SELECTION AND IMPROVEMENT OF THE METHOD AND TOOL FOR RESTORING THE ANATOMICAL INTEGRITY OF THE RETINA AFTER ITS DETACHMENT

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ABSTRACT

Introduction. Retinal detachment (RD) is a common pathological condition that without timely surgical treatment leads to vision loss. The patients with significant RD undergo one of three retreatment procedures: Pneumatic Retinopexy, Scleral Buckling, and/or Pars Plana Vitrectomy. Techniques and tools for these procedures have been developed, but the methods themselves still have a significant number of complications. A possible alternative to their further improvement may be a fundamentally new method of treatment, coagulation of the retina with high-frequency electric current (HFEC), for which significant improvement of the tool is still possible.

The purpose of the study was to determine a safer method of RD treating and to improve medical tools for restoring anatomical integrity and repositioning a detached retina under two conditions: firstly, obtaining a reliable chorioretinal adhesion, and secondly, minimizing the number of incidental effects of surgical intervention.

Materials and methods. The bibliosemantic method, the system analysis method, an experiment on laboratory animals (rabbits) with RD simulation and its coagulation by HFEC, tissue biopsy of operated animals after their euthanasia on the 7th day after surgery, and the production of histological micro-preparations were used.

Results. To fulfill the conditions for improving the method, a chorioretinal high-frequency electrocoagulation operation with suprachoroidal access, a modified EK-300M1 generator (Kyiv, Ukraine) with an electrode with a gold hemispherical tip of 25 gauge and electrical generation parameters of 66 kHz, 10–16 V, 0.1 A was proposed, which causes chorioretinal adhesion in the place where the electrode is used. The method of calculating the parameters of heat transfer from the electrocoagulation tool to the tissues and fluids of the eye was selected: it was proposed to use the Fourier-Kirchhoff and Newton-Richmann equations. Destructive phenomena in the retina from the thermal effect of tissue coagulation in the form of the destruction of rods, cones, the development of cysts, the loss of bipolar, amacrine, horizontal and ganglion cells were noted. Atrophic changes in the retina were minimal at a voltage of 10–12 V.

Conclusions. The problem of improving the methods of restoring the anatomical position of the retinal layers has been relevant for many decades, but it does not lead to a significant reduction in the number of complications. The proposed method and tool for its application causes the creation of a reliable chorioretinal adhesion in a short period of time after surgical intervention with minimal thermal tissue damage. The use of the method of chorioretinal high-frequency electrocoagulation with suprachoroidal access is recommended in conditions of urgent restoration of vision, but not recommended for the prevention of retinal detachment in retinopathies.

Keywords: *retinal detachment, chorioretinal adhesion, high-frequency electrocoagulation, suprachoroidal access.*

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INTRODUCTION

During military operations in Ukraine, the frequency of traumatic eye injuries increased approximately 6 times compared to peacetime. Traumatic eye injuries account for 13–16% of all combat injuries, which is associated with modern types of weapons used on the battlefield [1–3]. The largest number of nonpenetrating eye injuries is caused by the blast wave, which damages the brain together with the eyes. Military damage to the eyes is more often bilateral, while in peacetime – unilateral. A frequent consequence of closed eye injuries during wartime is extensive traction retinal detachments (in peacetime, traction detachments are mainly the result of retinopathies). The number of such injuries increases in direct proportion to the increase in the number of head injuries [4; 5]. Similar observations were previously published regarding the injuries of servicemen during the USSR war in Afghanistan [6; 7].

Rhegmatogenous retinal detachment (RRD) is widespread and associated with a high risk of visual impairment without treatment [8]. Its frequency in peacetime is approximately 1 case per 10,000 population [9; 10], the general prognosis of treatment with timely and successful surgical intervention reaches 95% of vision recovery [11]. Surgical methods of RRD treating are first and foremost – Scleral Buckling (SB), Pars Plana Vitrectomy (PPV), a combined PPV/SB, and Pneumatic Retinopexy [12]. PPV is the most common general option, and in young phakic patients it is SB.

