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# Age-related distribution of longitudinal pre-strain in abdominal aorta with emphasis on forensic application

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ABSTRACT

It is a well-known fact that the length of an artery in situ and the length of an excised artery differs. Retraction of blood vessels is usually observed. This pre-tension plays crucial role in arterial biomechanics. It augments an artery wall load-bearing capacity. This paper presents the longitudinal pre-strain of the human aorta as an index of human age. The length of abdominal aortas was measured during autopsies before and after segment resection. The longitudinal pre-strain was calculated in 130 donors; 100 male and 30 female bodies. The pre-strain was defined as the ratio between in situ length and the length after the excision. The mean pre-strain was found to be $1.18 \pm 0.10$ for male and $1.14 \pm 0.10$ for female sample (mean ± standard deviation). The age in the male group was $41.6 \pm 15.9$ years; and $47.7 \pm 17.7$ years in the female group. Statistical analysis revealed the correlation coefficient between age and pre-strain $r = -0.821$ and $r = -0.839$ in male and female group, respectively. The analysis also confirmed close correlation between aortic circumference and age; and between circumference and pre-strain. Linear and power law regression equations were employed and prediction intervals were computed. The power law estimates the age more accurately than linear one model. Nevertheless, especially for small values of the pre-strain (aged individuals) the linear model can be advantageous.



## 1. Introduction

The estimation of the age of cadavers of unknown identity is one of the first steps in forensic identification. There are several recommended methods. They can be divided into radiological examination of dental or skeletal development, morphological examination of teeth and skeleton and biochemical analysis based on aspartic acid racemisation rate [1]. The accuracy of the above mentioned methods varies in children and adults and is the most important criterion in forensic practise. Radiological methods are accurate in children and can be used not only for cadavers but also for archeological cases and the living [2]. In adults, aspartic acid racemisation rate in dentine is the gold standard for age estimation, if teeth are available [3,4]. In case teeth are not available, accurate and reproducible results can be obtained by analysis of purified long-living proteins from other tissues [5–7].

Age estimation morphological methods are currently used especially for burnt bodies because the racemisation process of aspartic acid is highly temperature dependent [8]. There are also macro-morphological and histo-morphometrical methods, e.g. evaluation of pubic symphyseal and rib ageing patterns and evaluation of bone histology [9,10]. Most of these methods require experienced scientists and/or adequate laboratory equipment.

To the best of authors' knowledge nobody yet considered changes in biomechanical properties of tissues in forensic age estimation. The main goal of the present study is to illustrate that the longitudinal pre-strain of the abdominal aorta is suitable and easily obtainable quantity for this purpose. This phenomenon now will be briefly reviewed.

The non-pressurized artery is not in a stress-free state. This can be confirmed within excision of a tubular segment of an artery from a body; retraction of the sample is usually observed [11–14]. Bergel [11] reported mean shrinkage ranged between 32% and 42% (percentage of original length) for canine samples depending on the position in the arterial tree. Han and Fung [12] confirmed this result when reported monotonically increasing longitudinal pre-strain for canine and porcine aortas from 1.2 to 1.5 with increasing distance from the heart. Learoyd and Taylor [13] performed measurement with 59 samples of arteries obtained from 12 human donors. Their results proved position dependence of the pre-strain of human arteries and also suggested a negative correlation between the age and the retraction. Some studies performed with

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human subjects gave significantly smaller values of the pre-strain; Schulze-Bauer et al. [14] reported longitudinal pre-strain in aged iliac arteries 1.07 ± 0.09 (mean ± standard deviation).

Different authors call the same phenomenon different names – retraction, pre-stretch, pre-strain. It depends on the used reference configuration of an artery. In what follows we avoid the term "retraction" and only "pre-strain" will be used. This is defined as the ratio between the length in situ of the sample and the length of the sample measured after it was removed from a body.

The longitudinal pre-strain generates the longitudinal pre-stress remaining in an artery after a deflation of the blood pressure. This way generated pre-tension prevents an artery from a tortuosity [15,16]. Moreover, longitudinal pre-strain gives the possibility to carry the pressure pulse wave along an artery without significant change in axial force in the wall [14,17–19]. This is advantageous from a mechanical point of view.

The longitudinal pre-strain originates in the biological structure of an artery wall where different cells (smooth muscles, fibroblasts) and matrix proteins (collagen, elastin, and proteoglycans) interact together. They are subjected to growth, remodeling and ageing processes [15,16,20–26]. This results in age-dependent pre-tension of an artery. Our study maps age-dependency of the longitudinal pre-strain in the abdominal aorta and shows that it can be used in forensic age estimation. It also elucidates correlations between other characteristics of cardiovascular system such as aortic circumference, thickness of left ventricle, heart weight, and the degree of atherosclerosis.

## 2. Materials and methods

Measurements of the pre-strain in segments of the abdominal aorta were performed in the Department of Forensic Medicine of the Third Faculty of Medicine, Charles University and University Hospital Na Královských Vinohradech in Prague. Postmortem use of human tissue was approved by the Ethic committee of the University Hospital Na Královských Vinohradech in Prague.

Data sample was collected from 130 donors; 100 Caucasian male and 30 Caucasian female individuals. No putrefied bodies were involved. Age [years], longitudinal pre-strain [dimensionless], postmortem interval (PMI) [hour], circumference [cm], stature [cm], heart weight [gram], the thickness of left ventricle [cm], and degree of atherosclerosis [dimensionless] were documented. The thickness of the left ventricle was measured just above the anterior papillary muscle. The degree of atherosclerosis was quantified in the scale from 0 up to 4 according to the morphologic features: 0 – normal artery + fatty streaks; 1 – fibrofatty plaques; 2 – advanced plaques; 3 – calcified plaques; 4 – ruptured plaques [27].

