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TELEMEDICINE IN OPHTHALMOLOGY. PART 1. “COMMON TELEOPHTHALMOLOGY”

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✧ Telemedicine (TM) is one of the fastest growing segments of healthcare and medical business in the world. In a broad sense, TM means the use of the most modern data technologies in distant medical care practice. Teleophthalmology (TO) is an important area of TM, it includes several priorities, main of which being remote diagnosis, treatment and management of patients with ophthalmic diseases, in particular, diabetic retinopathy, glaucoma and age-related macular degeneration. The development of TO is conditioned by the need for high-tech specialized medical care for people in remote regions. On the path of introducing TO worldwide and in Russia, a huge number of obstacles exists: obtaining high-quality fundus images, training specialists to work in the TM area , creation of standards for image analysis and transmission, TM implementation into the legal field, ensuring of stable financing, creating positive patients and doctors attitude towards TO. In this part, we provide an overview of TO development trends, as well as ways to solve the problems standing in its way.

✧ ***Keywords:*** telemedicine; teleophthalmology; information standardization; fundus cameras.

ТЕЛЕМЕДИЦИНА В ОФТАЛЬМОЛОГИИ. ЧАСТЬ 1. «ОБЩАЯ ТЕЛЕОФТАЛЬМОЛОГИЯ»

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✧ Телемедицина (ТМ) — это один из наиболее быстро растущих сегментов здравоохранения и медицинского бизнеса в мире. В широком смысле под ТМ понимают использование самых современных технологий обработки и передачи данных в практике дистанционного оказания медицинской помощи. Телеофтальмология (ТО) — важная область ТМ, включающая ряд направлений, основным из которых является дистанционная диагностика, лечение и ведение пациентов с заболеваниями офтальмологического профиля, в частности, диабетической ретинопатии, глаукомой и возрастной макулярной дегенерацией. Развитие ТО обусловлено необходимостью оказания высокотехнологичной специализированной медицинской помощи населению удалённых регионов. На пути внедрения ТО во всем мире и в России стоит ряд препятствий: получение качественного изображения глазного дна, обучение специалистов для работы в ТМ-сфере, создание информационных стандартов анализа и передачи изображения, имплементация ТМ в правовое поле, налаживание стабильного финансирования, создание положительного отношения пациентов и врачей к ТО. В этой части приведён обзор современных тенденций развития ТО в мире и пути решения проблем, стоящих на её пути.

✧ ***Ключевые слова:*** телемедицина; телеофтальмология; информационная стандартизация; фундус-камеры.

INTRODUCTION

Telemedicine (TM) is one of the fastest developing healthcare segments worldwide. According to the Global Telehealth Market Outlook study, the global TM market will grow by 25% and reach $40 billion in 2018–2024 [1].

From political and legal points of view, the formal definition of TM is important. According to the American Telemedicine Association, TM is the use of modern technology for remote diagnosis and monitoring of patients' health status. N.S. Khodzhaev [2] described TM in more detail. According to him, TM is an application sector of medical science related to the development and practical application of methods of remote medical care, exchange of specialized information, and solving organizational and methodological issues using modern telecommunication technologies.

Combining the above definitions, the concept of TM, in the broadest sense, implies using the most modern technologies for processing and transmitting data in the practice of remote medical assistance and the organization of communication among doctors.

Ophthalmology is a narrow specialty that requires highly specialized equipment and knowledge. The primary common ophthalmic diseases require image diagnostics; therefore, ophthalmologists are interested in photographic registration and creation of a photographic database. Therefore, teleophthalmology (TO) is an important and large segment of TM.

Providing highly specialized medical care everywhere is impossible, which makes TM in general and TO in particular inevitable. Different geographic, socioeconomic, and cultural obstacles often come between the patient and the doctor.

The most crucial obstacle is a territorial one. High expenses for training a large number of qualified personnel and acquiring diagnostic equipment limit the ability to provide medical care to people in remote regions. There is a considerable number of subspecialties and fields in ophthalmology. As a rule, the most narrowly focused specialists work in urban medical centers, so patients must travel relatively long distances to seek medical help, which is a constraining factor for most of them. The capacity of ophthalmic care in countries with developing economies is limited in large cities as well as small ones. Besides, providing patients with medical care can be challenging in many large countries with vast rural regions, such as Russia, China, and India [3, 4].

