

Optical visualization of blood flow in the elimination of nosebleeds by ligation of the external carotid artery according to angiography

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ABSTRACT

The evaluation of blood flow indicators in the elimination of nosebleeds by ligation of the external carotid artery according to angiography data is considered. It has been shown that due to the ligation of one main vessel, which leads to an increase in the perfusion rate, respectively, with a subsequent decrease in pressure on the walls of the vessels, hypotension is observed. This reduction in pressure additionally leads to easier relief of nosebleeds in the presence of relatively small erosive or destructive changes in the vessels of the nasal cavity, which are also supplied by the internal carotid artery, and not just the external one. The result obtained means that when the external carotid artery is ligated (temporarily excluded from the circulatory system), the static blood pressure on the walls in the internal carotid artery (due to a decrease in the diameter of its cross section and an increase in the linear velocity of blood flow in it at a constant blood volume flow) decreases within 3÷15%. Accurate personalized values of blood flow parameters for the model can be obtained using additional research methods, such as Doppler imaging. It is also possible to refine the model by taking into account the current pressure in the norm with parallel blood flow in two (external and internal) carotid arteries, although this refinement will be insignificant. This allows, on the basis of a simple model, to carry out planning for stopping nosebleeds, based on the data of biophysical modeling of the mechanics of blood circulation. The perspective of the work is the refinement of the model by CFD methods and the use of telemedicine services for remote consultation and planning for the relief of profuse nosebleeds. Based on the foregoing, it can be concluded that ligation of the external carotid artery in recurrent profuse nosebleeds, regardless of the systemic blood supply, has not lost its significance to date and remains relevant as a method of effectively eliminating this formidable pathological process.

Key words: optical visualization blood pressure, human health, arteries, nosebleeds, model.

1. INTRODUCTION

Epistaxis is one of the most common conditions in otorhinolaryngology, the treatment of which may require hospitalization and the involvement of doctors from other specialties. Intense bleeding and their recurrent nature require the provision of highly specialized medical care^{[1],[2],[3]}. Assessment of the airway, respiration, and circulation precedes identification of the source of bleeding, control of pain, and achievement of hemostasis. Treatment options include local vasoconstrictors, direct pressure, cauterization, tranexamic acid, nasal swabs, Foley catheters, or surgery^{[4],[5],[6]}. At present, a fairly large number of minimally invasive stopping methods have been introduced into clinical practice, among which, first of all, embolization of the vascular bed of the marginal part of the bleeding area can be distinguished^{[5],[6],[7]}. Methods of endoscopic distal approach directly to the erosive zone have found wide application. However, these methods are not always sufficiently effective and efficient^{[8],[9]}.

Interest in the problem of nosebleeds is due both to an increase in the proportion of this pathology in the overall structure of diseases, and to the insufficient effectiveness of therapeutic measures carried out at all stages of stopping the disease. Therefore, the relief of nosebleeds remains relevant to the present. To a large extent, this is due to the polymorphism of the etiopathogenetic factors that cause them, associated both with local changes in the vascular bed, the peculiarities of

its architectonics, the resistance of the hyaline membranes of the vessels of the nasal cavity, and general changes in the blood flow rheology characterizing the state of the systemic blood flow^{[5][6][7]}.

A serious clinical problem is profuse nosebleeds from the posterior and postero-upper sections of the nasal cavity, in the vascularization of which not only the distal sections of the external, but also the internal carotid arteries take part. These bleedings pose a real threat to the life of the patient and require complex therapeutic measures, including anterior and posterior tamponade or surgical intervention^{[5][6][7]}.

However, despite extensive therapeutic measures, bleeding of this localization is difficult to control and in some cases can lead to death. Moreover, at present there is no single, unified protocol (standard) for the provision of medical care for nosebleeds. There are separate local protocols in Germany, France, Belgium and other countries that cover limited parts of this complex pathological process.

