DOI: 10.23888/PAVLOVJ2018262238-244

ВОЗРАСТНАЯ ДИНАМИКА УПРУГОСТИ ГЛУБОКОЙ ДОРСАЛЬНОЙ ВЕНЫ ПОЛОВОГО ЧЛЕНА ЧЕЛОВЕКА ПО ДАННЫМ ПРЯМЫХ ИЗМЕРЕНИЙ

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Обоснование. Венозной системе полового члена отводится важная роль в механизме развития и поддержания эрекции. В то же время, диагностика и хирургическая коррекция нарушенного венозного оттока оказывается успешной далеко не во всех случаях. Частота нарушений эрекции связана с различными факторами, но прогрессивно растет с увеличением возраста. ***Цель.*** Определить в прямом эксперименте возрастную динамику упругости основного магистрального венозного сосуда полового члена – глубокой дорсальной вены. ***Материалы и методы.*** Исследования проводились на образцах глубокой дорсальной вены, полученных при аутопсии 30 лиц мужского пола, погибших внезапно от травм или острых заболеваний в возрасте от 18 до 83 лет. Глубокую дорсальную вену полового члена выделяли острым путём без окружающих тканей. Фрагмент вены длиной около 2,5-3,5 см выделяли дистальнее поддерживающей связки, служившей ориентиром. В процессе экспериментов образцы вен подвергались воздействию дискретно возрастающей растягивающей силы в продольном направлении с фиксацией соответствующих абсолютных приращений их длины на специально спроектированной установке по оригинальной методике. ***Результаты.*** Математический анализ результатов прямых измерений упругих свойств исследуемой вены, позволил выявить существенное – около 20% – уменьшение упругости вены в исследуемом возрастном диапазоне 18 лет – 83 года от $\alpha_0 = 6{,}2 \cdot 10^{-8}$ м^2/Н до $\alpha_0 = 5{,}0 \cdot 10^{-8}$ м^2/Н. С увеличением силовой нагрузки среднее значение упругости вены быстро убывает, асимптотически приближаясь к установившемуся значению порядка $\alpha = 1{,}4 \cdot 10^{-8}$ м^2/Н. При этом сохраняется возрастная тенденция к снижению упругости при различной степени функциональной нагрузки. ***Заключение.*** Выявленные закономерности снижения упругости отражают изменения стенки глубокой дорсальной вены с возрастом и могут играть роль в возрастном увеличении частоты эректильной дисфункции. Примененный метод определения упругости может быть использован для определения упругости сосудов другой локализации, а также ряда других биологических тканей в норме и при патологии.

Ключевые слова: *глубокая дорсальная вена, прямое измерение упругости, математический анализ, эректильная дисфункция.*