There is a need and conditions for the creation of new methods of treatment of retinal detachment (RD) associated with legislative circumstances, an increase in the number of eye injuries in wartime, a high RD rate in peacetime, a known number of complications of existing treatment methods and the development of modern technologies that allow improving methods treatment and tools [13].

The purpose of the study was to determine a safer method of treatment of retinal detachments and to select parameters for instruments developed or used for this purpose in ophthalmology, from the point of view of minimizing the number of incidental effects and complications of operations and simultaneously achieving reliable indicators of patients' vision recovery.

Materials and methods

At the first stage of the investgation, literature sources (monographs and articles) available for study on PubMed, Medline, EMedicine, UpToDate and Cochrane Library were subjected to analysis; with reference checking in DiseasesDB, OMIM (Online Mendelian Inheritance in Man) and MeSH. The analysis of the received information was carried out according to the principle of system analysis according to the scheme "study – synthesis – primary hypothesis – hypothesis testing – improvement – determining future prospects", with minimal detailing of the steps. Circumstances for determining the relevance of the research are determined by the conditions of peacetime, strengthened by the consequences of military operations.

At the second stage of the research, technical achievements in conducting operations to eliminate RD using existing microsurgical instruments were analyzed and a proprietary method and a tool developed for it were proposed. The obtained result is projected on the hypothetical practice of an ophthalmologist during the treatment of RD within the stage of "improvement" of the system analysis method. To test the research hypothesis, we turned to the results of our own research on laboratory animals (rabbits), which were simulated RD, which was eliminated with the help of high-frequency electric current for the coagulation using a modified EK-300M1 generator (Kyiv, Ukraine) with a frequency of 66 kHz generation, with voltages in the range of 10–16 V, current strength of 0.1 A and with an electrode with a gold hemispherical tip of 25 gauge. Description of the experiment with animals was not the purpose of our research. It is only important to note that the conditions of its conduct did not violate the ethical principles of experiments with laboratory animals, and the results were statistically reliable, with an estimate of $p<0.05\%$ according to the Student's t-test. To evaluate the results of using retinopexy with HFEC, selective photomicrographs of the biopsy of the eye of rabbits 7 days after the surgical intervention were used. The results are compared with literature data of similar experiments using laser- and cryopexy.

Results and discussion

Legislative prerequisites for the creation of new methods of treatment of RD in Ukraine are reliable, and are represented by a number of Orders of the Ministry of Health of Ukraine and clinical protocols for providing ophthalmic care to the population.

The Order of the Ministry of Health of Ukraine No.372 on May 14, 2013 "On the system of ophthalmological care for the population of Ukraine" states the need to provide 24-hour emergency care for eye injuries (art. 2.2.12); conducting scientific research on topical issues of diagnosis and treatment of eye diseases and visual impairments (art. 2.2.19); development and implementation of the latest forms and methods of treatment of eye diseases (art. 2.2.23). Treatment of retinal breaks and detachments is recommended to be carried out both in laser offices and in laser centers of specialized ophthalmic care (Appendix 3) [14].

The morphological features of RD and adhesion as a result of its treatment have been studied long enough, which explains the large number of references to literary sources about the original studies of 1970–2000 years. During this time, considerable data has been accumulated on various methods of retinopexy, their reliability and safety. These data have been repeatedly verified in various studies, including those related to oncology, which will not be the subject of our study. Only research results with a high level of evidence were taken into account.

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Thus, the authors of a Cochrane review (Znaor L. et al., 2019) [15] based on an analysis of 10 studies in European countries, India, Iran, Japan and Mexico, which included 1307 patients, concluded that PPV compared to SB less often leads to repeated RD, with the exception of iatrogenic and cataract progression cases, but has the same result in terms of visual recovery. The authors of another Cochrane review (Sena D.F. et al., 2021) [16] based on the analysis of the results of studies conducted in Ireland, the USA and Italy, which included 274 participants (276 eyes), concluded that SB can be more or less equally effective compared to pneumatic retinopexy (PR) in terms of reliability of chorioretinal adhesion and reduction of the risk of re-detachment. However, the use of SB resulted in more myopic progression, which was interpreted as a sign of cataract development.