One solution is the formation of mobile teams of specialists and the organization of temporary mobile posts of technological assistance in remote regions. This solution is well suited for surgical methods of medical care, but it is still very limited by technical regulations. The modern TO is based on a fundamentally new type of interaction between doctors and patients through contemporary electronic communication systems (smartphones and headband displays), including the extensively developing Internet.

The TM market of consultations seems especially necessary in the Russian Federation, with its vast territories [5]. The President of the Russian Federation has repeatedly emphasized the importance of providing the rural population with highly specialized medical care [6]. At present, in the Russian Federation, the medical care of patients by doctors of different "lines" or "links" is relevant, from primary medical assistance to specialized and qualified medical care. Such an approach ensures continuity but affects ergonomics significantly. Implementing TM could provide direct interaction between a medical specialist and a patient, bypassing intermediate doctors, thus increasing medical care efficiency. Several legislative reforms over the past 20 years aimed at facilitating TM implementation; the second part of this review addresses them in greater detail.

The technological expansion and the availability of electronic resources are incredibly different among people in different countries. Developed and developing countries have an incomparably better-prepared base for implementing TM technologies than countries with developing economies [7], which is also noted by the World Health Organization, that launched the VISION 2020 global initiative in 1999. It aims to provide high-quality professional assistance to every person, regardless of his or her place of residence. However, implementing TM in countries with economies in transition is the objective of its later phases [8].

FIELDS OF TELEOPHTHALMOLOGY

Initially, TM played the role of a tool for conducting multicenter clinical trials, but so far, it has developed into a full-fledged clinical service [9].

Several fields are distinguished in TO based on the modern definition of TM [10, 11].

TO can be a diagnostic and treatment tool for almost any eye disease. In this case, the condition necessary for remote diagnostics is the presence of visible changes. TO is most relevant for diseases such as diabetic retinopathy (DR), age-related macular degeneration (AMD), glaucoma (which is widespread prevalence among older, low-mobility patients), and retinopathy of prematurity (ROP). DR, AMD, and ROP have a dangerous complication, which is the appearance of new vessels. Moreover, neovascularization and the stages preceding it could be monitored by high-quality images of the patients' fundus. In addition to the image of the optic nerve head, several additional examinations are required to diagnose glaucoma. Personnel without higher medical education can master these techniques [12]. Thus, a specialist in a particular field, whether a glaucomatologist or a ROP specialist, should be able to obtain high-quality data on the patients' status in very remote areas. It is also important to establish a feedback among doctors.

Most modern TO systems are configured for remote single-patient consultation, although there are examples of the introduction of long-term patient management systems [13]. The consultations are mainly held as delayed or retrospectively; that is, the specialist does not respond to the data immediately but does it after a few days. The field of direct online consultations is also actively developing [14].

Training and education of ophthalmologists and patients comprise the second field of TO. Telecommunications should enable doctors in different parts of the world to share expertise and improve professional skills; it was from this sphere that TM started. TM is implemented through the creation of Internet portals for doctors, medical forums, and communities in social networks, and webinars with direct online interaction among specialists. The policy of flexible digital distribution of applications in the mobile sector enables the development and implementation of specialized applications for smartphones and tablets.

Remote learning and interaction with patients are sometimes determined as a separate category, that is, telehealth [15]. This includes the use of modern technologies to help patients control the course of their illness by improving their self-care (e.g., monitoring vital parameters [blood pressure], with independent digital visualization [photographing their fundus]) and access to educational resources.

A separate TO field can be a remote case conference, which includes teleconference bridge, video conferencing, and "live" surgery.

PLACE OF TELEOPHTHALMOLOGICAL CONSULTATIONS IN THE STRUCTURE OF HEALTHCARE

The current model of healthcare in the field of ophthalmic medical assistance is summarized as follows. Patients receive assistance at different levels (links) of medical institutions, depending on the availability of the necessary level of specialist's training and technical support.

