384. RESEARCH OF THE INFLUENCE OF LOAD, SYSTOLIC BLOOD PRESSURE AND PATHOLOGY ON LOCAL PRESSURE IN ELASTIC ARTERIES

M. Mariūnas
Vilnius Gediminas technical university,
J. Basanavičiaus str. 28 a, LT - 03224 Vilnius, Lithuania
E-mail: mariunas@me.vgtu.lt,
Tel.: +370 6 52744748

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Abstract: Paper presents dependencies between local blood pressure in the place of pathology and the magnitude of the load, the level of vessels pathology, the systolic blood pressure, age and gender, derived by analytical-numerical and experimental ways. The balance of the influence of estimating parameters to local blood pressure in the place of pathology have been formed and it presents the following results: the major part of effect falls in to the level of vessels pathology – 43–47 %, the effectiveness caused by systolic blood pressure – 28–30 %, the part of person's loading magnitude exceeds 16–20% and only 7–9% falls into person's age. Presented analytical expression enables to calculate the local blood pressure in the place of pathology due to particular vessels pathology level, load, systolic blood pressure and age.

Keywords: age, systolic blood pressure, load, pathology, pressure in the place of pathology, elastic arteries, balance.

Introduction

Most of the scientific studies are devoted to analyze the influence of the effect of blood flow parameters to blood pressure or velocity [1–8]. It was noticed that the level of pathology has a significant influence to the local blood pressure in the place of pathology and velocity. Several scientific works [8–12] evaluated the influence of the magnitude of the load, age and gender to systolic blood pressure. Although, numerous studies of blood flow have been conducted [1, 2, 5, 6, 8], only a few have considered realistic anatomies under correct physiologic conditions as well as vessel wall mechanics. Works [4, 5, 6, 8, 11, 15, 16, and 17] analyzes the variety of methodic and systolic blood pressure evaluation ways. Numerical methods [2, 4, 6, and 16] were used for solving Navier-Stokes equation and calculation of the influence of local blood pressure in the place of pathology to systolic blood pressure and vessels pathology level. Unfortunately, only few works [1, 5, and 14] present investigated influences of the magnitude of loading, person's gender and age to a local blood pressure in the place of pathology and have derived and presented dependencies of before mentioned parameters. Sad, but not enough experiments have been made and the presented results were not comprehensive. Furthermore, received results of influences of load to systolic blood pressure haven't been associated to the blood pressure in the place of pathology. Either, the effect of person's age, gender, load and the complex action of systolic blood pressure to pressure in the place of pathology of the elastic arteries. Local maximal blood pressure in the pathology place could be evaluated only by assessing person's age, gender, load, systolic blood pressure and pathology at the same time and to compare these parameters to permissible pressure. Therefore, the purpose of this paper is to make a research by a non-invasive way of essential values of systolic blood pressure dependencies to person's age, gender and load, and to associate these results analytically with maximal local blood pressure in the place of pathology, evaluating vessels pathology level also.

The main objectives are to model vessels anatomy in realistic way, to use correct physiologic flow conditions, and to account vessel wall compliance. For this purpose the equations of Navier–Stokes were solved using finite element method for analysis of characteristics of blood-flow by ANSYS software.

Methods

Dependencies of blood pressure in elastic vessels to their pathology level were derived by calculating Navier–Stokes equations by using 2D finite element model with the grid of rectangle finite element. Navier–Stokes equations for incompressible flow of Newton fluids in vector form:

$$\rho\left(\frac{\partial V}{\partial t}+\nabla V\right)=-\nabla p+\mu\nabla^2 V+f\,, \tag{1}$$

where V is the flow velocity; ρ is the fluid density; ∇ is the del operator; f stands for other body forces (such as gravity or centrifugal force); ∇p is gradient of pressure of surface forces; μ is effective viscosity; p is pressure.

In the three-dimensional Cartesian coordinate system with coordinates (x, y, z), the operator is defined in terms of partial derivative operators as:

$$\nabla = i\frac{\partial}{\partial x}+j\frac{\partial}{\partial y}+k\frac{\partial}{\partial z}. \tag{2}$$

The differential form of the continuity equation is:

$$\frac{\partial\rho}{\partial t}+\nabla(\rho V)=0\,, \tag{3}$$

t is time.

