Giedrė UZDILAITĖ

THE INFLUENCE OF PATHOLOGIES TO BLOOD PRESSURE AND VELOCITY IN BLOOD VESSELS

Summary of Doctoral Dissertation
Technological Sciences, Mechanical Engineering (09T)

1324

Vilnius LEIDYKLA TECHNIKA 2006

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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Scientific Supervisor

Prof Dr Habil Mečislovas MARIŪNAS (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T)

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Chairman

Prof Dr Habil Mindaugas Kazimieras LEONAVIČIUS (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T)

Members:

Prof Dr Habil Viktoras VASILIONKAITIS (Baltic States Institute of Medical Biomechanics and Artificial Organs, Biomedical Sciences, Medicine – 07B)

Prof Dr Habil Algimantas FEDARAVIČIUS (Kaunas University of Technology, Technological Sciences, Mechanical Engineering – 09T)

Prof Dr Habil Genadijus KULVIETIS (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T)

Prof Dr Habil Marijonas BOGDEVIČIUS (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T)

Opponents:

Prof Dr Habil Vladas VEKTERIS (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T)

Prof Dr Habil Egidijus Vytautas BARKAUSKAS (Vilnius University, Biomedical Sciences, Medicine – 07B)

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Address: Saulėtekio al. 11, LT-10223 Vilnius-40, Lithuania

Tel.: +370 5 274 49 52, +370 5 274 49 56; fax +370 5 270 01 12;

e-mail: doktor@adm.vtu.lt

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VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

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PATOLOGIJŲ ĮTAKOS KRAUJO SLĖGIUI IR GREIČIUI KRAUJAGYSLĖSE TYRIMAS

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Technologijos mokslai, mechanikos inžinerija (09T)

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prof. habil. dr. Mindaugas Kazimieras LEONAVIČIUS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, mechanikos inžinerija – 09T).

Nariai:

prof. habil. dr. Viktoras VASILIONKAITIS (Baltijos šalių medicininės biomechanikos ir dirbtinių organų institutas, biomedicinos mokslai, medicina – 07B),

prof. habil. dr. Algimantas FEDARAVIČIUS (Kauno technologijos universitetas, technologijos mokslai, mechanikos inžinerija – 09T),

prof. habil. dr. Genadijus KULVIETIS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, mechanikos inžinerija – 09T),

prof. habil. dr. Marijonas BOGDEVIČIUS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, mechanikos inžinerija – 09T).

Oponentai:

prof. habil. dr. Vladas VEKTERIS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, mechanikos inžinerija – 09T),

prof. habil. dr. Egidijus Vytautas BARKAUSKAS (Vilniaus Universitetas, biomedicinos mokslai, medicina – 07B).

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Adresas: Saulėtekio al. 11, LT-10223 Vilnius-40, Lietuva.
Tel.: +370 5 274 49 52, +370 5 274 49 56; faksas +370 5 270 01 12;
el. paštas: doktor@adm.vtu.lt
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GENERAL CHARACTERISTIC OF THE DISSERTATION

Topicality of the problem

As the sociological data provides, every third person in the World dies of blood vessels disorders.

Regarding the tendency in the spread of blood circulation diseases constantly more attention is being paid to arterial blood vessels. Scientists of various specializations – physicians, biologists, biomechanical and mechanical scientists, point their attention towards the research of ethiology and pathogenesis of some of the circulatory disorders by clarifying some phenomena of hemodynamics. Particular emphasis is placed on the research of new and more effective treatment methods as well as on the development of new substitutes to blood vessels.

In Lithuania, the blood circulatory disorders are widely spread. Since 1997, they have taken the first place.

The main reasons for blood circulatory disorders in carotid and other arteries is progressing atherosclerosis, artheriitis, and pathologic twisting of arteries. These cases of pathology affect the radius of lumen, thickness, length and permeability of blood vessels. The form and level of pathology make influence to pressure and velocity inside the lumen of the blood vessel. At some alteration of geometry of blood vessels local pressure inside the lumen increases significantly. It affects the wall of the blood vessel and raises critical stresses that could cause the rupture of a blood vessel.

In order to enable foreseeing the probability and the place of rupture of the blood vessel local values of velocity, pressure and stresses that occur at particular kind of pathology must be explored.

Aim and tasks of the work

The object of the research – the phenomena of the blood flow occurring in the pathological arteries with elastic walls; influence of physical load and particular level of pathology to the physical efficiency of a person as well as the definition of relation among the level of pathology, physical load and maximum blood pressure. The main tasks of the work are:

- to develop and explore a model of the blood flow and to define the phenomena occurring in pathological arteries;
- to define the relation among the physical load, the level of pathology, maximum blood pressure and flow rate transferred to the artery;
- to build engineering computation methodology for estimation of the physical efficiency of the person.

Scientific novelty

The investigation covered the blood flow phenomena in pathologic elastic arteries. The main parameters of the blood flow, and the relation among the level of pathology and human physical loading were defined. The mythology for determining the allowed physical load for a person was developed.

Methodology of research

For the tasks defined in this dissertation work experimental, analytic, numerical and statistic research methods were used. The modeling was performed using finite element method by ANSYS software.

Experimental research was carried out at the Vilnius Ambulance Hospital. Duplex scanning method was used.