Approaches to the treatment of patients with RD in Ukraine have been developed and established in numerous medical care protocols. Ukraine is on the path of implementing international medical care protocols into medical practice, which replace the previous outdated ones. These protocols regulate the stages of diagnosis, treatment, recovery after operations [17; 18].

At the outpatient and inpatient stages of providing ophthalmic care for RD (code of the International Classification of Diseases X revision – H33, XI revision – 9B73) the following examinations are recommended: general ophthalmological examinations; binocular reverse ophthalmoscopy of the periphery of both eyes; biomicroscopy with a Goldmann lens of the retina and vitreous body; surgical treatment with and without vitrectomy. The average duration of treatment until the recovery of normal vision and working capacity is 20 days [19]. However, the use of modern methods of restoring the functional state of a detached retina makes it possible to improve vision by 2–3 times immediately after surgery (for example, from 20% to 40–60%).

The choice of the method of restoring the integrity of the retina and its adhesion to the underlying tissues largely depends on the nature of the retinal damage: a fixed retinal rupture without detachment, detachment without a rupture, or detachment combined with a rupture. So, rhegmatogenous detachment most often means its lifting, moving during eye movements, wrinkling. If there is a retinal rupture, it has a valvular or holey appearance, the detachment can reach the dentate line (ora serrata). Anterior detachment is accompanied by hemorrhage into the vitreous body, pigment cells are found in the anterior part. Posterior detachment is often accompanied by a decrease in intraocular pressure, and the detached retina forms wrinkles.

In the case of *traction detachment*, the retina can be stationary, with a smooth surface that is either convex or concave, and the detachment itself rarely extends to the serrated edge. In retinopathies, there are fibrous bands in the vitreous body, which separate the retina from the pigment epithelium. This requires little effort, because there are no anatomical structures that connect these tissues: the intraocular fluid and the vitreous body press these layers together [20]. However, both of these RD types are subject to urgent surgery. If the detachment is spread to the area of the macula, the operation must be done in the first 2 days to vision saving.

Another widespread RD pathogenetic type is exudative, which is most often associated with an oncological process. In the case of retinal tumors without metastases and enlarged lymph nodes, organ-saving operations are possible by means of diathermocoagulation, photocoagulation, or cryocoagulation. The treatment period is 7–10 days, recovery of working capacity lasts 4–6 weeks. But the main goal of treatment in such cases is to preserve the eye and prevent tumor metastasis, and only in the second place is to eliminate complaints about visual impairment and restore visual acuity.

Exudative detachment can regress on its own after elimination of its immediate cause [21].

Retinal ruptures require surgical intervention (using laser or cryoprocedures, scleroplasty, etc.) within 2–3 days from the onset of the incident. A month after the operation, the patient recovers his work capacity, he should limit physical activity for up to three months. The duration of sanatorium-resort treatment is 18–24 days on an average.

To eliminate RD, it is necessary to remove the accumulated subretinal fluid, bring the retina closer to the choroid, perform retinopexy with the formation of a chorioretinal adhesion, which will not allow fluid to accumulate in the subretinal space again. The strength of the chorioretinal adhesion is affected by the type of retinopexy (cryopexy, diathermy, laser photocoagulation, electrocoagulation of biological tissues). At the current stage, transciliary vitrectomy can be performed with gas or silicone oil tamponade and without the use of vitreous substitutes.

Retinal adhesion is influenced not only by the choice of surgical intervention method and the chosen instrument, but also by some humoral factors. For example, oxygenation and the state of collagen metabolism [22].