The first level or link is the doctor who is first visited by the patient presenting with any ophthalmic problem. Depending on the patient's region of residence, this may be a primary care physician in a polyclinic, a general practitioner at the family medicine center, or a paramedic practitioner in a paramedical and midwifery station. At this stage, ophthalmic care can be provided only in the mildest cases, and most of these patients will require access to an ophthalmologist.

Ophthalmologists conventionally represent the second level in the healthcare model. It may be an ophthalmologist at the same clinic as the first-level doctor, or it may be a doctor from a completely different institution. It is challenging to get an ophthalmologist's consultation in remote regions because of geographic and other obstacles. Even at this stage, introducing TM can significantly change the approach to providing medical care. The primary care physician can photoregister the patient's condition easily with a smartphone, and it is also quite feasible in current conditions to send the photograph to an ophthalmologist. An ophthalmologist can assess the patient's condition remotely in complex and controversial cases, separating patients who require a full-fledged ophthalmological examination and those who can receive care from a primary level doctor. Thus, TO enables two-way communication between specialists of different levels.

Second-level ophthalmologists cannot deal with all eye diseases independently. There are many subspecialties, such as glaucomatologists, retinologists, ophthalmic surgeons of different fields, and pediatric ophthalmologists. These third-level specialists usually work in specialized ophthalmological centers, both separately and as part of large multidisciplinary clinics. Patients are referred to a third-level doctor by an ophthalmologist, and the number of such subspecialists is much lower. Introducing TO at this stage is even more useful because it enables photoregistration in more detail, and teleconsultations among doctors of the same specialty are more effective. Thus, for example, if a second-level ophthalmologist has the technical ability to perform laser photocoagulation in disputable cases, it becomes unnecessary to refer the patient to the laser center, and it is possible to perform treatment in situ, as prescribed by a specialist in this field. Because the number of ophthalmologists of various subspecialties is lower, the principle of "sorting" patients by second-level doctors is effective ergonomically.

Nowadays, introducing TO at all stages of the ophthalmological care is relevant, with special attention to establishing links between the most highly specialized doctors (DR specialists, glaucomatologists) and primary patients.

OBSTACLES IN THE IMPLEMENTATION OF TELEOPHTHALMOLOGY

The central concept of teleassistance to ophthalmic patients is as follows [16]. A primary level doctor in a remote region provides patient data to a far-settled ophthalmologist, who is a specialist in a specific disease. This specialist, in turn, analyzes the data sent and gives recommendations to the doctor without any personal contact (Figure 1).

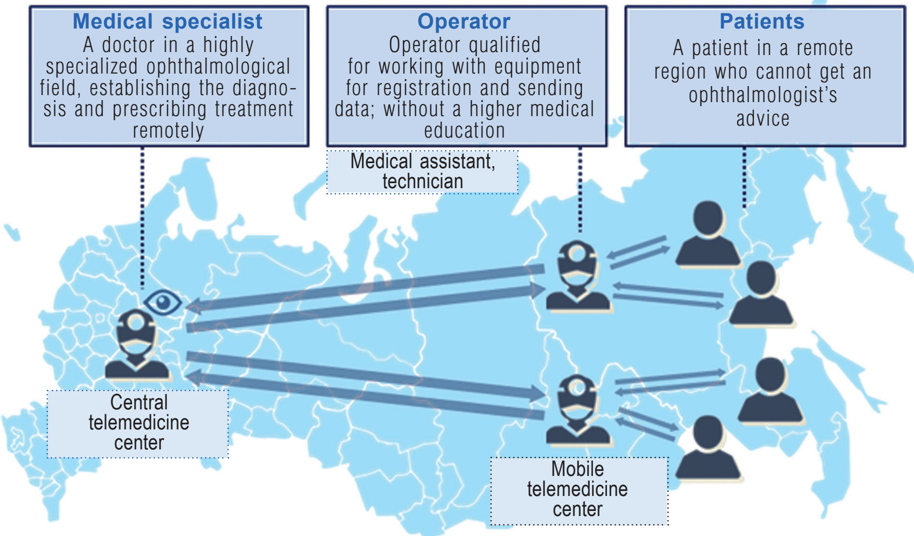
The advantages of introducing TO systems into the ophthalmological practice include economic efficiency, reduced patient examination time, and access to even the narrowest specialties.