The choice of treatment for profuse nosebleeds is associated with the elimination of their causes. Thus, determining the causes of profuse nosebleeds and the role of collateral blood flow in recurrent bleeding allows us to calculate the optimal amount of intervention to perform radical hemostasis. The possibilities of otolaryngologists and maxillofacial surgeons in eliminating this pathology are limited and in most cases come down to alloying the distal parts of the adductor vessels supplying the bleeding area^{[8][9][21]}. Often, with profuse bleeding, embolization of the branches of the distal carotid arteries and interruption of blood flow by clipping, local destruction of bleeding vessels directly in the bleeding area (sphenopalatin artery, ethmoid arteries) are carried out.

However, these methods are not always sufficiently effective and efficient. This is due to the peculiarities of the architectonics of vascular blood flow in the nasal cavity and adjacent areas, the presence of an extensive system of anastomoses or redublicant arteries.

In cases of recurrent bleeding, ligation of the external carotid artery is necessary. This method, it seems to us, is undeservedly forgotten. It finds application in oncologists during surgical interventions on the upper respiratory tract. In addition, with this method, it is possible to reduce the static pressure on the walls of the internal carotid artery. To do this, it is necessary to create a model of a one-dimensional blood flow through the common, external, and external carotid arteries and calculate the model parameters, taking into account both averaged data and personification, based on the results of angiographic image analysis.

The aim of the work is to assess blood flow parameters in the elimination of nosebleeds by ligation of the external carotid artery according to angiography.

2. MATERIALS AND METHODS

The studies were carried out in the clinic of the Kharkiv National Medical University on the basis of the Department of Head and Neck Surgery and the Diagnostic Center of the Kharkiv Regional Clinical Hospital. A survey was conducted of 46 patients aged 38 to 69 years with a diagnosis of epistaxis against the background of a hypertensive crisis. The duration of bleeding ranged from 2 to 6 days. All patients from the moment of admission to the hospital underwent massive hemostatic therapy with parallel application of anterior and posterior tamponade. Patients underwent angiography using the diagnostic X-ray cardiovascular system "Integris Allura", angiograph "Trideros-Optimatic-2000", Siemens). An example of angiographic image and visualization of the vessels of the nasal region is shown in Figure 1. In 15 (32.6%) patients, surgical intervention was performed in the form of ligation of the external carotid artery at the site of its origin from the bifurcation of the common carotid artery. A retrospective analysis of the causes that led to the elimination of nasal bleeding during ligation of the external carotid artery in 15 (32.6%) patients was carried out. It was found that in 12 (26.1%) patients, bleeding was due to vascular destruction in the external carotid artery, and in 3 (6.5%) patients, bleeding was observed from the internal carotid artery.

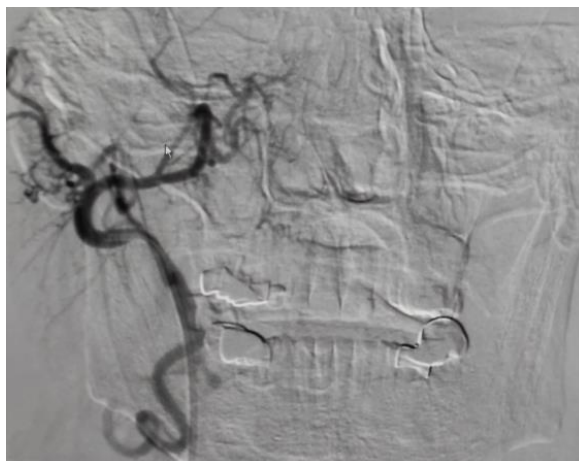


Figure 1. Example of angiographic image and visualization of the vessels of the nasal region.