The rate of change of density can be replaced by the rate of change of pressure and the rate where which density changes with the pressure:

$$\frac{\partial\rho}{\partial t}=\frac{\partial\rho}{\partial p}\cdot\frac{\partial p}{\partial t};\ \frac{\partial p}{\partial t}=\frac{1}{\beta}, \tag{4}$$

where β stands for bulk modulus; $\beta=10^{15}$ for a perfectly incompressible fluid.

Solving Navier–Stokes equations by numerical methods the algorithm was used, which enables to calculate the relative value of pressure but not absolute. Therefore, the equations of absolute values of blood flow calculation were reformed. But they are not presented because of amount of the paper.

Inlet blood pressure was modeled by different laws (sinusoid and trapezium form), when solving the equation system (1). As an example, the description of sinusoidal law of the blood pressure at the duration of the first cycle is presented below:

$$p(t)=\begin{cases}0, t=0;\\ p_0\sin(\omega t), 0\le t\le\dfrac{T}{2}; T=\dfrac{2\pi}{\omega};\\ 0, t>\dfrac{T}{2}.\end{cases} \tag{5}$$

When $T/2 < t \le T$, the inlet pressure is $p(t)$=0. At second cycle it was analogically repeated.

For calculations following presumptions were accepted: the velocity under vessels wall is equal to zero; $\mu = 4\cdot 10^3$ *kg/ms* and density $\rho = 1050$ *kg/m*^{3}.

The object of analysis is elastic stenotic carotid artery. The following levels of stenosis were examined: 50 %, 60 %, 70 %, 80 %, 90 % and 95 %.

Dependency of systolic blood pressure on person's age, gender and load was received by using veloergometer Kettler. Males and females attended experiments. They were divided into six age groups of 16, 25, 35, 45, 55 and 65 years. The average age was set and it varies about 4 years. During the experiment the load was kept from 0 to 200 *W*, when it was set by the step of 50 *W* every time, so it could be said, that 5 loadings were appointed for the experimental research. People without expressed pathologies took part in the experiment research.

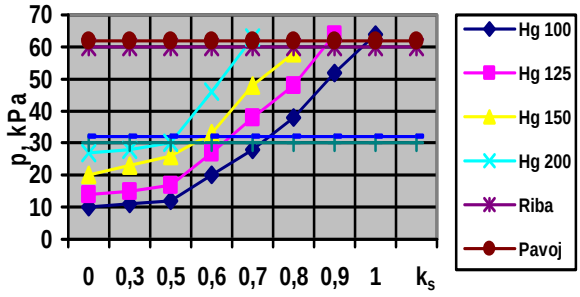

Fig. 1. Influence of vessels pathology k_s to local pressure of blood at different values of blood pressure *mmHg*

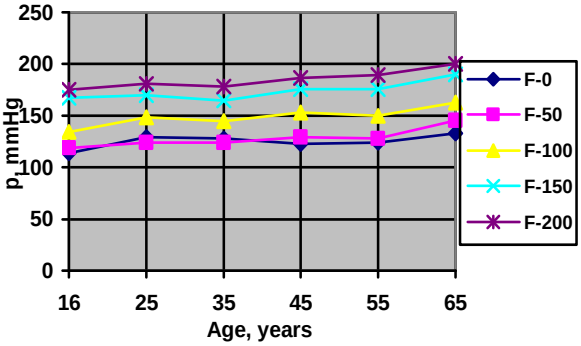

Fig. 2. Relations between blood pressure and men age *A,y* in years under different loadings *F,W*

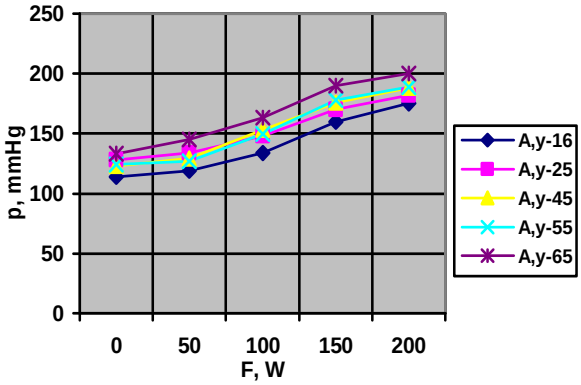

Fig. 3. Blood pressure in *mmHg* dependency on loading magnitude *F,W* at different men age *A,y* in years