Each of the retinopexy methods has its own disadvantages: cryopexy leads to the formation of intracellular ice crystals, diffuse atrophy of the retinal pigment epithelium and damage to small vessels, a decrease in the layer of photoreceptor cells and the formation of chorioretinal adhesions [23–28]. When using a laser, its light energy is mainly absorbed by the cells of the pigment epithelium and transmitted to the neighboring tissues. Overheating leads to the destruction of photoreceptors, choriocapillaries, the formation of scars that fix the retina too firmly [29–32]. The photosensory layer also thins, and ganglion cells are strongly irritated, strong adhesion does not occur in the first days, but only on the fourth day, and gains strength in only three weeks. At the same time, the effect does not depend on the type of the laser.

Jaccoma E.H. et al. (1985) established [33] that cryocoagulation and photocoagulation with an argon laser destroy the hematoretinal barrier, which can be the cause of proliferative vitreoretinopathy. In addition, the risk of recurrence of RD when using laser and cryoretinopexy reaches approximately 10% [34], mainly due to insufficient retinopexy, proliferative vitreoretinopathy or a new retinal rupture. Long-term formation of reliable adhesion requires long-term tamponade with oil, air, or gas, which is uncomfortable for the patient and increases the risk of cataracts, scars, and atrophy of the optic nerve [35; 36].

The use of laser- or cryoretinopexy in patients with horseshoe retinal ruptures reduces the risk of secondary RD from 30% to 1%. But for coagulation the retina with a laser, its intensity is regulated from 100 to 500 mW, depending on the pigmentation of the fundus, the presence and severity of cataracts. The damage to the neurolayer of the retina by excess thermal energy cannot be reduced so far. As well as the damaging effect of cryoretinopexy.

Other methods of treatment associated with tamponade have many complications. Thus, to ensure chorioretinal adhesion in RRD, viscoelastic material is injected into the suprachoroidal space. The patient's retina is leveled with an air bubble or a heavy perfluorocarbon liquid that leaves intravitreal air in the eye for a long time, a bubble of SF6 or C3F8 gas, or silicone oil. The procedure is called SupraChoroidal Buckling (SCB). Antaki F. et al. reported complications of the procedure in the form of bleeding in 23% of cases with the predominant location of the detachment zone in the lower quadrants of the eye. In 4%, combined subretinal and suprachoroidal hemorrhage was recorded against the background of tuberculosis. And although 50% of the patients experienced an improvement in vision as a result of the procedure, 67% experienced re-detachment [37]. The authors concluded that the procedure needs additional safety testing and improvement to reduce the number of complications.

Other common RD treatment methods listed at the beginning of the article have a defined sequence of use in most cases of significant detachment. Thus, PR leads to successful attachment of the retina in approximately 70% to 80% of cases after one procedure, therefore, in cases of failure, patients undergo SB as a second step. Of those patients who undergo SB, 80–90% are successful in reattachment of the retina. Others undergo vitrectomy.

In 2012, Umanets N.N. et al. proposed to use high-frequency electrowelding of biological tissues for the formation of a chorioretinal adhesion endovitreally [38]. The method turned out to be the fastest for obtaining a strong chorioretinal adhesion: it was stronger already an hour after coagulation, but also strong a month after coagulation [39; 40]. The method demonstrated less retinal damage and eliminated the need for prolonged tamponade. In my own research, the method was developed in the form of the use of an electrocoagulation tool with a gold hemispherical tip of 25 gauge, connected to a modified EK-300M1 generator (Kyiv, Ukraine) (*Fig. 1*) with the following electrical generation parameters: frequency 66 kHz, voltage 10–16 V, current 0.1 A [41]. The selection of parameters of the new tool is the result of long-term research and modeling of thermal processes in the tool and tissues of laboratory animals with the aim of creating a reliable chorioretinal adhesion in a short time after surgical intervention with minimal thermal tissue damage.