Practical value

- The algorithm of the model of the blood vessel that was developed during the research allows making corrections to it according to individual geometry and blood pressure and performing the calculation of local blood flow parameters in a specific case. The results of research allow defining the direction, value and magnitude of biggest local pressure. This information is useful in preparing for angiochirurgic surgery or for prognosis tendencies of further development of pathology.
- The methods developed allow choosing a safe work load by estimating individual cases and parameters of arterial pathology including the greatest stresses on the wall of the blood vessel.

Defended propositions

- The dynamic model of the blood flow developed during the research allows variations of geometry according to the individual cases of pathology and common blood pressure values as well as to perform the calculation of parameters of local hemodynamics in every case.
- The results of the research enable defining the relation among the blood flow parameters, the level of pathology, and physical loading of a person as well as the direction, place and magnitude of the greatest stresses. This information is useful in preparing for angiographic surgery or in making prognosis of tendencies for further development of pathology in arteries.
- The methods developed allow rational selection of safe work load for a patient after the assessment of individual parameters of blood flow and greatest stresses that occur in the artery.

<u>The volume of the scientific work.</u> The scientific work consists of the general characteristic of the dissertation, 4 chapters, conclusions, list of literature, and addenda. The total volume of the dissertation is 101 pages, 35 pictures, 7 tables.

STRUCTURE OF THE WORK

The first chapter gives a review of scientific research works on the influence of the level pathology to blood flow parameters. The results and possibilities of experimental research in defining the geometry and physical parameters in pathological blood vessels were presented. Evolution and comparison of different mathematical models of blood flow and blood vessels were presented. The main tasks of the scientific work were defined at the end of the chapter.

The second chapter presents the development of non-linear model of pathological artery. The model was developed and numerical calculations were performed using ANSYS software. The process of the model development consists of three consequent stages:

1. Analysis of fluid processes in arteries presuming that the walls of blood vessels are undeformable.
2. Analysis of the blood flow in elastic artery model.
3. Effects of homodynamic to the wall of elastic carotid artery.

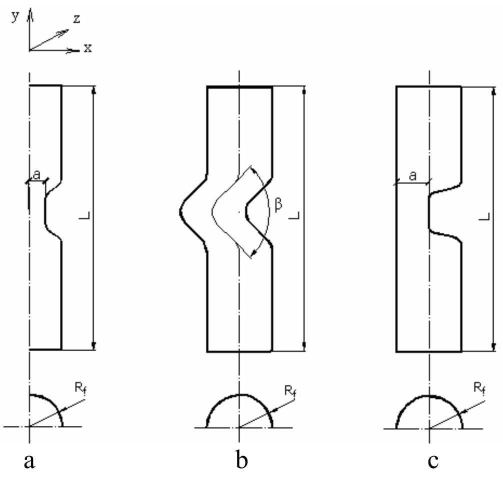

Fig 1. Types of blood vessels pathologies analyzed: a – stenosis; b – bending; c – one-sided stenosis; *a* – linear level of pathology; *β* – angular level of pathology, º

Starting with the first stage, the 3-D model was developed that varied in type and the level of pathology. Three types of pathologies: stenosis (a = 50 %, 70 %, 90 %), one-sided stenosis (*a* = 50 %, 70 %, 90 %) and bending (*β* = 50 º, 70 º, 90 º) were explored in the figure 1.

During the first stage, variation of velocity and pressure of blood-flow in pathological places, to indicate direction and magnitude of forces that bring influence to the walls of blood-vessels was analyzed.

The blood flow was examined by solving Navier-Stokes equations for incompressible fluids:

$$\frac{du}{dt} + u\nabla u = -\frac{1}{\rho} \cdot \nabla p + v \cdot \nabla^2 u \; ; \qquad (1)$$

and the equation of continuinity:

$$\frac{du}{dt} + \nabla u = 0 \; ; \qquad (2)$$

where $\nabla = \frac{\partial}{\partial x} i + \frac{\partial}{\partial y} j + \frac{\partial}{\partial z} k$; i, j, k – vectors; u = $(u,v,w)^T$ – velocity field of an element.

The influence of bending and stenosis of the blood vessel to variation of velocity and pressure was examined (figure 2). Direction of action of the resulting forces (figure 3) and characteristics of variation of the velocity were defined in extreme cross sections.

The results of analysis show that there are 3 critical cross sections where the pressure gains the critical values. In all types of pathologies examined the tendency was noticed that in the beginning and in the end of pathologies that geometry contains the highest degree of pathology, the pressure varies from the highest positive to the highest negative value. Similar phenomena occur in stenotic arteries. Highest positive values of pressure that form at the beginning of the pathology condition the expansion of the pathology. The highest negative values occur at the end of pathology cause vacuum inside the blood vessel and compress it. Such phenomena of expansion and compression contribute to the further development of the pathology and after reaching unallowable values could cause rupture of the blood vessel.