3. RESEARCH RESULTS AND DISCUSSION

The construction of a biophysical representation of blood flow in this area was based on a model of one-dimensional blood flow through the vessels according to Bernoulli's law. Figure 2 shows a magnetic resonance image of the main vessels of this area^{[3][9]}, which shows the common (CCA), internal (ICA) and external (ECA) carotid arteries. It was concluded that the main reason for stopping bleeding was a decrease in static pressure on the walls of blood vessels, which depends on the speed of blood flow^{[24][25][26]}.



Figure 2. Magnetic resonance angiogram of the supra-aortic vessels showing the occipital artery originating from the internal carotid artery^[3]

According to Bernoulli's law, the redistribution of pressure on the walls of blood vessels in two areas (the common and internal carotid arteries), when the external carotid artery is ligated, the blood flow is carried out from the common CCA only through the internal (ICA) carotid artery), which will be written as follows

$$p_{CCA} + \frac{\rho V_{CCA}^2}{2} = p_{ICA} + \frac{\rho V_{ICA}^2}{2}, \quad (1)$$

where p_{CCA} and p_{ICA} – static pressures on the walls of the common and internal carotid arteries, respectively;

V_{CCA} and V_{ICA} – linear blood flow velocities in the common and internal carotid arteries, respectively;

ρ – blood density.

Based on equation (1), the static pressure on the wall of the internal carotid artery will be determined as

$$p_{ICA} = p_{CCA} + \frac{\rho V_{CCA}^2}{2} - \frac{\rho V_{ICA}^2}{2} = p_{CCA} + \frac{\rho}{2} (V_{CCA}^2 - V_{ICA}^2). \quad (2)$$

The linear velocity of blood flow in the arteries is defined as

$$V = \frac{Q}{S}, \quad (3)$$

where Q – volumetric blood flow, S – sectional area of an artery perpendicular to blood flow.

The next step is to define the geometric parameters of the model. To assess blood flow parameters, either averaged data^{[10][11][12]} or various imaging methods are used, such as multidetector helical X-ray computed tomography in angiographic mode^{[13][14]}, or magnetic resonance angiography^{[15][16][17]}. A personalized approach for their determination in the work was carried out on the basis of segmentation of radiographic angiographic images. An example of an angiographic image of the area of bifurcation of the common carotid artery is shown in Figure 3a. The image is pre-processed with histogram correction to increase the contrast and compensate for possible areas of uneven intensity^{[18][19]}. Next, the construction of the binary characteristic function is carried out $H(i, j)$ areas of arteries D on the input image $B(i, j)$ according to expression

$$H(i, j) = \begin{cases} 1; & (i, j) \in D; \\ 0; & (i, j) \notin D. \end{cases} \quad (4)$$

Segmentation of the vascular area is carried out by the threshold method based on the determination of the boundary value T of the intensity to determine the area D of the vessels, taking into account a priori data that this area has a lower intensity on diagnostic images

$$H(i, j) = \begin{cases} 1; & B(i, j) \leq T; \\ 0; & B(i, j) > T. \end{cases} \quad (5)$$

The boundary value of the intensity T is determined in an automated mode according to the formula that calculates the coefficient α_n

$$\alpha_n = \frac{M_k}{m_n + 1}, \quad (6)$$

where M_k – local maximum by histograms;

m_n – local minimum by histograms between global and local M_k maxima. The boundary value of the intensity will be consistent with the minimum m_n with the maximum value of the coefficient α_n

$$T = m_n, \text{ } npu \text{ } \max(\alpha_n).$$

An illustration of the histogram of the angiographic image from Figure 3a, which clearly shows the intensity maxima corresponding to the areas of the arteries (the area of the maximum on the left side of the histogram with fewer intensity

levels in the extremum area) and surrounding tissues (the area of the maximum on the right with more extended intensity levels) is shown in figure 3, b. The threshold value T for segmentation of the vascular area is taken according to formula (6) to be 98. The results of the segmentation of the vascular area, as well as the morphological operation to highlight the contour on an already segmented image, are shown in Figures 3c and 3 d, respectively.

