a DP103 differential pressure transducer (Validyne, U.S.A.) at the mid point of the aorta. The total fluid volume inside the pig aorta divided by the total length was used to measure the correlated lumen cross-sectional area and the inner radius r_0. The total fluid volume was measured by the total fluid weight.

The pressure-strain elastic modules of different conditions were measured through $E_p=r_0\Delta P/\Delta r_0$. This E_p is quite similar to the definition by Peterson *et al.* [5] except that we define the r_0 as the inner radius of the aorta.

Manuscript received March 29, 2008. This study was supported by a grant from the National Science Council of R. O. C. (Grant No. NSC 96-2112 – M – 003 – 006).

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978-1-4244-1815-2/08/$25.00 ©2008 IEEE.

Percentage of stretching is the controlled variable in the experiment

Figure 1 shows the elastic modulus E_p of the aorta of the pig in terms of the longitudinal stretching percentage. The results are obtained from five measurements on one pig aorta.

We can see that increasing of the stretching properly will cause a decrease of the E_p, and therefore increases the power delivering efficiency.

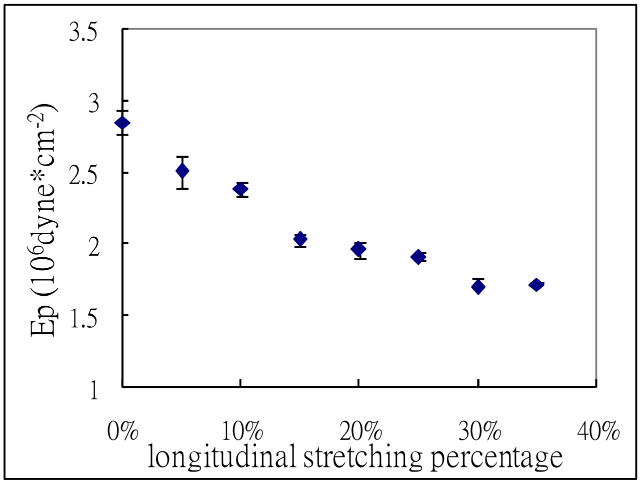

Figure 1: The in vitro pressure-strain elastic modulus E_p of pig aorta versus the longitudinal stretching percentage

IV. CONCLUSION AND DISCUSSION

It has been widely reported that arterial stiffness is a predictor of cardiovascular mortality [11], [12]. It seems that improve the elasticity of the artery is an important factor for rehabilitation. This preliminary in vitro experimental result shows that proper stretching may cause a decrease of the E_p. It gives one of the reasons why all arteries in vivo are subjecting to a strong longitudinal stretching ranged from 21% to 42% [1], [2].

The Peterson's modulus E_p is related to the circumferential incremental Young's modulus E_{inc}, the radius of the artery r and the wall thickness h_w as $E_p = E_{inc}\, h_w / r$. Change of the E_p by longitudinal stretching may due to the change of all three parameters. In order to know the exact behavior of the arterial wall under longitudinal stretching, further in vivo experiments shall be performed.

The PS wave equation we have derived is analogous to a one dimensional transverse wave on a string with the cross-sectional area S plays the role of the transverse displacement of the string.[7] The longitudinal tension connects the whole arterial system together. As a taut string can sustain a better transverse vibration wave than a saggy string, the essential of a proper longitudinal stretching becomes obvious.

Exercise involves the local stretching does have benefit to the local blood circulation. We suggest that the future rehabilitation exercise for cardiovascular diseases shall take this stretching effect into consideration.

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