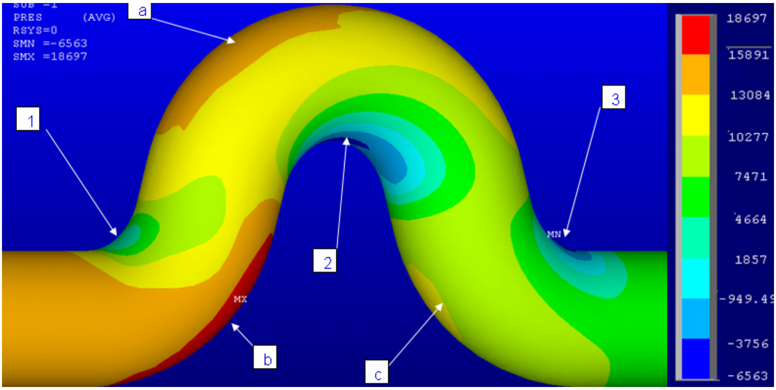

Fig 2. Distribution of pressure

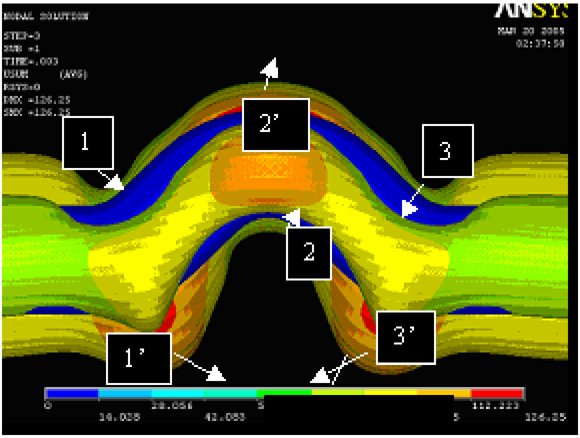

Fig 3. Definition of the resulting forces

Therefore, a model containing elastic blood vessels walls’ was developed (figure 4). In this phase it focused on the stenosis of arteries, leaving other types of pathologies aside. In the course of the research explored the influence of the value of arterial pressure and the level of pathology to the mechanical parameters of walls of blood vessels. The level of pathology was gradually increased from 50 % to 95 %. The pressure varied from normal 100 mmHg till 200 mmHg was tested. Dynamic pressure was set at the inlet of the model.

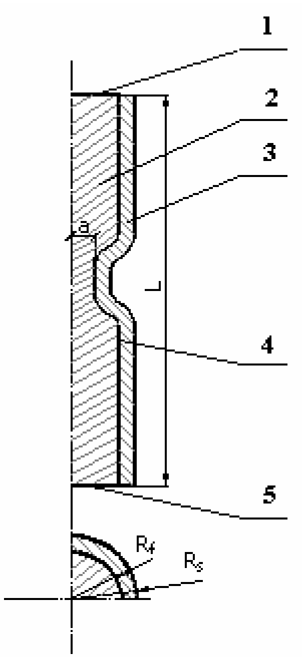

Fig 4. Computational scheme of stenotic carotid artery: 1 – outlet; 2 – fluid; 3 – wall of the blood vessel; *a* – the level of pathology, %; 4 – the surface of fluid-structure interaction; 5 – inlet; R_f – radius of fluid; R_s – external radius of the wall

The third stage – the interaction of the fluid and the structure (figure 5) at a mesh interface causes the pressure to exert a force applied to the structure and the structural motions produce an effective "fluid load." The governing finite element matrix equations then become:

$$[M_s]\{\ddot{U}\}+[K_s]\{U\}=\{F_s\}+[R]\{P\}; \qquad (2)$$

$$[M_f]\{\ddot{P}\}+[K_f]\{U\}=\{F_f\}+\rho_0[R]^T\{\ddot{U}\}; \qquad (3)$$

where [R] is a "coupling" matrix that represents the effective surface area associated with the each node on the fluid-structure interface (FSI).

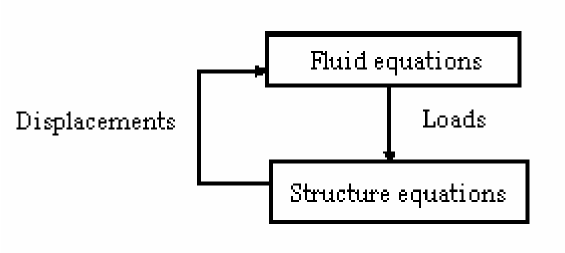

Fig 5. Fluid-structure interaction

Both the structural and fluid load quantities that are produced at the fluid-structure interface are functions of unknown nodal degrees of freedom. Placing these unknown "load" quantities on the left hand side of the equations and combining the two equations into a single equation produces the following:

$$\begin{bmatrix} M_s & O \\ \rho_0 R^T & M_f \end{bmatrix} \begin{Bmatrix} \ddot{U} \\ \ddot{P} \end{Bmatrix} + \begin{bmatrix} K_s & -R \\ O & K_f \end{bmatrix} \begin{Bmatrix} U \\ P \end{Bmatrix} = \begin{Bmatrix} F_s \\ F_f \end{Bmatrix}. \qquad (4)$$

Following the results of the analysis, the limit of allowed local pressure was defined of 60 kPa. It was defined that stenosis of 70 % at blood pressure acceding 200 mmHg, 80 % at blood pressure acceding 150 mmHg, and over 90 % the elastic artery becomes vulnerable at any pressure.

According to the results of the analysis a diagram (figure 6) was developed. The diagram shows that with the increase of the degree of pathology the allowed systolic pressure decreases. For example, we can observe that at 70 % of stenosis critical systolic pressure would emerge at 200 mmHg. At the same time examining pathology of 90 % the zone of danger starts with 120 mmHg. It shows that with the increase of pathology 1.28 times the allowed systolic pressure should be lower 1.7 times.

It shows that with the increase of pathology the local pressure inside the lumen increases significantly. In order to keep the local pressure at allowed values the systolic pressure needs to be controlled and in this respect the workload needs to be diminished.