Results

Maximal values of local blood pressure in the place of pathology of the elastic artery were received by solving Navier-Stokes equations at different pathology level and systolic blood pressure, are presented in figure 1. Results form this figure presents small effect of the pathology level when $k_s \leq 0{,}5$ (or 50 %) to local blood pressure in the pathology place, and after $k_s > 0{,}5$ than local pressure very increases (Fig.1). For example, as k_s value enlarges from 0,5 to 0,7, the maximum local blood pressure in the place of pathology rises two times. Seen, that the systolic blood pressure influences to maximum local blood pressure very much. The effect of systolic blood pressure grows according to increase of pathology level, for example as the pathology level is $k_s = 0{,}5$ as concerning the systolic blood pressure increase from 100 to 200 *mmHg*, the maximal local blood pressure goes up from 12 to 30 *kPa* (Δp = 18 *kPa*). Meanwhile, on $k_s = 0{,}8$ – maximal local blood pressure in the pathology place increases from ~40 to ~79 *kPa* ($\Delta p \approx 39$ *kPa*). Presented results show, that in the studying pathology interval caused by the increase of systolic blood pressure from 100 to 200 *mmHg*, the maximal local blood pressure in the place of pathology grows about two times in comparison with rise, when k_s = 0,5. Such circumstances, as the systolic blood pressure and the pathology level are high they are harmful for a person. Systolic blood pressure (*mmHg*) dependencies on age and load in male and female groups are presented in figures 2, 3, 4 and 5. Figures results show the much more stronger effect of the loading size either of the person's age in male and female groups (Fig. 2 and 3 presents results in male group and Fig. 4 are 5 – female group). Characteristic is the fact, that large spread of systolic blood pressure data received from younger women after small loadings (see Fig. 4 and 5). Presented experimental research results (Fig. 2, 3, 4 and 5) show systolic blood pressure dependency on age, gender and load, but they aren't associated with local blood pressure in the place of pathology. Therefore, it is very important to fix the age and to estimate the effect of gender and load to a local blood pressure in the place of pathology. Following assumptions were made for the set mentioned relation. If there is 120 *mmHg* and at pathology level $k_s = 0{,}7$, the local blood pressure is $p \approx 35$ *kPa* (Fig. 1), so because of the load F = 150 *W* and age A=25 years, the systolic blood pressure increases (Fig. 2). Thus, because of enlarged load the pressure will be not 120 *mmHg*, but 160 *mmHg*. In the figure 1 presented result enables to derive the rise of the local blood pressure in the pathology place from 38 to 50 *kPa*. The rise of the systolic blood pressure until ΔHg = 40 *mmHg* as the initial Hg = 120, affects the increase of local blood pressure in the place of pathology - Δp = 50 - 38 = 12 *kPa*. Knowing the dependency of systolic blood pressure on age, gender and load (Fig. 2, 3, 4, 5), analogically, according to described methodic, the effect of these parameters to local blood pressure in the place of pathology could be evaluated.

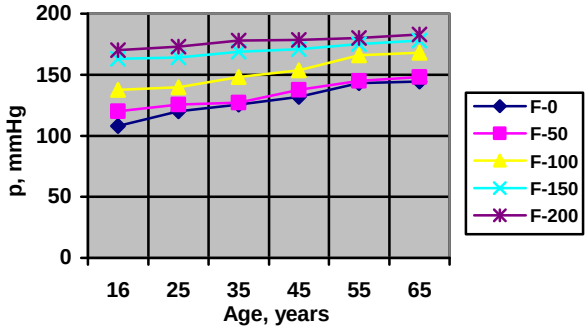

Fig. 4. Blood pressure *mmHg* dependency on female age *A,y* under different loadings *F,W*

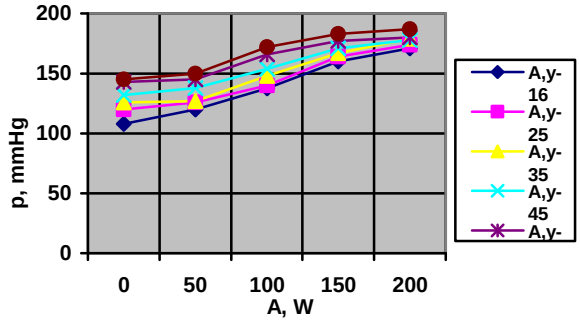

Fig. 5. Blood pressure *mmHg* dependency on loadings *F,W* under different female age *A,y*