DOI: 10.23888/PAVLOVJ2018262238-244

AGE-RELATED DYNAMICS OF ELASTICITY OF DEEP DORSAL VEIN OF HUMAN PENIS ACCORDING TO RESULTS OF DIRECT MEASUREMENTS

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Background. An important role in the mechanism of the development and support of erection is assigned to the venous system of penis. At the same time, diacrisis and surgical correction of the disordered venous drainage is not successful in all cases. The rate of erection disorders is associated with various factors, but progressively grows with the age. ***Aim.*** To define the age-related dynamics of flexibility of the major venous vessel of penis – a deep dorsal vein – in a direct experiment. ***Materials and Methods.*** Research was conducted on samples of a deep dorsal vein of penis obtained in autopsy of 30 males who have died suddenly from injuries or acute diseases at the age from 18 to 83 years. A deep dorsal vein of penis was isolated by an acute method without surrounding tissues. A fragment of the vein 2.5-3.5 cm in length was isolated distally the retaining ligament used as a reference point. In the course of experiments samples of veins were exposed to discretely increasing stretching force in the longitudinal direction with fixation of the corresponding absolute increments in the length on a specially designed installation using the original technique. ***Results.*** The mathematical analysis of the results of direct measurements of elastic properties of the studied vein permitted to reveal a considerable – about 20% – reduction in the elasticity of the vein in the studied age range 18 years – 83 years from $\alpha_0 = 6{,}2\cdot10^{-8}$ m^2/N to $\alpha_0 = 5{,}0\cdot10^{-8}$ m^2/N. With increase in the force of load, the average value of vein elasticity rapidly declined, and asymptotically approached the established value of the order of $\alpha = 1{,}4\cdot10^{-8}$ m^2/N. Here, the age-related tendency to reduction in the elasticity with different degree of the functional load persists. ***Conclusion.*** The identified regularities of decline in the elasticity reflect changes in the wall of a deep dorsal vein with age that may play a role in the age-related increase in the rate of erectile dysfunction. The applied method of determination of elasticity can be used for determination of elasticity of vessels of other localizations and also of some other biological tissues in norm and pathology.

Keywords: *deep dorsal vein, direct measurement of flexibility, mathematical analysis, erectile dysfunction.*

The venous system of penis is assigned an important role in the mechanisms of development of and supporting erection [1]. The diagnostics and surgical correction of pathological venous outflow is not always successful [2]. The rate of erectile disorders is associated with different factors, but it progressively grows with age. Changes in the venous vessels of different localization in norm and in pathology were studied in several works [3,4]. However, among numerous research works in the field of phlebology there are no publications concerning direct measurements of the elasticity of veins with quantitative evaluation of this parameter [5].

In works [6,7] the authors propose a physical model of a biological tissue and a method of its mathematical description permitting to determine reduction in the elasticity of the fibrous tunic and cavernous arteries of penis with age. The aim of our research is experimental study of age-related dynamics of elasticity of the major venous vessel of penis – the deep dorsal vein (DDV).

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Materials and Methods

Research was conducted on samples of DDV received in autopsy of 30 male individuals who suddenly died from traumas or acute diseases at the age of 18 to 83 years. The DDV of penis was isolated by acute method without surrounding tissues from a standard incision used in autopsy. A fragment of vein 2.5-3.5 cm in length was isolated distally to the retaining ligament served as a landmark. The obtained material was transported with strict observance of the temperature and humidity requirements. The period from the moment of death to the study did not exceed 18 hours.

In the experiment the samples of veins were subject to discretely increasing stretching force F in the longitudinal direction with record of the corresponding absolute increments of the length Δl on a specially designed setup [6,7].

Subsequent mathematical processing of experimental results consisted in transformation of the mass of discrete data into analytical dependences of the kind:

$$\frac{\Delta l}{l} = f\left(\frac{F}{S}\right), \tag{1}$$

where l and S – initial length and cross-sectional area of the samples.

Transformation was carried out using the general approximating function [6]:

$$\frac{\Delta l}{l} = \left[\frac{1}{a} + \frac{1}{b + c\dfrac{F}{S}}\right] \cdot \frac{F}{S}, \tag{2}$$

where a, b and c – constant coefficients characterizing the properties of a specific sample. Coefficients a and b have dimension of Young's module (N/m^2), coefficient c is a dimensionless value.

According to the definition of elasticity α, its numeric value equals the slope of the curve to dependence (2) and, consequently, is determined by the expression:

$$\alpha = \lim_{\Delta(F/S)\to 0} \frac{\Delta(\Delta l/l)}{\Delta(F/S)} = \frac{d(\Delta l/l)}{d(F/S)}. \tag{3}$$

Thus, after differentiation of the Equation (2), we receive:

$$\alpha = \frac{1}{a} + \frac{b}{\left(b + c\dfrac{F}{S}\right)^2}. \tag{4}$$

As it is seen, the value of elasticity is not a constant since it considerably depends on force load F/S. Therefore, it is possible to speak only about its initial value α_0 as some limit to which α tends at $F \to 0$.