There are specific difficulties [16] that hinder the introduction of TM systems, from obtaining high-quality source data (primarily images) to the legislative aspects of protecting personal data. Also, not all doctors and patients are ready to work in TO systems.

Obtaining a high-quality image

The most important aspect of the diagnosis of ophthalmic diseases is obtaining high-quality images of the fundus that are suitable for analysis. Efforts should focus on obtaining a clear image of the optic nerve head to diagnose glaucoma. For DR, AMD, and ROP, it is necessary to image the fundus at the widest possible angle [17].

The simplest option for obtaining fundus images are slit lamp adapters to connect the camera and adapters for smartphones and tablet computers.



Layout of telemedicine center work
Схематичное устройство работы телемедицинского центра

Obtaining fundus images using the Google Glass optical head-mounted display has also been considered [18]. All these methods are cheap and easy to learn and implement. Smartphones with a high-resolution camera are currently widely available [19]; drawings of adapters for a slit lamp or ophthalmoscopic camera lens systems are freely available in large quantities. However, the refraction of the microscope and the extreme inconsistency of the characteristics of smartphone cameras about microphotography do not enable us to achieve high image clarity. Therefore, the analysis of such photographs is complicated. Also, image acquisition is possible only under conditions of mydriasis. Such mobile methods for obtaining images are used only in the diagnostics of emergency pathologies in the current concept of TO [20]. Fundus photographs of all patients with emergency conditions made using mobile devices were considered suitable for remote assessment [21].

A more convenient option is hand-held fundus cameras, which are specialized medical devices with integrated high-resolution cameras, which enable us to take a fundus photo quickly, even without mydriasis. Such tools were used for a long time in veterinary ophthalmic practice and are also a variant of choice when working with young children.

Nowadays, the gold standard for obtaining the most detailed images of the fundus are desktop nonmydriatic fundus cameras, including traditional ones with field coverage of 45° and more (iCam, OptoVue; CR-2 Plus, Canon; VISUCAM 200, Zeiss; EasyScan, iOptics) and wide-field ones with coverage up to 200° of the field (Daytona, Optos; CLARUS500, Zeiss). Such devices are expensive and difficult to operate, but they enable us to obtain the highest-quality and stable image over a minimum amount of time.

Although the image can be acquired with an undilated pupil, pharmacologic mydriasis improves the quality of images significantly [22, 23].

Obtaining a high-resolution fundus image with a minimum number of artifacts is only one of the difficulties in implementing TO. The establishment of TM systems also requires capturing images most similar to each other, that is, standardized ones. Ideally, the fundus photo of all patients should cover the segments of the fundus equal in angular size, calibrated according to the same landmarks, and have the same resolution and color rendering. If a stereo photo is taken, then the angle of the camera lens shift should not be arbitrary.

The accumulation of standardized photos in the form of databases can be advantageous for training ophthalmologists and creating automatic algorithms for the initial analysis of images that can be implemented in the software of fundus cameras. Traditional image processing algorithms give way to contemporary programs based on self-learning [24].

Machine learning (deep learning) is a section of artificial intelligence based on the development of a search for self-improving algorithms to search for repeating patterns in incoming information flows [25]. An application implementation of such a program in TO is a convolutional neural network that is a unique architecture of artificial neural networks aimed at efficient image recognition.

Specialist training

The operator's role in the process of working with the fundus camera remains a key link, even with the necessary equipment and the adoption of quality standards. A specialist taking a fundus photo must be competent and able to work with the camera, process the photographs, edit them if necessary, and ensure the transfer of images.

The question on who should undertake the operator's obligations is disputable. On the one hand, thorough and complex training of personnel is necessary; on the other hand, the specialized ophthalmological education for the fundus camera operator is optional.