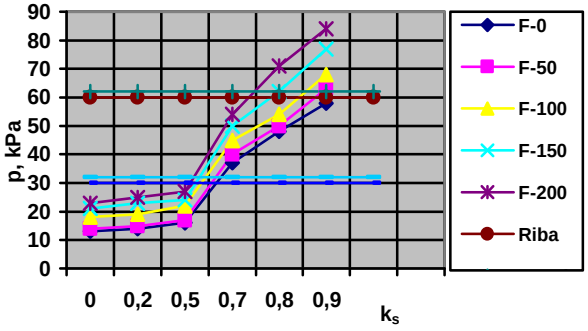

Fig. 6. Local pressure dependency on loading *F, W* different vessels pathology level k_s, *Hg=120 mmHg* and age *A,y* = 25 years in male group

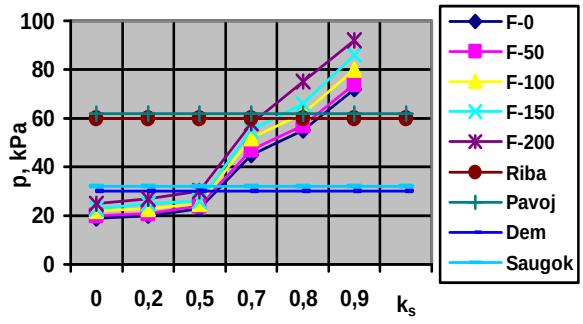

Fig. 7. Local pressure dependency on loading *F, W* different vessels pathology level k_s, *Hg=120 mmHg* and age *A,y* =65 years in male group

The local blood pressure in the place of pathology dependency on load F at different pathology level k_s, Hg = 120 *mmHg*, and age of 25 and 65 years, was derived from calculations and they are presented in figure 6 and 7. Estimated, that in the male group, approximately 0,320 *mmHg* falls on one watt of the load and in female group – approximately 0,280 *mmHg* of systolic blood pressure. But in the female group aged from 16 to 45 years old there was noticed the major spread of data. Further investigation leads to the balance of local blood pressure in the place of pathology formation (Fig. 8). The balance shows the amount in percents of the influence of following parameters: a load (F), males and females age (A), the pathology level (k_s) into summarized local blood pressure in the place of pathology at normal systolic blood pressure (Hg = 120 *mmHg)*. Noticeable, that in the male and female groups, the major part of increase of local blood pressure occurs due to vessels pathology (60–68%), which is caused by a load about 23–28%, and because of the age only – 9–12%. Additionally, evaluating enlarged systolic blood pressure, there were received results of formed balance of local blood pressure in the pathology place and they are presented in the figure 9. At this point, the increase of local blood pressure in the place of pathology is the most caused by pathology level and it is about 43–47%. Second influence parameter is the systolic blood pressure, which affects about 28–30 % and further, load influence is about 16–20%. Person's age the least influences to local blood pressure in the place of pathology, only 7–9%. Analyzing the influence of gender to the local blood pressure in the pathology place (Fig. 8 and 9) was noticed, that in female group, the influence of vessels pathology level to estimated factor is correspond to the upper level of effect in percents, that is 47 and 68 %, while in male group the amount is about 43 and 60 % (Fig. 8 and 9). In the male group, the local blood pressure in the place of pathology is major effected by a loading size and age and appropriately is 16–20 % by a load and 7–9% by the age. In such a way the results of the balance of parameters affected into local blood pressure obviously presents the worst situation for a person as he has high systolic blood pressure and vessel pathology level (Fig.7), because effect of these features is about 71–77 % of increase of local blood pressure in the place of pathology in male and female groups.

