INSTANTANEOUS AORTIC WALL THICKNESS MEASUREMENTS IN CHRONICALLY INSTRUMENTED CONSCIOUS DOGS

by

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ABSTRACT Arteries have been measured for more than 100 years, however a reliable method for mensuration of arterial wall thickness is not available. The reason, among others, for this is that autopsy arterial speciments are not the same as "in vivo", due to agonal and postmorten changes. In this study different methods to measure the aortic wall thickness are reviewed. A new technique for measuring, instantaneously, the thickness of the aortic wall in chronically instrumented conscious dogs is presented. The method presented here take into account the Furuyama's technique and an algorithm developed in our laboratory.

KEY-WORDS: instantaneous thickness, aortic wall, conscious dogs.

INTRODUCTION

The study in vivo of the mechanical aortic wall properties involves the calculation of several parameters like radial, circunferencial and longitudinal stress, the incremental elastic modulus, etc. These are complexes calculus that require the utilization of mathematical models. Furthermore, it is necessary to use reliable mathematical models as a measurement technique with a high degree of accuracy.

The study of physiological indexes of aortic wall function in conscious dogs implies some problems, one of them is the

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aortic wall instantaneous measurement. Since the dog is alive, chronically instrumented, and the studies are performed with the animal in conscious state, there is no any chance of a direct measurement. So, indirect evaluation must be performed by using an algorithmical method, which allows the calculus of the aortic wall thickness starting with the external aortic diameter measurement. This one is usually measured by using ultrasonic techniques, as was referred by Pagani (1979) and Cabrera (1987 and 1988).

Mc Donald (1960), and Dobrin and Rovick (1964) have determined wall thickness by the aplication of the Archimede's Principle calculating the aortic wall thickness utilizing a short segment of the artery that was weighed at thr end of the in vivo experiments. In this way the wall thickness is calculated assuming no changes in the wall volume. The aortic wall thickness is indirectely calculated from the in vivo external diameter.

Bauer (1984) utilized direct measurements of external diameter and aortic wall thickness by using excised segments of arteries slipped over a cylindrical rod and stretched to its in situ lengths. Aortic wall thickness measurements in this case were performed microscopically.

To develop the method cited above is necessary to weight the segments of the arteries and measure their lenghts. Our purpose is to develop an algorithm that allows to obtain the same information on basis at anatomopathological samples, so in according to our better knowledge, it is necessary to analyse the anatomopathological samples and then perform the instantaneous aortic wall thickness measurements.

The purpose of this work was the development of a new method for the instantaneous aortic wall thickness measurements utilizing anatomopathological arterial samples.

MATERIAL AND METHODS

Six adult mongrel dogs (males) of an estimated age of 52 ± 3.09 (mean ± SD) months and weighing 22.1 ± 1.5 kg were included in this study. All of them were ventilated under general anesthesia and a thoracotomy was performed in the 4th intercostal space. The fatty tissue covering the upper third of the descending thoracic aorta was dissected and two ultrasonic

crystals (5 MHz) of 4 mm diameter were placed diametrically opposed in order to measure in vivo external aortic diameter. Aortic pressure was measured by using a miniature pressure gauge (Konigsberg P7) which was attached to a polyvynil fluid-filled catheter for in situ calibration, passed via the left brachial artery, so that the pressure sensor lay in the descending thoracic aortic lumen. Finally, an pneumatic cuff occluder was placed in the descending thoracic aorta. A diagram of the surgery instrumentation can be seen in figure 1. All cables and catheters were tunneled subcutaneously to emerge at the interscapular region in the back of the dog. After surgery all animals were recovered receiving humane care in compliance with the "Principles of Laboratory Animal Care" formulated by the National Society for Medical Research and the "Guide for the Care and Use of Laboratory Animals" prepared by the National Academy of Sciences and Published by National Institutes of Health (NIH Publication Nº 80-23, revised 1978).

After a recovering period of seven days, the aortic pressure and diameter signals were recorded on a Hewlett-Packard FM tape recorder (model 3968 A). See figure 2. When basal aortic pressure and diameter signals had been recorded, intravenous angiotensin (0.5 µg/kg) and nitroglicerine (25 µg/kg) boluses were performed. Besides, a distal aortic occlusion was performed using the pneumatic cuff occluder. See figure 3. These signals were sampled and analysed off-line on an IBM-XT computer, which was equipped with a Data Translation 2801-A analog to digital converter. A 20 msec sampling rate was chosen. All data were stored in floppy disks.