Results and Discussion

Processing of experimental data was performed using the extension package Curve Fitting Toolbox of the computational environment Matlab, and consisted in determination of coefficients a, b and c in equation (2). The results of approximation, with indication of the age are given in Table 1. The values of reliability of approximation R–square given in the Table, evidence practically ideal coincidence of experimental results with their presentation in the analytical form using approximating function (2). This also confirms the correctness of the ratio following from it (4) that considerably extends possibilities of the analysis of the experimental results.

Thus, use of coefficients a and b permits to calculate the initial (maximal) value of the elasticity of the samples α_0 and to determine its dependence on age. The results of calculations by formula (4) are given in Figure 1.

No less informative is the parameter of dependence of the average value of elasticity $\bar{\alpha}_0$ on the force load F/S (Fig. 2) calculated by formula (4) on the basis of the average values of coefficients $\bar{a}$, $\bar{b}$ and $\bar{c}$:

$$\bar{a} = \sum_{i=1}^{N} \frac{a_i}{N} = 8{,}150 \cdot 10^7 \ \text{N}/\text{м}^2;$$

$$\bar{b} = \sum_{i=1}^{N} \frac{b_i}{N} = 2{,}413 \cdot 10^7 \ \text{N}/\text{м}^2;$$

$$\bar{c} = \sum_{i=1}^{N} \frac{c_i}{N} = 12{,}691,$$

where N=30 – the number of studied samples.

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Table 1

Results of Mathematical Processing of Experimental Data

№ of sample	Age, years	Coefficients			R-square	№ of sample	Age, years	Coefficient			R-square
		a, N/m²	*b*, N/m²	*c*				*a*, N/m²	*b*, N/m²	*c*	
1	44	$7{,}942·10^7$	$2{,}373·10^7$	10,891	0,9999	16	48	$8{,}132·10^7$	$2{,}308·10^7$	11,274	0,9998
2	50	$8{,}113·10^7$	$2{,}391·10^7$	12,063	0,9999	17	52	$7{,}655·10^7$	$2{,}380·10^7$	11,846	0,9997
3	48	$7{,}845·10^7$	$2{,}550·10^7$	11,812	0,9999	18	80	$8{,}968·10^7$	$2{,}568·10^7$	15,074	0,9998
4	79	$8{,}711·10^7$	$2{,}672·10^7$	15,121	0,9996	19	76	$8{,}891·10^7$	$2{,}581·10^7$	14,353	0,9997
5	43	$7{,}824·10^7$	$2{,}252·10^7$	10,731	0,9998	20	43	$7{,}673·10^7$	$2{,}312·10^7$	10,986	0,9993
6	53	$8{,}216·10^7$	$2{,}442·10^7$	12,345	0,9992	21	39	$7{,}424·10^7$	$2{,}278·10^7$	10,763	0,9994
7	81	$9{,}053·10^7$	$2{,}680·10^7$	15,447	1,0000	22	41	$7{,}846·10^7$	$2{,}231·10^7$	10,954	0,9998
8	81	$8{,}600·10^7$	$2{,}420·10^7$	14,981	0,9998	23	45	$7{,}653·10^7$	$2{,}274·10^7$	11,428	0,9999
9	66	$8{,}350·10^7$	$2{,}280·10^7$	13,322	0,9995	24	65	$8{,}521·10^7$	$2{,}455·10^7$	13,427	0,9999
10	75	$8{,}841·10^7$	$2{,}615·10^7$	14,915	0,9998	25	49	$7{,}623·10^7$	$2{,}269·10^7$	11,711	0,9997
11	83	$8{,}632·10^7$	$2{,}640·10^7$	15,552	0,9998	26	77	$8{,}210·10^7$	$2{,}450·10^7$	14,583	0,9998
12	36	$7{,}621·10^7$	$2{,}278·10^7$	10,514	0,9998	27	76	$8{,}411·10^7$	$2{,}548·10^7$	15,017	0,9999
13	56	$7{,}830·10^7$	$2{,}310·10^7$	12,315	0,9985	28	76	$8{,}773·10^7$	$2{,}663·10^7$	14,871	0,9998
14	61	$8{,}415·10^7$	$2{,}420·10^7$	12,942	0,9997	29	26	$7{,}156·10^7$	$2{,}135·10^7$	9,377	0,9987
15	67	$8{,}621·10^7$	$2{,}519·10^7$	13,907	0,9984	30	18	$6{,}952·10^7$	$2{,}097·10^7$	8,195	0,9994