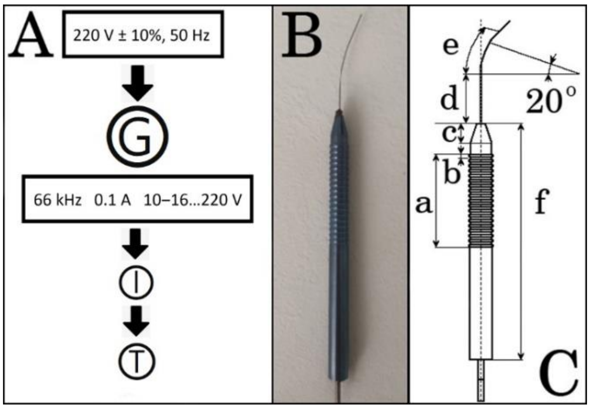

Fig. 1. Equipment for high-frequency electrocoagulation of the retina:

A – conversion of electric current:
(G – Generator, I – Instrument (B, C), T – Tissues);
B – electrode with a 25-gauge hemispherical tip (diameter 0.5 mm);
C – drawing of the electrode with dimensions (rounded to whole values):
a – 37 mm, b – 2 mm, c – 8 mm, d – 20 mm,
e – 18 mm, f – 95 mm.

SolidWorks, Abaqus, etc. software are used to model thermal processes in the electrocoagulation tool. [42; 43]. During the simulation, coagulation temperature, mechanical load on tissues, coagulation time and voltage are taken into account. When calculating heat transfer parameters, the Fourier-Kirchhoff equations were used for moving media (eye fluids), and the Newton-Richmann law was used for the external environment/tissue boundary:

$$-\lambda \frac{dt}{dx} = \varepsilon\sigma(T_T^4 - T_C^4), \qquad (1)$$

where λ – thermal conductivity coefficient (W/m × degree);
σ – thermal conductivity (W/degree).

When the coagulation tool affects tissues, taking into account the processes of melting and hardening, the formula describes the heat transformation for the boundary between the solid and liquid phases of the eye:

$$-\lambda \frac{dt}{dx} = r \times \rho \frac{d\varepsilon}{d\tau} + q_{\mathrm{P}}, \qquad (2)$$

where r – latent specific heat of the phase transformation;
$d\varepsilon/d\tau$ – speed of movement of the two-phase boundary;
ρ – density of the body part;
ε – thickness of the solid part of the body normal to the two-phase boundary;
q_P – heat flow from the liquid phase to the two-phase boundary.

According to Nikolsky O.I. and Sheremet O.P. [44, p. 10], equation (2) in relative parameters has the form:

$$-\frac{d\theta}{d\eta} = K \frac{d\xi}{dF_o} + \delta_L, \qquad (3)$$

where $\left(\xi = \frac{\varepsilon}{\tilde{x}}\right)$ – relative thickness of the solid phase (dense tissues);

$\delta_L = \frac{q_{\mathrm{P}}\tilde{x}}{\lambda\cdot(t_{max}-t_{min})}$ – dimensionless heat flow;

$F_o = \frac{a\tau}{\tilde{x}^2}$ – Fourier criterion;

$K = \frac{r}{c\cdot(t_{max}-t_{min})}$ – physico-chemical transformation (or crystallization) criterion;
r – latent specific heat of phase transformation.

The use of high-frequency electrocoagulation of the retina with suprachoroidal access and a tool with our chosen parameters in an experiment on animals [41] showed high adhesion in the area of application of the electrode, rapid (within an hour) formation of a strong adhesion, which further strengthened over time. Meanwhile, the destruction of rods and cones, the development of cysts, the loss of bipolar, amacrine, horizontal and ganglion cells (*Fig. 2*), damage and migration of choroidal melanocytes occurred in the retina. Characteristic changes in the form of thinning (degeneration) of the retina were observed for 30 days. A reliable adhesion appeared within an hour after surgery and gained strength during the day. Calculation of tissue heat transfer by formula (3) allowed us to choose a voltage range from 10 to 16 V, in which the electric current caused minimal exudation during acute retinal necrosis and left the vitreous body intact. Atrophic changes in the retina were minimal at a voltage of 10–12 V.

without preventive coagulation of the retina, these patients should still be given additional attention in the form of preventive examinations.