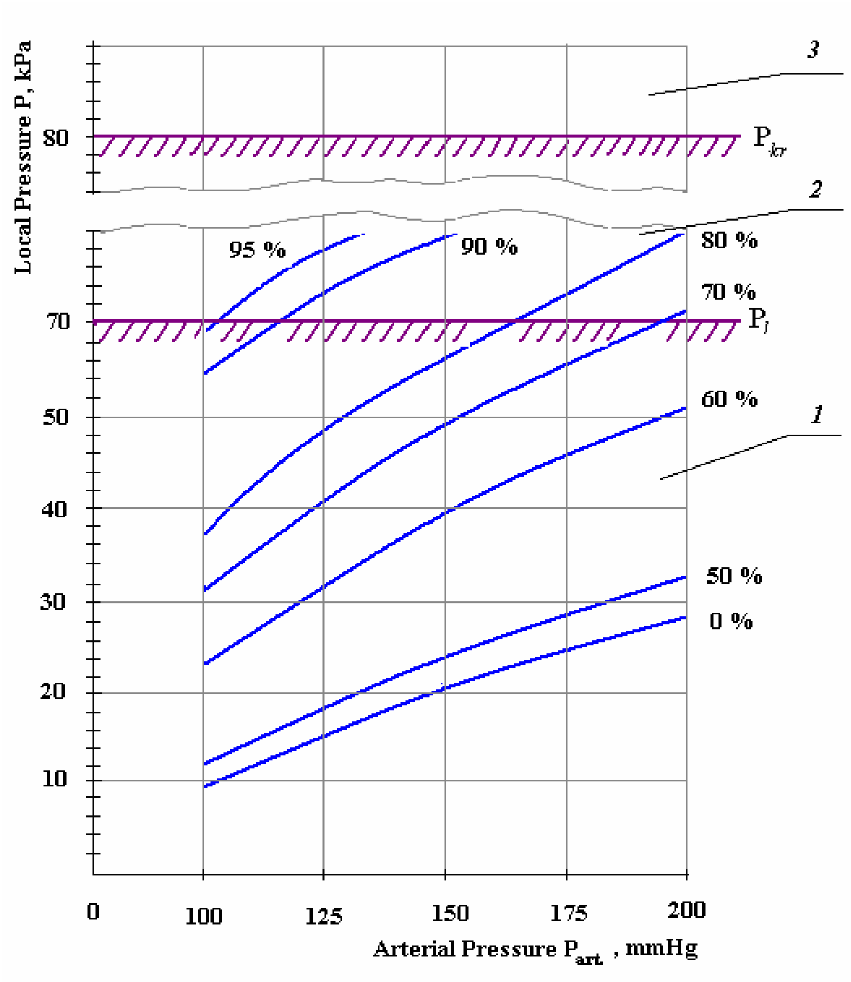

Fig 6. Relation among the maximum local blood pressure, the maximum local velocity and the degree of stenosis in the cross-section before the pathology:
P_l – limit of allowed local pressure inside the lumen; P_{kr} – critical allowable local pressure; 1 – active work zone; 2 – zone of restricted work load; 3 – zone of heart attacks and strokes

Further on, the research elaborates on a study to the research on stresses in pathological elastic arteries and on the influence of blood flow to the vessel in elastic stenotic arteries. Algorithm, which is easy to adjust to real conditions for calculation was developed. Numerical analysis with fluid structure interaction was used. Practical use of the algorithm in examining the elastic stenotic arteries is suggested (figure 7).

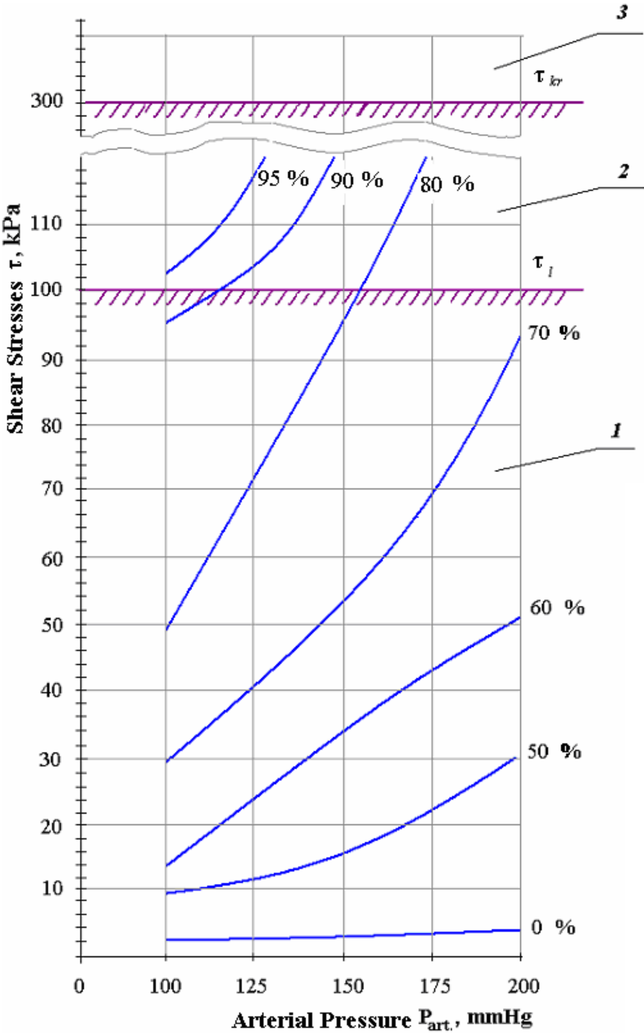

Fig 7. Relation among highest local shear stresses, arterial pressure and the level of pathology in the cross section before the pathology: τ_l – the limit of allowable local shear stresses; τ_{kr} – the limit of critical local shear stresses; 1 – active work zone; 2 – zone of restricted work load; 3 – zone of heart attacks and strokes