As at this time it was necessary to consider the aortic wall thickness value, we performed its calculation as it went on. After the experiments all the animals were sacrified and autopsied. The first third of the descending aorta was dissected and a 3 cm sample free of conective tissue was cut. These samples were fixed in buffered formaline and embedded in parafin. Afterwards, 5 µm sections were stained with Verhoeff's elastic tissue stain and Masson's trichrome methods without the nuclear stain. Using a camera lucida and a graphic table (Apple II Europlus) the internal elastic lamellae length and aortic wall area were measured.

Afterwards, taking into account the aortic diameter and pressure signals a computarized calculation of the aortic wall

instantaneus thickness was performed. This automatic data processing was made utilizing the Furuyama's method, this method was previously used by Pesonen (1974) and Cook and Yates (1973).

THEORETICAL ANALYSIS

In order to clarify the method used to calculate the instantaneous aortic wall thickness a theoretical analysis is performed. If we consider an aortic sample with a given length (L), a given external and internal radius (Re and Ri, respectively) we can determine the Volume (V) of this cylindrical structure:

$$V = \pi L (Re^2 - Ri^2) \quad (1)$$

or

$$\frac{V}{\pi L} = Re^2 - Ri^2$$

Changing Ri by Re-h, where h is the aortic wall thickness, we obtain:

$$\frac{V}{\pi L} = Re^2 - (Re-h)^2 \quad (2)$$

As Re can be chosen equal to the mean value of the external aortic radius and h is the aortic wall thickness calculated with the aid of the Furuyama's method, we can calculated only one $V/\pi L$ value in each dog. Thus, we postulate that if there are no changes in the mass density, we can obtain the Ri value as follows:

$$Ri = \sqrt{Re^2 - (V/\pi L)} \quad (3)$$

Therefore, for a given $V/\pi L$ value, we can obtain the different values of Ri for every change of Re. Finally, we obtain the instantaneous aortic wall thickness according to the next formula:

$$h_{(t)} = Re_{(t)} - Ri_{(t)} \quad (4)$$

where $h_{(t)}$, $Re_{(t)}$ and $Ri_{(t)}$ represents the intantaneous values of these parameters.

RESULTS

Table 1 shows the group baseline values for systolic, diastolic and mean aortic pressures and diameters and heart rate.

The mean aortic wall thicknesses obtained from the basal state for each dog are listed in Table 2. The mean value of the h/Re relationship in basal state was 0.145 ± 0.029 mm.

The aortic wall properties studies require to consider the aortic wall thickness values and its variation along the cardiac cycle including those observed after induced pathological or pharmacological changes. Angiotensin increased the aortic pressure by 138 ± 18.3% and the aortic diameter by 12.6 ± 5.7%. Nitroglycerine produced a 43.3 ± 10.1% decrease in the aortic pressure and a 11.6 ± 3.8% decrease in the aortic diameter.

In figure 3 we can see the aortic pressure augmentation effect after an angiotensin bolus. In this experiment we can observe the pulse and mean pressure values augmentation while the aortic pulse diameter show a notorius decreased join with an increased of its mean value. The aortic wall thickness variations accompanied the diameter changes, but the aortic pulse and mean thickness values decreased while the pulse and mean diameter increased. When nitroglycerine boluses were administrated (Figure 4) the aortic pressure and diameter values decreased while the aortic wall thickness values increased. Finally, the aortic cuff occluder inflation determined similar variations in the aortic pressure and diameter that those observed when an angiotensin bolus was administrated.

DISCUSSION

The aim of this study was to develop in conscious, unsedated and chronically instrumented dogs a method for the assessment of the instantaneous aortic wall thickness utilizing anatomo-pathological arteria sampling.

To determine the pressure-diameter relationship in the conscious animals the ultrasonic dimention technique (Pagani, 1979; Pieper, 1969) and a miniature pressure gauge (Konigsberg P7) were used. The high frequency response of the dimension gauge (100 Hz) and the pressure transducer (1200 Hz) and the linearity of their responses allowed acurate and reproducible measurements

over a long period of time. The 200 Hz sample rate used in digitalization is at least two times higher than the highest frequency components in the pressure and diameter spectra, thus allowing signals reconstruction without distortion.