Considering the specifics of the forthcoming work, training the ophthalmologists or general practitioners themselves is the easiest way; however, involving a specialist doctor in remote regions can be complicated. Global practice shows that personnel with secondary medical or secondary technical education can be trained to work with a patient in TM centers [26, 27]. Medical assistants, medical technicians (medical technologists), optometrists, and nurses can work with a fundus camera, perform additional patient examinations if necessary, and, of course, send the information collected to the central TM center. This significantly reduces the burden on primary link doctors and enables them to organize the direct provision of specialized care to the patient.

Theoretically, an individual TM specialist can be trained as an operator with the established work of a large TM center [28].

There is a similar discussion regarding specialists who are to analyze data remotely. On the one hand, the obligations of specialist ophthalmologists can be expanded, and on the other hand, individual specialists for TM consultations can be trained.

In an anonymous study by M.A. Woodward et al. [29], 82% of the surveyed ophthalmologists expressed their willingness to participate in the interpretation and evaluation of fundus photographs, but 59% of them rated their confidence in assessing the patient's condition using a single photograph and issuing the correct recommendations as "low." At the same time, automated algorithms for analyzing photographs can be useful tools for both the operator and the specialist, which can significantly simplify the work with the patient.

Attitude of patients and doctors to teleophthalmology

A study by K.J. Mueller et al. [10] found that, among 252 doctors in hospitals where ophthalmologist teleconsultations are actively used, 95% of the surveyed general practitioners agreed that TM ophthalmological consultations improved the quality of medical care.

If doctors, in general, understand the potential of TO and apply technology in medical practice, then a specific cohort of patients present a conservative attitude. Thus, according to a survey by N.G. Valikodath et al. [30], most patients of the older age group did not want to refuse a personal visit to the doctor, and most of them had multiple diseases. However, it is worth noting that the contemporary concept of TO consultations does not imply a complete refusal from the personal interaction of the doctor and the patient, but is only supplementary for specialists in diagnosing and determining treatment activities.

Nevertheless, patients have a general positive attitude toward TO [16] according to numerous sociologic surveys conducted in TM centers regarding the quality of remote care provided to patients and patient satisfaction with it.

Thus, according to a survey of J.Y. Lee et al. [31], most parents of newborn children whose fundus images were photoregistered and analyzed remotely gave positive ratings to the "photographic recording of the fundus of children as a way to record a child's health status" (average rating, 4.4 of 5.0) and agreed with the statement that "contemporary technologies improve the quality of medical care" (average rating, 4.3 of 5.0). It should be noted that the survey involved parents aged mainly up to 40 years.

When interviewing patients aged 18 years and older (348 patients were interviewed) who received comprehensive TM consultations, 99.8% of them were completely satisfied with it. Almost 75% said that this method of examination was a priority for them compared with a personal visit to a medical center [32].

For glaucoma patients, the very first such survey conducted in 1999 by A. Tuulonen et al. [33] reported that despite the same satisfaction with the examination in patients of the teleglaucoma and conventional glaucoma centers, 96% of patients preferred remote consultations to personal visits to the doctor. Later, a similar survey was conducted at a teleglaucoma center in Austria among 118 regular patients, both children, and adults; the satisfaction level with TM consultations was 98% [34]. In the British "virtual glaucoma center," both users of TO consultations and patients of a conventional glaucoma center were interviewed, and satisfaction with assistance was comparable (4.5 of 5.0 in a "virtual" center and 4.6 of 5.0 in a conventional clinic) [35].

Almost 88% of DR patients registered at the TM center, where their fundus changes were photographed, were completely satisfied with this approach to diagnose their disease, and more than half of them preferred the remote method of consultation to a personal visit to the doctor [36].

Teleophthalmology center financing

The development of long-term financial strategies will ensure stable operation of TM centers. In economically developed countries, such as the USA, Australia, Canada, and China, financing is provided from the state fund and reserves of insurance companies [12]. The definition of fiscal policy in developing countries is a more complex issue and even a key one for some countries [37]. The development of financing strategies is the task of the late stages of the VISION2020 initiative [38], but the results of its implementation have not yet been published.

In Russia, the issue of acquiring equipment for TO centers is particularly relevant. Because Russian manufacturers are not involved in the production of fundus cameras, at this stage, the solution is to purchase devices from foreign companies, which is not economically feasible in the long term. A logical solution to the problem is the establishment of the Russian production of specialized equipment.