Analyzing the diagram it is noted that increasing the degree of pathology the allowable systolic pressure decreases. For example, we can observe that at 70 % of stenosis critical systolic pressure would emerge at 200 mmHg. At the same time examining pathology of 90 % the zone of danger starts with 120 mmHg. It shows that with increase of pathology 1.28 times the allowable systolic pressure should be lower 1.7 times.

The diagram in figure 7 in standard pathologic cases allows the physician to receive additional information on the ability of a person to carry physical loads depending on the level of pathology and maximum local shear stresses occurring on the wall of the artery. In the cases when the geometry of the pathology is more complicated it is easy to test the methodology developed in this study on specific conditions and define the allowed maximum systolic pressure.

It was defined that in the places of the greatest pressure rupture of the blood vessel might occur. According to the results of the research it was defined the permitted norm for local pressure is 100 kPa and for local shear stresses – 60 kPa. The research also revealed that the blood vessel can break at 70 % stenosis, when pressure accedes to 200 mmHg, at 80 % stenosis, when pressure accedes to 150 mmHg and at 90 % stenosis at any value of the arterial pressure.

To conclude, we can state that with the increase of pathology the local pressure inside the lumen increases significantly. In order to keep the local pressure at allowed values the systolic pressure needs to be controlled and in this respect the work load needs to be diminished.

In the third chapter the relation among artery pathology, blood pressure, blood velocity, the level of pathology and loads was experimentally investigated. It was defined that the level of pathology has significant impact on blood pressure in the places of pathology. With the increase of the level of pathology its influence to blood pressure increases nonlinearly.

It was shown that the value of the load has a significant impact on the blood pressure in pathological blood vessels. Approximate dependencies among the level of pathology, blood pressure in the location of pathology and work load were introduced.

The characteristic measurement results of the level of pathology and its geometry are presented in the figure 8. Using the duplex scanning method the levels of pathology, and blood pressure as well as local blood flow velocity were defined. The experimental research was performed with the age group of 40–70.

In the mathematical processing of the results of the experimental research it was defined that at the same level of pathology increasing the work load 2.97 times blood pressure will increase by 1.26 times. The pulse of a patient increases 1.47 times. In this way the heart pumps 1.47 times more and the amount of transferred blood increased that much times. It means that systolic pressure increases 1.47 times as well. If we consider that during the rest period the heart pumps blood 6 l/min. so with increase of work load 3 times, it will transfer 6 x 1.47 = 8.82 l/min.

a b

Fig 8. Investigation of the geometry of the artery and the blood flow velocity inside the lumen using Duplex scanning method:
a – occlusion of carotid artery; b – critical stenosis of internal carotid artery (Duplex scanning method)

In this respect increasing the work load of a person for 3 times, blood flow rate transfer to the arteries increases 1.47 or 1.5 times, i.e. the increase is approximately 2 times lower then the load of a person. It could be noted that the pressure increased from 1.22 till 1.34 times at putting different loads on a person i.e. in average 1.27 times. Comparing the increase of local blood pressure to systolic pressure it was noted that (1.5/1.27 = 1.18) the average value of their relation is 1.2 times. In such respect, blood pressure in the arteries increases 1.2 times less then its velocity.

The results of the experimental research allow defining approximate relation among blood pressure, velocity and influence of loading as well as the level of artery pathology.

In the fourth chapter, application of the results of the research on the blood flow parameters in pathological blood vessels and diagnostics of the physical work load in clinical practice. Two algorithms of the application of the results in practice are presented that will enable measuring status of arteries and will help in setting norms for allowed physical load of a person with pathological arteries. The first one is based in the calculations introduced in this work; the other is a simplified algorithm (figure 9).

