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A brief overview

Smart Technologies in Ophthalmology: Current State and Development Prospects

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Abstract

The rapid development of digital technologies has significantly transformed many areas of healthcare, including ophthalmology. Smart technologies are increasingly integrated into ophthalmic practice to improve disease detection, monitoring, and management. The present study aims to systematize contemporary smart technologies used in ophthalmology and evaluate their clinical applicability, advantages, and current limitations.

The analysis demonstrates that smart technologies in ophthalmology can be broadly categorized into three principal groups: artificial intelligence–based diagnostic systems, telemedicine and mobile health solutions designed to expand access to care. Among these, AI-based image analysis tools have achieved particularly high diagnostic performance in the detection of retinal diseases and glaucoma. Teleophthalmology platforms and smartphone-based imaging technologies enable remote screening, facilitate communication between patients and specialists, and improve healthcare accessibility in geographically remote areas. In addition, novel monitoring devices, including implantable intraocular pressure sensors and wearable contact lens–based systems, allow continuous evaluation of disease-related parameters, which is especially relevant in the management of glaucoma.

Keywords: digital technology, ophthalmology, mobile application, artificial intelligence.

1. Introduction

Smart technologies in ophthalmology encompass a wide range of advanced digital tools, including artificial intelligence (AI), machine learning, connected devices, mobile applications, and telemedicine systems designed to enhance the detection, follow-up, and management of eye diseases. In recent years, the integration of these technologies into ophthalmic practice has accelerated considerably, driven by rapid progress in telemedicine as well as the healthcare challenges highlighted during the COVID-19 pandemic [1].

These innovations allow clinicians and patients to monitor important visual parameters and disease-related symptoms remotely, extending access to ophthalmic care beyond traditional clinical environments. Various portable and wearable devices—such as wrist-worn monitors, smart glasses, and contact lens–based sensors—have been developed, alongside numerous smartphone applications that

support vision screening and patient self-assessment [2]. Furthermore, the growing use of artificial intelligence and large-scale data analytics is contributing to the development of personalized ophthalmic care, enabling automated interpretation of medical images and improved prediction of therapeutic outcomes.

Objectives. To systematize contemporary smart technologies in ophthalmology, including AI–based solutions, mobile applications, telemedicine and cloud platforms, and portable or implantable devices, and to evaluate their clinical applicability, limitations, and implementation prospects.

2. Materials and methods

For this narrative literature review, peer-reviewed publications from international and national scientific journals in ophthalmology, biomedical engineering, and medical informatics were used.

The search was conducted in electronic databases and search platforms (PubMed, MEDLINE, Scopus, Web of Science, Google Scholar) using English-language keywords and their combinations: smart technology, digital health, artificial intelligence, deep learning, teleophthalmology, screening, mobile app, glaucoma.

Priority was given to studies published within the last 10 years (2015–2025) as the most relevant to digital healthcare.

Inclusion criteria:

1. Original studies demonstrating the clinical validity of smart technologies in ophthalmology;
2. Systematic reviews on AI, telemedicine, and mobile technologies in ophthalmology;
3. Publications describing real-world implementation, cost-effectiveness, and organizational aspects.

Exclusion criteria:

1. Non-peer-reviewed sources lacking sufficient methodological information;
2. Publications without reported data and performance metrics;
3. Solutions unrelated to ophthalmology or lacking clinical orientation.

3. Results

Comparative analysis demonstrates that smart technologies in ophthalmology can be conventionally divided into three key groups:

1. AI algorithms for diagnosis and prognostication;
2. Telemedicine and mobile applications for expanding access to care;
3. Wearable and implantable devices for monitoring glaucoma and other chronic ocular diseases.

From the standpoint of clinical implementation, AI systems for screening and mobile applications are the most mature. At the same time, technologies for continuous intraocular pressure monitoring and multimodal AI models remain under active development and have significant potential for personalized ophthalmology.

AI in ophthalmology includes machine learning approaches—particularly deep neural networks—that can process clinical data and ocular images to identify pathological changes, forecast disease progression, and assist clinicians in decision-making. The greatest advances have been observed in automated image analysis, where contemporary neural network models are trained on extensive datasets of high-resolution images and can achieve diagnostic performance comparable to experienced specialists [2].