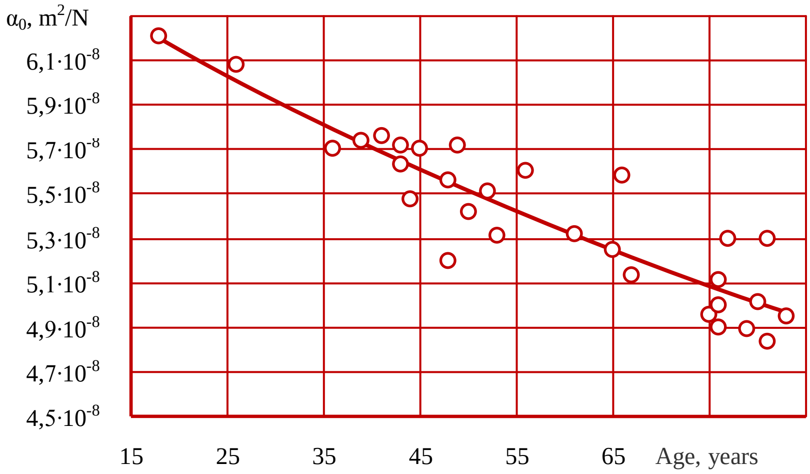

Fig. 1. Dependence of initial elasticity of DDV on age

As it follows from the given data, the initial (maximal) value of the average elasticity $\bar{\alpha}_0$ at $F \rightarrow 0$ is of the order of $5.4·10^{-8}$ m²/N.

With increase in the force load the average value of the elasticity rapidly declines and asymptotically approaches the stabilized parameter of the order of $1.4·10^{-8}$ m²/N. Here, the most considerable change is seen with force loads less than $3·10^6$ N/m².

DOI: 10.23888/PAVLOVJ2018262238-244

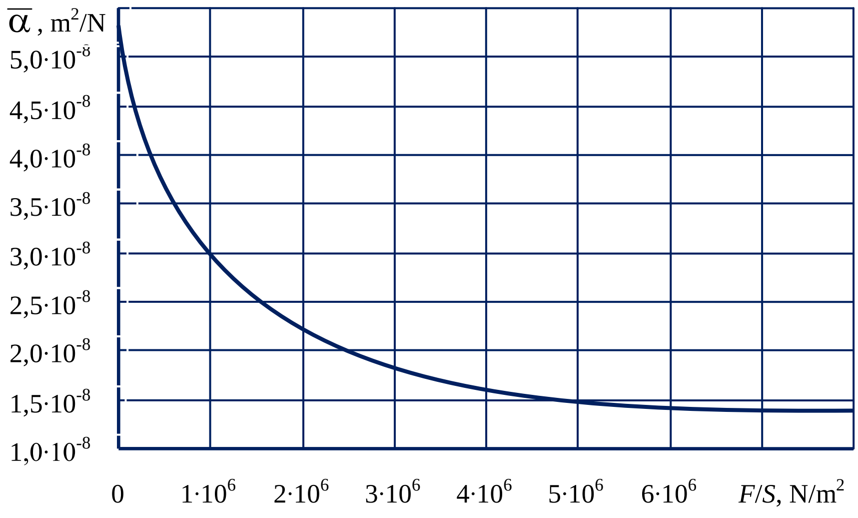

Fig. 2. Dependence of the average value of elasticity of DDV on force load

It should be noticed that the results of the calculations well agree with the results of the direct experiments. In particular, they demonstrate a rather rapid transition of relative increments of length $\Delta l/l$ at low force loads and their subsequent decline with a smooth transition to practically linear dependence on the mechanical tension F/S.