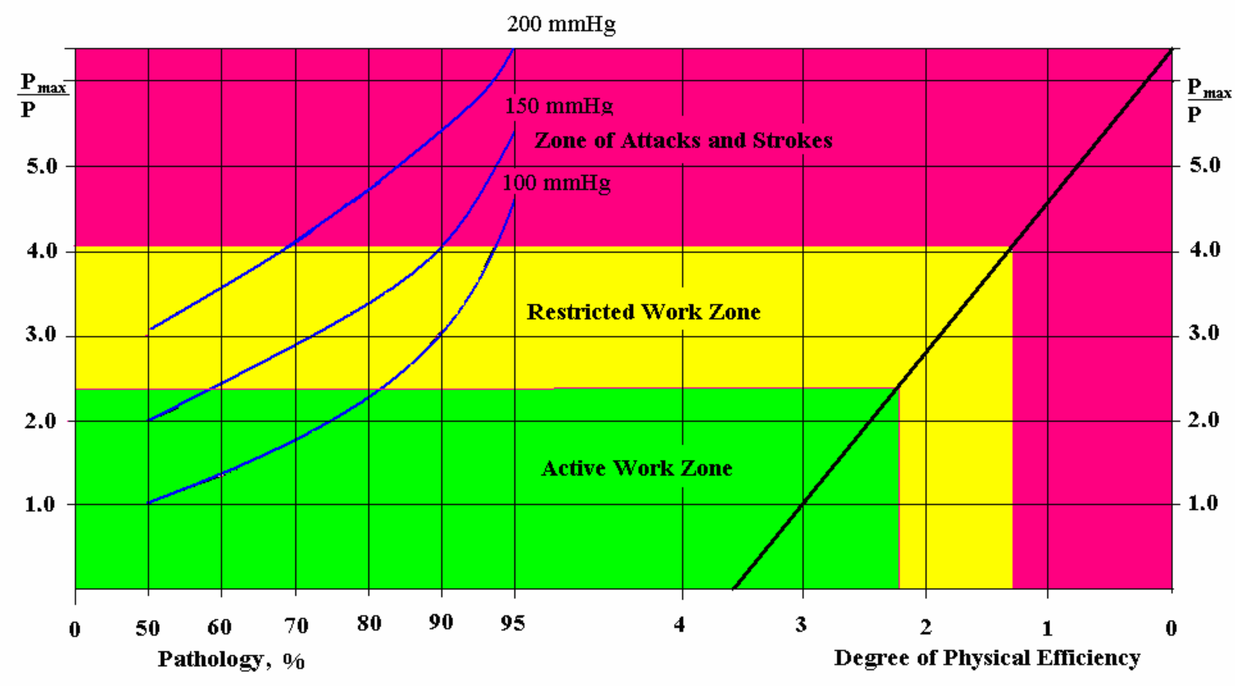

Fig 10. Nomogramme for defining the allowed physical loading for a person having a certain level of arterial pathology–simplified method

GENERAL CONCLUSIONS

After performing the analysis of the blood flow parameters and their interrelation in pathological arteries the following conclusions could be made:

1. Analytical models of the blood flow in the arteries allowed analyzing and defining the following main specific features and characteristics:
   - In pathological arteries there exist few zones of danger, where the blood velocity and pressure perform a significant increase comparing with the systolic pressure and velocity.
   - Local pressure gains the biggest value in the cross-section which is located before the pathology and the negative pressure appears in the end of pathology. In the pathologies of bending the negative pressure can occur in other places inside the pathological lumen.
   - A great positive pressure in the beginning and a negative pressure in the end of the pathology create conditions to form for maximum blood velocity between these cross-sections and turbulent behavior of the blood flow.
   - In the places of the greatest pathology the resultant forces containing opposite direction occur that create preconditions for blood flow for bypassing pathology in the shortest way possible.
   - The relation between arterial blood pressure and the level of pathology was defined. It was proved that with the increase of the level of pathology maximal pressure in the beginning of the pathology increases significantly. With increase of the pathology 1.9 times, the pressure increases 3.2 times.
2. Experimental research showed that the following relation between the physical load of a person and the level of pathology exists: the flow rate transferred to the arteries is two times lower then the physical load of a person, i.e. with increase of physical load 3 times, the flow rate increases 1.47 times and the blood pressure increases about 1.27 times.
3. The conditions of the artery rupture were analyzed and it was shown that the level of pathology and the physical load of a person have a significant influence on their rupture. It was defined that with increase of the pathology 1.9 times, the pressure increases 3.2 times and shear stresses increase 5 times.
4. The research proved that using the results of the study it is possible to perform a definition of a physical load of person considering the level of pathology. In defining the physical load of a person 3 characteristic zones were observed:
   - allowed zone that allows active physical activity for a person;

- zone of precaution allows limited activity for a person;
- zone of danger is the zone of strokes and heart attacks.

5. By the results of the research the sequence of procedures and calculations could be used in the methodic of medical clinical practice was defined. The possibilities for practical use in determining the physical load of a person in view of the level of pathology in the arteries were suggested. Two forms of methodics of practical application for diagnosis of allowed physical load for a person were developed:

- diagnosis algorithm and methodic using computer;
- simplified method.

<u>Published works on the topic of the dissertation</u>

In the acknowledged editions

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2. Uzdilaitė, G. Research on the Influence of Pathology Level to Stresses in Elastic Arteries. *Journal of Vibroengineering*, Vol 8, No 3. Kaunas: Technologija, 2006, p. 30–35, ISSN 1392–8716.

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About the author

Giedrė Uzdilaitė was born in Vilnius, on 12 of October 1978 in the family of engineers.

First degree in Mechanical Engineering, Faculty of Mechanics, Vilnius Gediminas Technical University, 2000. Master of Science in Mechanical Engineering, Faculty of Mechanics, Vilnius Gediminas Technical University, 2002. 2002–2006 – PhD student at the Vilnius Gediminas Technical University of Biomechanics Department.

PATOLOGIJOS ĮTAKOS KRAUJO SPAUDIMUI IR GREIČIUI KRAUJAGYSLĖSE TYRIMAS

Darbo aktualumas

Mokslo literatūroje nurodoma, kad kas trečias žmogus pasaulyje miršta nuo kraujagyslių funkcijos sutrikimų.

Pastaruoju metu įvairių specialybių mokslininkai – medikai, biologai, biomechanikai, atkreipę dėmesį į spartėjantį kraujo apytakos ligų plitimą, vis daugiau dėmesio skiria kraujo apytakos ligų etiologijai ir patogenezei, kraujotakos reiškiniams išaiškinti, o svarbiausia – naujų širdies-kraujagyslių ligų gydymo metodų ir pažeistų žmogaus kraujagyslių optimalių pakaitalų kūrimui.