Processing results of the influence of separate parameters: age, gender, load, vessels pathology level, and systolic blood pressure into local blood pressure in the place of pathology by the least squire method with probability 0,95 and degree of freedom υ = *9* in male group the approximate dependency was derived:

$$p_v(k_s, Hg, F, A) = 0.18\,k_s\,A + 0.092F + \\ + 0.9(100\,k_s - 50) + 0.28\,k_s\,Hg, \quad (6)$$

under the such boundary limits: $0{,}5 \le k_s \le 1{,}0$; $16 \le A \le 6{,}5$; $100 \le Hg \le 200$; $0 \le F \le 200$;

where $p_v(k_s, Hg, F, A)$ is a local blood pressure in the place of pathology in the male group; k_s is the pathology level; A is the person's age in years; F is the the load, W; Hg is systolic blood pressure, *mmHg*.

Local blood pressure in the place of pathology in female group could be approximately calculated in such a way:

$$p_m(k_s, Hg, F, A) = 0.17\,k_s\,A + 0.09F + \\ + (100\,k_s - 50) + 0.29\,k_s\,Hg, \quad (7)$$

under the such boundary limits: $0{,}5 \le k_s \le 1{,}0$; $16 \le A \le 6{,}5$; $100 \le Hg \le 200$; $0 \le F \le 200$;

$p_v(k_s, Hg, F, A)$ is a local blood pressure in the pathology place in female group.

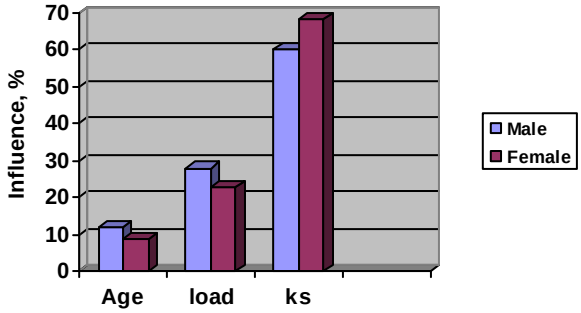

Fig. 8. Influence of age, load and pathology level k_s to local pressure expressed by percents, when Hg=120mm

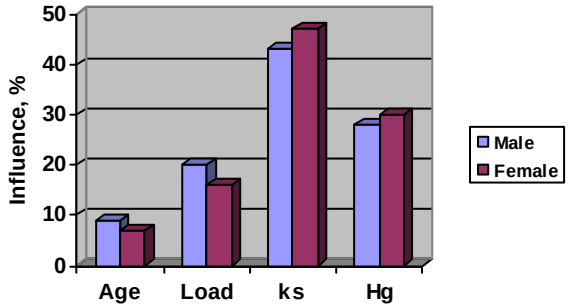

Fig. 9. Influence of age, load, pathology level k_s and blood pressure Hg to local pressure expressed by percents

Results for male group were calculated according to expression (1) and (6) for 25 and 65 years male, and presented in the figure 10. Symbol *Spl* marks curves, which results were received by experiments and calculated by Navier-Stokes equations, *mkb* – marks results calculated by expression (6). Numbers 25 and 65 show the male age.

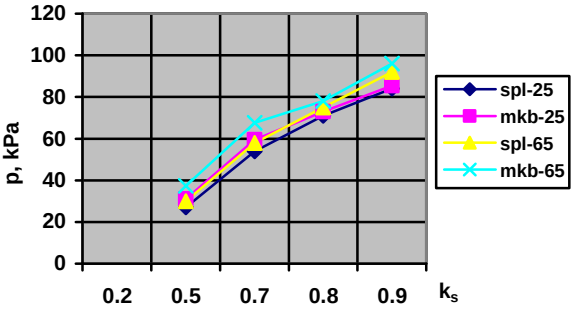

Fig. 10. Comparison of curves of male groups local pressure received by different ways at Hg = 120 *mmHg*, F = 200 *W*, in 25 and 65 yeas old group

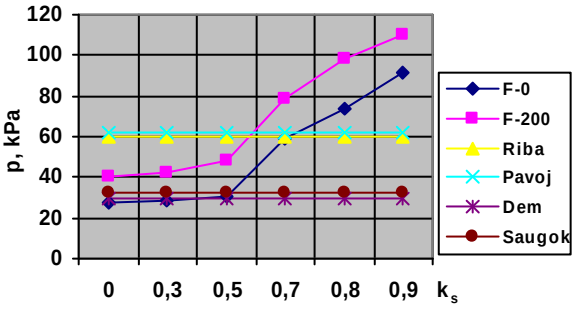

Fig. 11. Dependency of local pressure to load at different vessels pathology level k_s, Hg = 200 *mmHg* and A = 25 years in male group

When k_s < 0,5, expressions (6) and (7) are invalid, because vessel pathology k_s affects the local blood pressure in the place of pathology very little, besides, the systolic blood pressure has a small effect too.