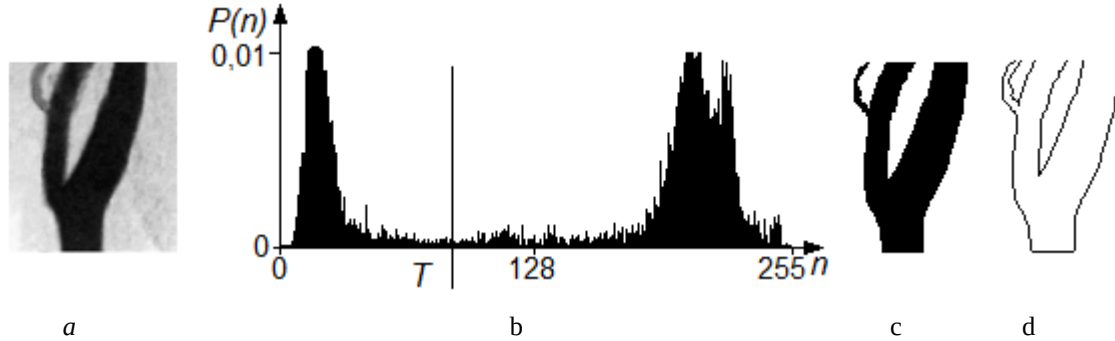


Figure 3. Illustration of vessel segmentation on the hagiographic image: a - input image; b - histogram of the intensity of the input image with the delimitation of the boundary level of the intensity T ; c - segmented image of vessels; d - contour image of vessels

After that, the diameter of the corresponding arteries is determined, as in an automated mode (with a vertical orientation of the image area of the vessels): the common carotid artery - taking into account the condition that there are no segmented connected objects horizontally in the nearest area, as well as the internal and external carotid arteries, which are oriented parallel and present in the image as separate (but connected) objects in horizontal scanning. The area of analysis is selected within 4-7 mm above the bifurcation point of the arteries. The minimum linear size of the contour image of the corresponding vessel is taken as the diameter of each of the arteries. The data obtained from patients on the diameters of the common and external and internal carotid arteries correspond with the data of the authors^{[10][11][22]} and average the ratios: $d_{ICA} / d_{CCA} = 0,75$ and $d_{ECA} / d_{CCA} = 0,65$ at average diameters $d_{CCA} = 6,5 \pm 1,6$ mm, $d_{ICA} = 4,9 \pm 1,3$ mm and $d_{ECA} = 4,2 \pm 1,1$ mm. These data correspond to the approximate equality of the sum of the geometric areas of the sections of the outer S_{ECA} and internal S_{ICA} carotid arteries total cross-sectional area S_{CCA} carotid artery according to the expression

$$S_{CCA} = S_{ICA} + S_{ECA}. \quad (7)$$

For such indicators, taking into account the approximation of the cross-sectional area S_{CCA} common carotid artery circle with diameter d_{CCA} (similarly, we use the formula for ICA and ECA), we obtain

$$S_{CCA} = \frac{\pi \cdot d_{CCA}^2}{4}. \quad (8).$$

Taking into account the above relation $d_{ICA} / d_{CCA} = 0,75$, we simply assume that the area of the internal carotid artery is approximately two times less than the area of the common carotid artery

$$S_{ICA} = \frac{S_{CCA}}{2}. \quad (9)$$

Taking into account the condition of constancy of blood flow Q through the arteries $Q = const$, according to formulas (3) and (9), the linear velocity of blood flow through the internal carotid artery during ligation of the external carotid artery (temporarily excluding it from the circulatory system) will be determined as

$$V_{ICA} = \frac{Q}{S_{ICA}} = \frac{Q}{\frac{S_{CCA}}{2}} = \frac{2Q}{S_{CCA}} = 2V_{CCA}. \quad (10)$$

Substituting in equation (2) from the reference data the values of mean arterial pressure in the common carotid artery $p_{CCA}=100 \text{ mmHg.} = 13,3 \text{ kPa}$, linear blood flow velocity $V_{CCA}=0,47 \text{ m/s}$ and blood density $\rho =1,05 \cdot 10^3 \text{ kg/m}^3$, we get the value of static pressure in the internal carotid artery $p_{ICA}=12,95 \text{ kPa}$.