Statistika rodo, kad nuo 1997 metų kraujo apytakos sistemos ligos Lietuvoje užima pirmąją vietą.

Pagrindinės kraujotakos sutrikimų miego ir kitose arterijose priežastys yra progresuojanti aterosklerozė, arteriitas, patologiniai arterijų susisukimai. Ši patologija įvairiai keičia kraujagyslės spindį, sienelės storį, ilgį ir pralaidumą. Priklausomai nuo susidariusios patologijos formos ir dydžio kinta kraujo tėkmės slėgis ir greitis. Prie tam tikrų kraujagyslės sienelės geometrijos nuokrypių dėl tėkmės pokyčių kraujagyslėje išauga vietinis slėgis. Tai veikia kraujagyslės sienelę ir sukelia joje kritinius įtempimus, dėl kurių kraujagyslė gali plyšti.

Prognozuojant kraujagyslės plyšimo vietą ir galimybę svarbu ištirti vietines greičio, slėgio ir įtempimo reikšmes, susidarančias prie tam tikro patologijos laipsnio.

Darbo tikslas ir uždaviniai

Tyrimo objektas – reiškiniai, vykstantys kraujo tėkmėje patologiškose arterijose su tampriomis sienelėmis, fizinės apkrovos ir patologijos laipsnio įtaka žmogaus darbingumui bei ryšys tarp patologijos laipsnio, apkrovos ir maksimalaus kraujo slėgio į kraujagyslės sienelę.

Darbo tikslas – analitiniu ir eksperimentiniu būdu ištirti tampriose patologiškose arterijose vykstančius reiškinius, nustatyti ryšį tarp žmogaus fizinės apkrovos, kraujagyslės patologijos laipsnio, maksimalaus kraujo slėgio ir kraujo padavimo į arteriją debito bei sudaryti praktinio tyrimo taikymo – žmogaus darbingumo nustatymo – metodiką. Pagrindiniai tyrimo uždaviniai:

1) ištirti kraujo tėkmės procesą patologiškose kraujagyslėse nagrinėjant:
- netamprių ir tamprių arterijų modelius bei skirtingas patologijų rūšis;
- patologijos ir kraujo tėkmės parametrų ryšį;

2) eksperimentiniu ir analitiniu būdu ištirti arterijų patologijos laipsnio ir fizinio krūvio žmogui ryšį;

3) apibendrinant tyrimo rezultatus sudaryti fizinio krūvio žmogui normavimo pagal patologijos laipsnį metodiką.

<u>Mokslinis naujumas</u>

Išnagrinėti kraujo tėkmės reiškiniai patologiškose arterijose ir nustatytas pagrindinių kraujo tėkmės parametrų, patologijos laipsnio ir žmogaus fizinio krūvio sąveikos ryšys bei metodika, kuri leis normuoti leistiną krūvį žmogui, įvertinant patologijos laipsnį.

<u>Tyrimų metodika</u>

Užsibrėžtiems tikslams pasiekti disertaciniame darbe naudoti analitiniai, eksperimentiniai, skaitiniai ir statistinio tyrimo metodai. Kraujo tėkmės patologiškose arterijose modeliavimas atliktas naudojantis baigtinių elementų metodu ANSYS programiniame pakete.

Eksperimentiniai tyrimai buvo atlikti Vilniaus Greitosios pagalbos ligoninėje. Juose naudotas dvigubo skenavimo metodas.

<u>Praktinė vertė</u>

- Sudaryto kraujagyslės modelio algoritmas leidžia modelį koreguoti priklausomai nuo individualios patologijos geometrijos ir bendro kūno kraujo slėgio bei tiriamu atveju atlikti vietinės hemodinamikos parametrų skaičiuotę. Skaičiavimų rezultatais nustatytos didžiausio slėgio ir įtempimo vietos, kryptis ir dydis kraujagyslės sienelėje. Ši informacija naudinga rengiantis angiochirurginei operacijai arba prognozuojant tolesnes patologijos vystymosi tendencijas.
- Prognozavimo metodika leidžia pasirinkti saugų darbo krūvį, įvertinant individualius arterijų kraujotakos parametrus ir sienelės patologijos vietose susidariusį didžiausią slėgį bei šlyties įtempimus.

<u>Ginamieji teiginiai</u>

- Pagal individualią kraujagyslės patologijos geometriją ir realias kraujo tėkmės sąlygas sudarytas tamprios kraujagyslės dinaminis modelis kiekvienu atveju leidžia atlikti vietinės hemodinamikos parametrų skaičiuotę.
- Skaičiavimų rezultatai leidžia nustatyti kraujagyslės sienelėje susidariusių didžiausių įtempimų vietas, kryptį ir dydį. Ši informacija naudojama klinikinėje praktikoje, rengiantis angiochirurginei operacijai bei prognozuojant tolesnes patologijos vystymosi tendencijas.

- Sudaryta skaičiavimo metodika leidžia racionaliai pasirinkti saugų fizinį krūvį, įvertinant individualius arterijos kraujotakos parametrus ir patologiškose kraujagyslės sienelėse susidariusį didžiausią įtempimą.