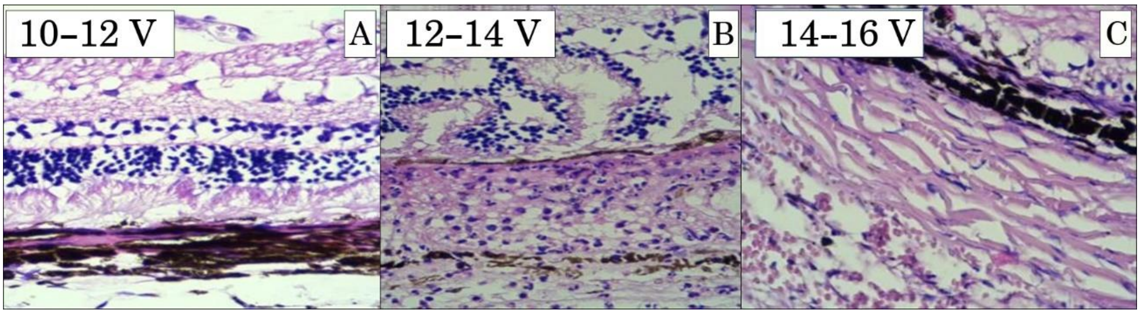

Fig. 2. Morphology of the chorioretinal adhesion in the rabbit's eye at 7 day, when using a voltage of 10–12 V (A), 12–14 V (B) and 14–16 V (C). *Hematoxylin-eosin, ×400*

An important achievement of the use of the HFEC for choreoretinal coagulation was the rapid production of chorioretinal adhesion. Its strength one hour after surgery was similar to strength when using laser coagulation after a similar retinal detachment one week after surgery [35]. At the same time, adhesion strength gradually increased, more so during the first week after surgery, and equaled the strength after laser retinopexy one month after surgery. Direct tissue coagulation time was also reduced by approximately 27%.

The success of the intervention put before us an additional question about the possibility of using high-frequency coagulation with a preventive purpose, and not only for urgent restoration of vision. For this purpose, we turned to the Cochrane Library.

The use of surgical interventions with a preventive purpose, when there are only risks of repulsion, cannot be considered safe in view of the lack of reliable evidence for such a statement [45]. Instead, early identification of retinal ruptures and prompt treatment is advisable, which protects against additional and repeated RDs and significant vision loss. This conclusion of the author of the Cochrane review Wilkinson C.P. (2001–2014), originally obtained for the methods of laser- and cryopexy of the retina, is also valid for its high-frequency electrocoagulation (HFEC). However, for patients with a giant retinal rupture in the paired eye, prophylactic treatment may be appropriate.

It is also known [46–49] that RD can be a complication of cataract surgery and is associated with the use of fluoroquinolones. Therefore,

Conclusions

Chorioretinal high-frequency electrocoagulation with suprachoroidal access, an electrode with a 25-gauge gold hemispherical tip and electrical generation parameters of 66 kHz, 10–16 V, 0.1 A, which causes chorioretinal adhesion in a place of electrode application, is the operation of choice for traction and rhegmatogenous retinal detachments. As a result of surgical intervention, a strong chorioretinal adhesion occurs within an hour, which reduces the time of surgical intervention, minimizes the risks of repeated detachment, and cancels the need for eye tamponade. In terms of adhesion quality, the method is superior to laser and cryoretinopexy. The use of the method is appropriate in conditions of urgent restoration of vision, but inappropriate for the prevention of retinal detachment in retinopathies.

The optimal voltage parameters, according to the results of morphological studies of laboratory animals' tissues, are 10–12 V, which reduces the damaging current on the retina. The effect of electrocoagulation causes minimal exudation during acute retinal necrosis and leaves the vitreous body intact.

The proposed operative method and the tool improved for this purpose correspond to modern Ukrainian clinical protocols for the treatment of retinal detachment.

DECLARATIONS:

Disclosure Statement

The authors have no potential conflicts of interest to disclosure, including specific financial interests, relationships, and/or affiliations relevant to the subject matter or materials included.

Data Transparency

The data can be requested from the authors.

Statement of Ethics

The authors have no ethical conflicts to disclosure.

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