In the graphs (Fig. 1, 6, 7 and 11) could be parted in 3 zones: the first from 0 to 30 *kPa* of local blood pressure in the place of pahology; second – from 30 to 60 *kPa* and the third – up to 60 *kPa*. The upper limit of the first zone is 30 *kPa* and it was selected, because under normal systolic blood pressure Hg = 120 *mmHg*, vessel pathology level k_s < 0,5 and p < 30 *kPa*, the person is full efficient. With the increase of vessel pathology level and systolic blood pressure, the local blood pressure very enlarges in the place of pathology and the dangerous to person's health grows up. Therefore, the second zone is of limited efficiency. Its upper limit is p = 60 *kPa* and such was taken the vessels loses their elasticity and strength because of the person's pathologies. The third is the zone of very big risk and critical local blood pressure in the place of pathology and is the zone of person's incapacity also.

Analyzing results from the graphs in the figures 1, 6, 7 and 11 and above mentioned zones there was noticed, that when systolic blood pressure is 120 *mmHg* under all sizes of a load and in male age groups, as vessel pathology level $k_s \le 0{,}5$, the local blood pressure is $p \le$ 30 *kPa* (Fig. 6 and 7). Therefore, these people could be qualified as efficient. But if systolic blood pressure is 200 *mmHg* and F = 200 *W* (Fig. 11), the local blood pressure in the place of pathology even under $0 \le k_s \le 0{,}5$ is $p >$ 30 *kPa*, that means, that the person with such systolic blood pressure gets in to limited efficiency zone.

Processing results according to above mentioned methodology, the approximate dependency was got:

$$p(k_s, Hg, F, A) = 10 + 0.17\,k_s A + 0.04F + \\ + 4\,k_s + 0.080\,k_s\,Hg, \tag{8}$$

when k_s < 0,5; $16 \le A \le 40$; $100 \le Hg \le 200$; $0 \le F \le$ 200.

Thus the expressions (6), (7) and (8) could approximately evaluate the local blood pressure in the place of pathology according to the pathology level, the systolic blood pressure, the load, age and sex. Displayed local blood pressure in the place of pathology could be used for evaluating of the people efficiency level.

Conclusions

After observing analytical and experimental research results there were formulated the following conclusions:

1. The dependency of local blood pressure in the place of pathology on the pathology level and the systolic blood pressure has been derived by analytical-numerical method and it has displayed the following:

- up to $k_s \le 0{,}5$ the level of vessel pathology less affects to a local blood pressure of the place of pathology, when $k_s > 0{,}5$, its influence increases and values vary according to the case of systolic blood pressure;
- the systolic blood pressure leads to rise the local blood pressure of the place of pathology very much and its effect increasing meaningfully when the pathology level is $k_s > 0{,}5$;

2. Systolic blood pressure dependency on the loading magnitude, person's age and gender has been got by experimental way, and these evidences have been explored:

- in the male group approximately 0,320 *mmHg* falls on one watt of loading size and in female group – approximately 0,280 *mmHg* of systolic blood pressure; but in the female group aged from 16 to 45 years old there is noticed the major spread of data;
- person's age less acts the systolic blood pressure either the magnitude of the load.

3. The relation between the local blood pressure in the place of pathology, the load, age, gender, vessel pathology level and the systolic blood pressure has been appointed and the following notes have been disclosed:

- very dangerous occurrence for a person is when the pathology level of a vessel is $k_s > 0{,}5$ and the systolic blood pressure is increased, because at such a case local blood pressure enlarges in several times in the place of pathology;
- the balance of local blood pressure in the place of

pathology shows the effect of the influence in percents of the parameters: the major effect is caused of vessel pathology level, it is about 43–47 %, systolic blood pressure – 28–30 %, the load influences about 16–20 % , and person's age – only 7–9 %;

- there are presented empirical expressions for approximate calculation of values of local blood pressure in the place of pathology dependency on age, load, vessel pathology level and systolic blood pressure, when pathology level is $k_s > 0{,}5$ and when $0{,}5 \leq k_s \leq 1{,}0$.

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