Visco-elastic evaluation of the aortic wall properties necessarilly involves wall thickness calculations and its variations, i.e. the instantaneous aortic wall thickness. Since, every change in the radius of the aortic wall is accompanied with a change of the thickness, in vivo evaluation would be the most reliable method.

There are different techniques to measure in vitro the aortic wall thickness that take into account the degree of postmorten contraction of the artery (Pesonen, 1974; Cook and Yates, 1973; Wolinsky, 1964). Our study was focused on the developing of an algorithm to calculate in vivo the aortic wall thickness in basal state and after significative changes indused by pharmacological or physical maneuvers.

Instantaneous aortic wall thickness was obtained beginning with an aortic sample. This technique consist in the measurement of the length of the convoluted internal elastic lamellae and arterial wall area with a camera lucida in a stained aortic sample. This technique implies the following assumptions: a) the internal elastic lamellae is perfectly circular, b) its length does not change in the contracted site, c) the shrinkage caused by fixatives and dehydratation techniques is the same in all directions.

The instantaneous aortic wall thickness was obtained using the formulas (2) and (4) in which the mean external radius value has been considered. This method utilize the assumptions that the wall volume remains constant wich has been demonstrated by Dobrin and Rovick (1969) and the same value for the material density that those reported previously (Pagani, 1978, 1979; McDonald, 1960). The mean aortic wall thickness value divided by external radius (h/Re) is in agreement with Peterson (1960) and Gow (1968) at a mean pressure value of 105-124 mmHg and differ lightly respect to those reported by Milnor (0.105-0.130) (1982) but in this case the mean pressure value is unknown.

In this way the utilization of the present methodology makes possible the calculus of the aortic wall thickness in a wide

range of variations. These changes are in accordance with the aortic pressure and diameter.

CONCLUSION

Since temporal evolution of the aortic cycle involves changes in wall thickness values, instantaneous calculus are necessary. The present methodology provides a reliable method to calculate the instantaneous aortic wall thickness in chronically instrumented conscious dogs.

TABLE 1: BASAL HEMODYMAMICS STATE

aortic systolic pressure (mmHg)	129.60 ± 12.83
aortic diastolic pressure (mmHg)	79.86 ± 13.39
aortic mean pressure (mmHg)	103.91 ± 12.47
aortic systolic diameter (mm)	16.91 ± 1.69
aortic diastolic diameter (mm)	15.20 ± 1.42
aortic mean diameter (mm)	16.20 ± 1.50
heart rate (beats/min).	104.50 ± 15.99

Values are means ± SD.

TABLE 2: AORTIC WALL THICKNESS

Dog #	Wall thickness (mm)
1	1.13
2	1.19
3	1.23
4	1.27
5	0.84
6	1.07
mean ± SD	1.122 ± 0.15

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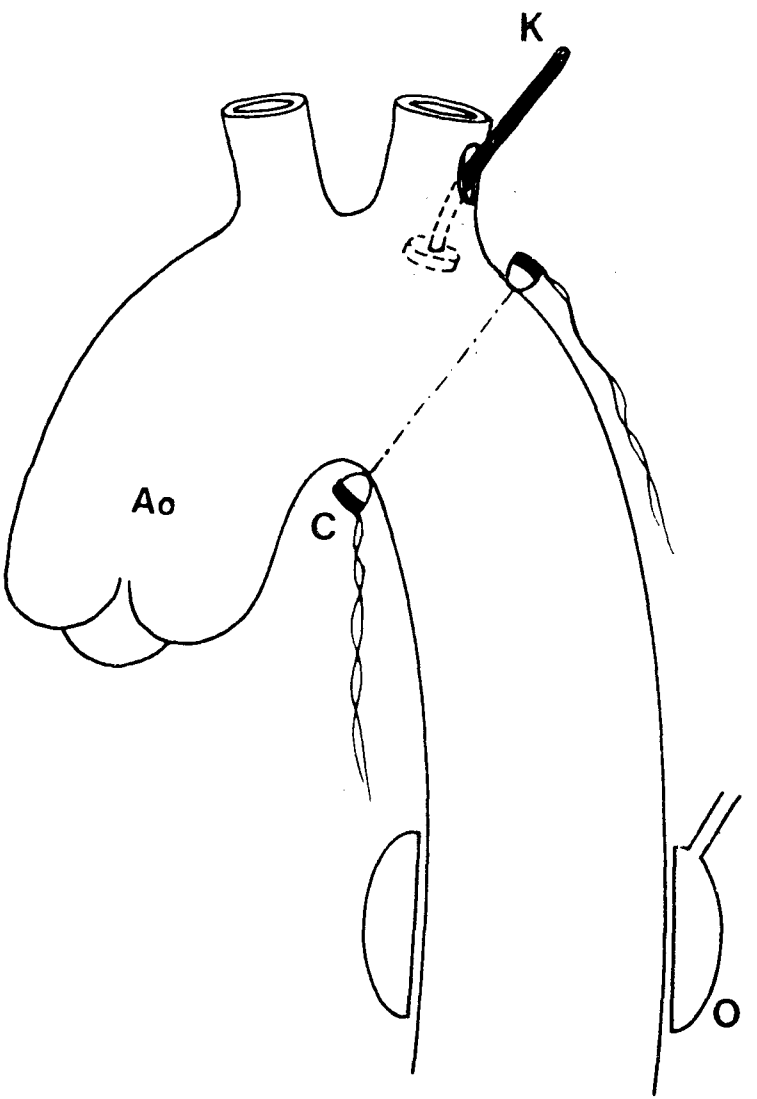