### 2.1. Longitudinal pre-strain

The abdominal aorta was thoroughly preparated during autopsy and two markers were made with permanent ink just below the origin of renal arteries and just above the bifurcation into the iliac arteries. The measurement of the size has been performed two times in situ and then immediately after the excision, using a ruler. Longitudinal pre-strain, $\lambda$, was defined by (1).

$$\lambda = \frac{l}{L} \tag{1}$$

Here $l$ denotes in situ length and $L$ is the length after removal from the body. This definition of the pre-strain is in accordance with [10,12]. The relative retraction mentioned in [12,14] is obtained as $(\lambda - 1)/\lambda$.

Subsequently a ring was cut off from the aortic segment. This ring was then cut to the strip and the circumference of aortic segment was determined as the length of this strip. The measurements of the length were performed two times.

### 2.2. Correlation

Statistical dependence of all documented quantities was evaluated via correlation analysis. It was based on the simple correlation coefficient $r$ defined in (2).

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y} \tag{2}$$

Here $n$ is the number of observations, $s_x$ and $s_y$ denote sample standard deviations of quantities $x$ and $y$. Mean values are written with bands.

### 2.3. Regression analysis

Linear regression Eq. (3) was suggested in order to employ $\lambda$ as the age estimator

$$y = A_j\lambda + B_j \tag{3}$$

Here the estimated age [years] is denoted $y$. Regression parameters $A_j$, $B_j$, were determined using least square algorithm. Male and female data are distinguished with index $j$ ($j = M$, and $F$).

Linear regression model was chosen to keep simplicity. After preliminary computations it was, however, decided to employ also power law model for age–pre-strain equation. Particular form of the model is expressed in (4). $C_j$ and $D_j$ ($j = M$, $F$) are the model parameters.

$$y = C_j\lambda^{D_j} \tag{4}$$

The power law model was transformed by logarithmic transformation into the linear problem and then optimized with least squares algorithm.

### 2.4. Comparison of the models

Two ways were approached in the models' comparison

First comparison was obtained making use of the correlation coefficient. In case of the linear model it is the same as in (2). The correlation coefficient for the power law model was obtained from (2) after the logarithmic transformation. A correlation coefficient, however, can only indicate the character of statistical relationship nay predictive capability of the model.

Predictive capability evaluation was based on so-called prediction intervals (confidence intervals for model prediction). It means the range in which future observation of the dependent variable will fall with probability equal to $\alpha$ (confidence level). Complete regression model, with implemented prediction intervals, can be written in the form (5).

$$y = y_R \pm t_{\alpha/2}(m)S_e\sqrt{1 + \frac{1}{n} + \frac{(x-\bar{x})^2}{s_{xx}}} \tag{5}$$

Here $y$ is predicted variable and $x$ is independent variable. $y_R$ denotes regression equation. $t_{\alpha/2}(m)$ is the quantile of Student's $t$-distribution with $m$ degrees of freedom (here $m = n - 2$, where $n$ is the number of observations). $S_{xx}$ and $S_e$ are defined with Eqs. (6) and (7).

$$s_{xx} = \sum_{i=1}^{n}(x - \bar{x})^2 \tag{6}$$

$$s_e = \sqrt{\frac{1}{n-2}\sum_{i=1}^{n}(y_i - y_{Ri})^2} \tag{7}$$

In (7) $y_{Ri}$ denotes model prediction for $i$-observation. The logarithmic transformation was again used to linearize power law model. Confidence intervals for model parameters were also computed. $\alpha = 0.95$ was considered through entire study.

## 3. Results

Data summary for male and female group is presented in Table 1. Female autopsy data were available with complete documentation. Male data, however, were incomplete in five cases. Therefore samples in male population range from 95 to 100.

**Table 1**
Summary of documented data; mean ± standard deviation. Following abbreviations were used: AGE – age [years]; PRESTR – longitudinal pre-strain [–]; CIRC – abdominal aortic circumference [cm]; HGHT – height [cm]; HWGHT – heart weight [cm]; TLVENT – thickness of left ventricle [cm]; DEGATHR – degree of atherosclerosis [–]; PMI – post mortem interval [hour]; $n$ – number of observations; $M$ – male; and $F$ – female.

| | $n$ | $M$ | $n$ | $F$ |
|---|---|---|---|---|
| AGE | 100 | 41.6 ± 15.9 | 30 | 47.7 ± 17.7 |
| PRESTR | 100 | 1.18 ± 0.10 | | 1.14 ± 0.10 |
| CIRC | 99 | 4.0 ± 0.7 | | 3.7 ± 0.6 |
| HGHT | 100 | 179 ± 7 | | 168 ± 5 |
| HWGHT | 95 | 417 ± 119 | | 359 ± 97 |
| TLVENT | 96 | 1.4 ± 0.3 | | 1.3 ± 0.3 |
| DEGATHR | 97 | 0# | | 0# |
| PMI | 100 | 42 ± 25 | | 40 ± 20 |

# The degree of atherosclerosis is characterized rather with the mode (the most frequent observation) than with the arithmetic mean; arithmetic mean gives 1.54 and 1.37 in male and female population, respectively.