For comparison, in another extreme case, we accept the equality of the sum of the diameters of the internal and external carotid arteries to the diameter of the common carotid artery

$$d_{CCA} = d_{ICA} + d_{ECA}, \quad (11)$$

we get

$$d_{ICA} = d_{ECA} = \frac{d_{CCA}}{2}, \quad (12)$$

and, accordingly, the area S_{ICA} of the internal carotid artery will be 4 times less than the area of the common carotid artery

$$S_{ICA} = \frac{\pi \left(\frac{d_{CCA}}{2} \right)^2}{4} = \frac{\pi \cdot d_{CCA}^2}{16} = \frac{S_{CCA}}{4}, \quad (13)$$

which from formula (3), respectively, means for determining the blood flow velocity

$$V_{ICC} = \frac{Q}{S_{ICC}} = \frac{Q}{\frac{S_{CCA}}{4}} = \frac{4Q}{S_{CCA}} = 4V_{CCA}. \quad (14)$$

Substituting the reference values from the previous paragraph, in this case we obtain the value of the static pressure in the internal carotid artery $p_{ICA}=11,56 \text{ kPa}$. In relation to the value of mean arterial pressure in the common carotid artery $p_{CCA}=13,3 \text{ kPa}$, the change (pressure decrease) in the internal carotid artery during ligation of the external one for the considered values will be in the range of 3÷15%. However, there may be a tendency to a greater decrease in pressure in the internal carotid artery when the external carotid is ligated due to refinement of the model. It is possible to refine this approximate calculation taking into account percentage ratios compared not with the pressure in the common carotid artery, but with increased pressure in the internal carotid artery in the norm (in the absence of ligation of the external carotid artery) by taking into account the parallel flow of blood through the external and internal carotid arteries, which, however, with averaged physiological indicators of both hemodynamics and the geometric dimensions of the arteries in this area, will increase the considered percentage by about 5%. For clarity, it is also possible to make personalized full-scale models of this area using 3D printing methods with the identification of vessels for their naturalistic visualization (see Fig. 4), which can also be used for training.



Figure 4. Personalized full-scale 3D models of the skull with identification of large arteries

4. CONCLUSIONS

The result obtained means that when the external carotid artery is ligated (temporarily excluded from the circulatory system), the static blood pressure on the walls in the internal carotid artery (due to a decrease in the diameter of its cross section and an increase in the linear velocity of blood flow in it at a constant blood volume flow) decreases within 3÷15%. Hypotension is observed due to the ligation of one main vessel, which leads to an increase in the perfusion rate, respectively, with a subsequent decrease in pressure on the walls of the vessels. This reduction in pressure additionally leads to easier relief of nosebleeds in the presence of relatively small erosive or destructive changes in the vessels of the nasal cavity, which are also supplied by the internal carotid artery, and not just the external one. Accurate personalized values of blood flow parameters for the model can be obtained using additional research methods, such as dopplerography. It is also possible to refine the model by taking into account the current pressure in the norm with parallel blood flow in two (external and internal) carotid arteries, although this refinement will be insignificant. This allows, on the basis of a simple model, to carry out planning for stopping nosebleeds, based on the data of biophysical modeling of the mechanics of blood circulation. The prospect of work is the refinement of the model by CFD methods and the use of telemedicine services^{[20][21][23]} for remote consultation and planning for the relief of profuse nosebleeds. Based on the foregoing, it can be concluded that ligation of the external carotid artery in recurrent profuse nosebleeds, regardless of the systemic blood supply, has not lost its significance to date and remains relevant as a method of effectively eliminating this formidable pathological process.

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