Figure 1. Animal instrumentation

Ao: Aorta. K: Pressure micromanometer.
O: Aortic cuff occluder.
C: Ultrasonic crystals.

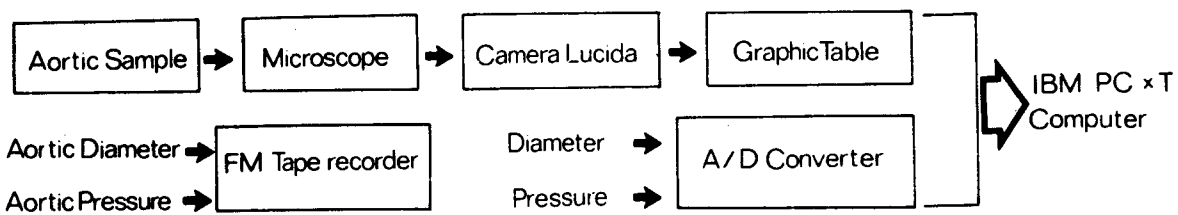

Figure 2. Block diagram. See text.

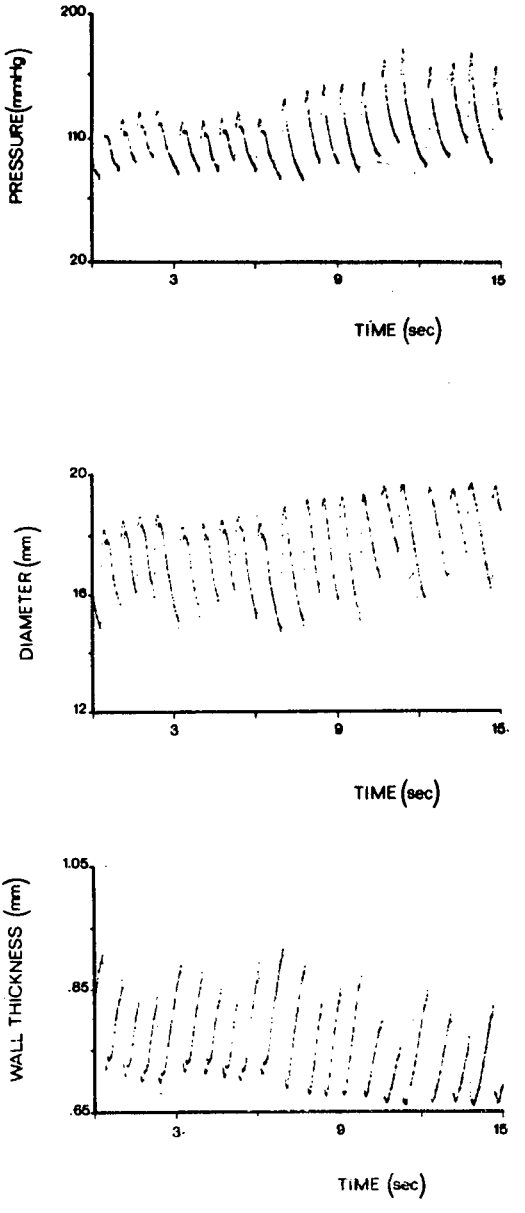

Figure 3. Aortic pressure, diameter and wall thickness, after aortic cuff occlusion.