Darbo apimtis

Disertacinį darbą sudaro įvadas, 4 skyriai, išvados, naudotos literatūros sąrašas, priedai. Darbo apimtis – 101 puslapis, 35 paveikslai, 7 lentelės.

Darbo struktūra

Pirmame skyriuje pateikta mokslo darbų apie kraujagyslių patologijos įtaką kraujo tėkmės parametrams analizė ir suformuluoti tyrimo uždaviniai.

Antrame skyriuje aprašomas taikant baigtinių elementų metodą sudarytas ir ištirtas dinaminis tamprus kraujagyslės modelis, nustatoma kraujagyslės geometrijos, patologijos formos ir dydžio, slėgio bei kraujo greičio kraujagyslėje, taip pat kraujagyslės sienelėje susidariusių įtempimų sąveika.

Trečiame skyriuje aprašytas atliktas kraujo tėkmės greičio patologiškose kraujagyslėse ir paciento darbingumo parametrų eksperimentinis tyrimas ir pateikti šio tyrimo rezultatai.

Ketvirtame skyriuje, remiantis paciento kraujo tėkmės parametrų ir kraujagyslės sienelės tamprumo savybių patologiškose kraujagyslėse tyrimo rezultatais, aprašoma sudaryta nauja paciento darbingumo diagnozavimo metodika ir pateikiami jos taikymo klinikinėje praktikoje pasiūlymai.

Apibendrinimai ir išvados

Atlikus kraujo tėkmės parametrų ir jų tarpusavio ryšio analizę patologiškose arterijose, galima suformuluoti šias išvadas:

1. Sudaryti kraujo tėkmės arterijose analitiniai modeliai leido išnagrinėti ir nustatyti šiuos pagrindinius charakteringus požymius bei charakteristikas:

- patologiškose arterijose egzistuoja kelios pavojingos zonos, kuriose kraujo slėgis ir tėkmės greitis gali būti nuo kelių iki keliolikos kartų didesnis nei arterinis slėgis ir greitis;

- didžiausias kraujo slėgis yra prieš patologiją, o neigiamas slėgis atsiranda už arterijų patologijos. Arterijų kilpose neigiamas kraujo slėgis gali atsirasti ir patologijos viduje;

- dėl didžiausio kraujo slėgio patologijos pradžioje ir mažiausio pabaigoje susidaro didžiausias kraujo tėkmės greitis patologijos viduje, atsiranda turbulencijos reiškiniai;

- dėl didelio slėgio arterijų patologijos pradžioje ir mažiausio slėgio pabaigoje atsiranda viena kitai priešingos krypties atstojamosios jėgos, kurios sudaro prielaidą kraujo tėkmei patologiją apeiti trumpiausiu keliu;

- nustatytas kraujo slėgio ir arterijų patologijos ryšys. Parodyta, kad, didėjant arterijų patologijos laipsniui, maksimalus slėgis patologijos pradžioje didėja netiesine priklausomybe; patologijai padidėjus 1,9 karto, vietinis slėgis padidėja 3,2 kartų.

2. Eksperimentais nustatytas apytikslis ryšys tarp žmogaus fizinio krūvio ir patologijos lygio. Išaiškinta, kad paduodamo į arterijas kraujo kiekio padidėjimas, augant fiziniam krūviui, yra apytiksliai 2 kartus mažesnis negu krūvio padidėjimas, t.y., krūviui padidėjus 3 kartus, kraujo padavimas į arterijas išauga apie 1,47 karto, o kraujo slėgis – apie 1,27 karto.

3. Išnagrinėtos arterijų plyšimo priežastys ir parodyta, kad labai didelę įtaką jų plyšimui turi patologijos laipsnis ir darbo krūvis. Nustatyta, kad padidėjus patologijos laipsniui 1,9 karto, vietinis slėgis padidėja 3,2 kartų, o šlyties įtempimai išauga 5 kartus.

4. Tyrimo metu gautų rezultatų analizės pagrindu nustatyta, kad galima normuoti fizinį krūvį pacientui, įvertinant jo arterijų patologijos laipsnį. Normuojant paciento darbo krūvį išskirtos 3 charakteringos zonos:

- leistina – aktyvaus darbo;
- atsargos – riboto darbingumo;
- pavojingoji – infarktų ir insultų zona.

5. Tyrimo rezultatais nustatytas atliekamų procedūrų taikymas gydymo praktikos metodikoje ir skaičiavimų nuoseklumas. Pasiūlytos praktinio taikymo galimybės normuojant krūvį pacientui, įvertinant kraujagyslių patologijos laipsnį. Sukurtos žmogaus darbingumo diagnozavimo praktinio taikymo metodikos:

- kompiuterinio diagnozavimo algoritmas ir metodika;
- supaprastinta metodika, įgyvendinama taikant sudarytas nomogramas.

Trumpos žinios apie autorių

Giedrė Uzdilaitė gimė 1978 m. spalio 12 d.Vilniuje inžinierių šeimoje.

2000 m. įgijo mechanikos inžinerijos bakalauro laipsnį Vilniaus Gedimino technikos universitete, Mechanikos fakultete. 2002 m. įgijo mechanikos inžinerijos mokslo magistro laipsnį Vilniaus Gedimino technikos universitete, Mechanikos fakultete. 2002–2006 – Vilniaus Gedimino technikos universiteto Mechanikos fakulteto Biomechanikos katedros doktorantė.

Giedrė Uzdilaitė
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