Problems with the financing of TM in the Russian Federation were solved in an alternative way, namely, introducing TM in the framework of large business projects. The pilot project "Health Module" was launched in 2017 by the online service DocDoc.ru and the network of medical centers "Medscan" with financial support from Sberbank. It is represented by a cabin with equipment installed in it, including a nonmydriatic fundus camera and a video communication system with doctors of the TM center, in which the patient can undergo a comprehensive examination of the skin, ears, and eyes [39].

Unified information standard

The development and implementation of information standards can help overcome the difficulties associated with the communication organization of TO assistance. All over the world and in all segments of TM, such an information standard is the 7-level Open Systems Interconnection (OSI) model that regulates the entire path of information distribution, from its typed receipt to the development of user interfaces at various levels [40]. Information storage, transmission, processing, and analysis are also standardized.

The OSI network model has seven layers. The first, the physical data level, defines the method of transmitting data in binary code on a diagnostic device (fundus camera, perimeter, optical coherence tomograph, etc.). USB and fiber optic cables are examples of standards at this level.

The second, data link layer, defines the data transfer among computers of the same network within the same network segment, that is, physically integrated. Here, routing standards are set within the local network, such as DSL, Ethernet, and PPP.

At these two levels, standards and network data transfer protocols within the local network are set for the initial data stream. An example of such a standard in TM is Digital Imaging and Communications in Medicine (DICOM), which distinguishes for TO its modality of Ophthalmological Photos (OP) [41]. The most relevant DICOM 3.0 standard nowadays, using the OP modality as an example, determines the attributes and demographic data of the patient, the model and manufacturer of the nonmydriatic fundus camera, the attributes of the medical institution and operator, the study conditions, the image parameters (series of fundus images), the obligatory images in a standardized form, and the generated encrypted DICOM local LAN routing protocol. The minimum image size suitable for remote evaluation was determined as what was applied to ophthalmic photographs [42].

At three higher levels, the functions of Internet routing and global addressing are implemented. The third layer, network, sets the standards for wireless communications (IPv4, IPv6). The fourth level, transport, defines short-term feedback among nodes of the same network. The fifth level, session, allows network applications to maintain interaction for a long time.

The sixth presentation level is especially important in TM, because it determines the encoding and decoding of the data transmitted. Encryption protocols are introduced at this level.

The highest level is the seventh, user application. User-network interaction is provided at this level. The interface for working with electronic medical information is subject to standardization.

It must be uniform for all specialists, understandable, accessible, and structured, but at the same time safe and secure.

Nowadays, an example of such an interface is Health Level 7 (HL7). HL7 is a standard for the exchange, management, and integration of medical information. It is a set of dictionaries and medical data templates for the possibility of maintaining an electronic medical history [43, 44]. HL7 is compatible with many other applied information standards [45], including some Russian-manufactured ones (e. g., Medialog [46], qMS [43], and CMIS [47]). Secure Diagnostic Imaging is another software option, which was introduced at Canadian telecenters at the initiative of the University of Alberta [48, 49].

CONCLUSION

TO will become an important part of healthcare, with its proper development and implementation, because it enables to provide specialized medical care to residents of remote regions. Its basis will be the creation of sustainable communications among specialists of different levels and between doctors and patients themselves.

The general distribution of TO consultations throughout the world, in particular in Russia, is hindered by several difficulties regarding the standardization of the approach to remote consultations.

To summarize, the main fields of preparation for TO implementation in Russia should be the following:

1) Training of qualified personnel. Establishing training for specialists having specialized secondary education to work with equipment of TO centers or training optometrists;

2) The development of Russian instrumentation, the development of fundus cameras, portable perimeters, and other equipment necessary for the TO center operation;

3) Continuation of the legal implementation of TM doctrines in the legislative field of the Russian Federation;

4) Adoption and development of information standards for the transfer of medical data among different TM centers.

Worldwide, there are a large number of examples of well-established work of TM centers in different directions, which will be described in detail in the second part of the study.

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