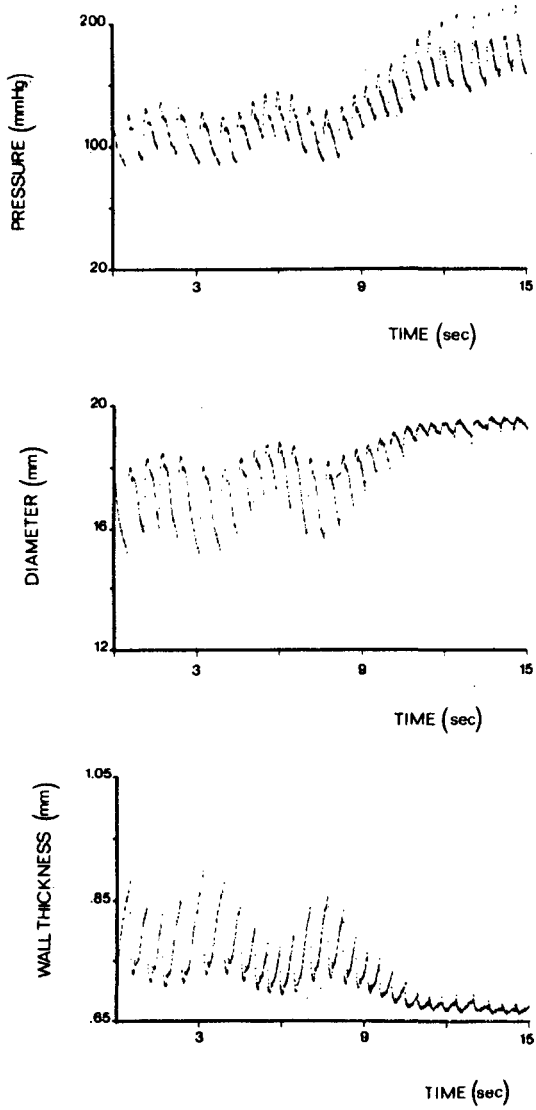

Figure 4. Aortic pressure, diameter and wall thickness, after angiotensin bolus administration.

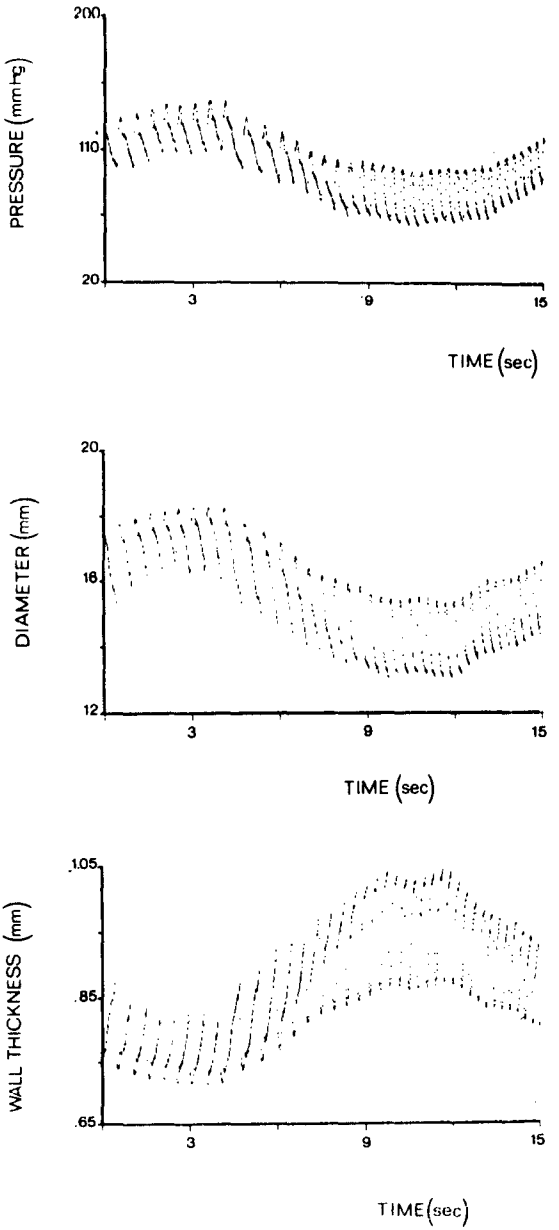

Figure 5. Aortic pressure, diameter and wall thickness, after nitroglicerin bolus administration.