Veins are referred to capacitance vessels that accommodate the most part of circulating blood and provide its return to the heart. This explains a high elasticity of a venous vessel at the beginning of its filling and smooth reduction in the elasticity with increase in the load. Nevertheless, with high loads, a vein can withstand high pressure in it [3,4]. The data obtained by us also confirm this regularity.

Mathematical analysis of the results of direct measurements of the elastic properties of DDV revealed a considerable – about 20% – reduction in the elasticity of vein in the studied age range 18-83 years from $\alpha_0 = 6{,}2 \cdot 10^{-8}$ m^2/N to $\alpha_0 = 5{,}0 \cdot 10^{-8}$ m^2/N. With increase in the functional load on the vein the elasticity rapidly decreases at the initial stage and then practically does not change having achieved a certain level of saturation. With this, the age-related tendency to reduction in the elasticity with different extent of functional load is preserved.

The revealed regularities of reduction in the elasticity reflect changes in the venous walls with age that may play a certain role in age-related increase in erectile dysfunction. The obtained data enrich our knowledge about peculiarities of elastic properties of veins, and also about age-related changes in their functional properties.

The used method of quantitative evaluation of the elasticity of vein can be used in study of other problems of scientific and clinical medicine.

Conclusion

1. A direct measurement of the elasticity of the deep dorsal vein of human penis (elasticity with low force loads) revealed a decline of the initial elasticity of the vein in the age range of 18-83 years from $\alpha_0 = 6{,}2 \cdot 10^{-8}$ m^2/N to $\alpha_0 = 5{,}0 \cdot 10^{-8}$ m^2/N. With increase in the functional load on the vein elasticity rapidly decreases in the initial stage, then it reaches a certain level and after that practically does not change.

2. The proposed method can be used for determination of elasticity of vessels of other localization, and of other biological tissues in norm and pathology.

DOI: 10.23888/PAVLOVJ2018262238-244

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Дополнительная информация [Additional Info]

Источник финансирования. ФГБОУ ВО Рязанский государственный радиотехнический университет. [**Financial support**. Budget of Ryazan State Radioengineering University.]

Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, о которых необходимо сообщить, в связи с публикацией данной статьи. [**Conflict of interests**. The authors declare no actual and potential conflict of interests which should be stated in connection with publication of the article.]

Участие авторов. Стрелков А.Н. – концепция и дизайн исследования, сбор и обработка материала, статистическая обработка, написание текста, редактирование, Улитенко А.И. – сбор и обработка материала, статистическая обработка, написание текста. [**Participation of authors.** A.N. Strelkov – concept and design of the study, acquisition and processing of the material, statistical processing, writing the text, editing. A.I. Ulitenko – acquisition and processing of the material, statistical processing, writing the text.]

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DOI: 10.23888/PAVLOVJ2018262238-244

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Цитировать: Стрелков А.Н., Улитенко А.И. Возрастная динамика упругости глубокой дорсальной вены полового члена человека по данным прямых измерений // Российский медико-биологический вестник имени академика И.П. Павлова. 2018. Т.26, №2. С. 238-244. doi: 10.23888/PAVLOVJ2018262238-244.

To cite this article: Strelkov AN, Ulitenko AI. Age-related dynamics of **elasticity** of deep dorsal vein of human penis according to results of direct measurements. *I.P. Pavlov Medical Biological Herald.* 2018;26(2):238-44. doi: 10.23888/PAVLOVJ2018262238-244.

Поступила/Received: 15.10.2017
Принята в печать/Accepted: 31.05.2018