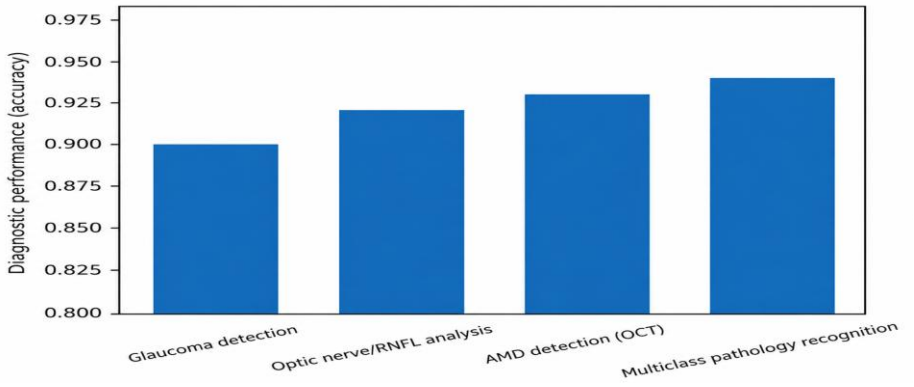

Figure 1 - Diagnostic performance of AI applications in ophthalmology

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Figure 1 presents a comparative assessment of the diagnostic performance of AI algorithms in solving key ophthalmic tasks. AI demonstrates high accuracy in glaucoma detection, analysis of the optic nerve head and retinal nerve fiber layer (RNFL), identification of age-related macular degeneration based on optical coherence tomography data, as well as in the recognition of ophthalmic pathologies overall.

Importantly, AI in ophthalmology is not designed to replace clinicians; rather, it functions as a supportive tool that complements physician expertise. These algorithms are capable of rapidly analyzing large volumes of imaging data and highlighting potentially abnormal findings for further evaluation. For instance, within diabetic retinopathy screening programs, AI-assisted systems improve screening capacity and operational efficiency, allowing earlier detection of a greater number of patients with disease [3–5].

Overall, AI has already proven to be clinically valuable in ophthalmic practice. With the ongoing expansion of medical datasets and continued improvement of analytical models, AI technologies are expected to become an increasingly integral element of routine eye care.

Mobile Health and E-Health technologies

Mobile and cloud-based technologies are increasingly being adopted in ophthalmology, enhancing the capabilities of both clinicians and patients. The widespread use of smartphones across virtually all age groups has led to the development of numerous dedicated mobile applications for eye care. Some of these applications enable patients to perform vision assessments at home, including tests of visual acuity, color vision, contrast sensitivity, and monitoring with the Amsler grid. A number of these tools have undergone clinical validation and have demonstrated results comparable to those obtained using standard clinical methods. Other applications are designed to support people with visual impairment in everyday life, offering functions such as navigation assistance, digital magnification, and text-to-speech technologies, which help increase patient independence [6].

For ophthalmologists, mobile technologies provide access to clinical guidelines, reference materials, and remote connectivity to diagnostic equipment. Of particular importance are solutions that allow smartphones to function as portable examination devices. With the help of relatively inexpensive optical adapters, a smartphone camera can be converted into a handheld ophthalmoscope or a simplified slit lamp, making it possible to capture images of the anterior segment and the ocular fundus. Smartphones can also be attached to slit lamps and even integrated with optical coherence tomography (OCT) systems, enabling real-time visualization of ocular structures and convenient storage of images for documentation and further analysis [7]. Figure 2 presents a transmission and mounting system for a slit lamp.



Figure 2 - MicroREC smartphone adapter for slit lamp

These solutions offer clear advantages in terms of portability and accessibility, which are especially valuable during outreach examinations, school-based screening programs, and in geographically remote regions. Images captured in such settings can be transmitted through mobile networks or Wi-Fi to specialized centers, where ophthalmologists can promptly review and interpret them. In this way, smartphones have become an essential element of teleophthalmology systems, connecting patients in peripheral locations with specialists in tertiary centers.

Teleophthalmology, a growing branch of telemedicine, allows ophthalmic services to be delivered remotely. It includes asynchronous ("store-and-forward") models, in which patient data—such as retinal images—are collected and later reviewed by a

specialist, as well as synchronous approaches that involve real-time video consultations and remote clinical interaction. Teleophthalmology has achieved particularly strong success in retinal disease screening. In many countries, large-scale diabetic retinopathy screening programs have been implemented, where fundus photographs obtained in primary care settings are transmitted electronically to ophthalmologists or automatically analyzed using AI algorithms [8]. This approach has proven to be effective and is now widely regarded as a standard strategy for expanding screening coverage.

Beyond retinal diseases, telemedicine is also being applied in other areas of ophthalmology. Virtual clinics for the management of glaucoma and cataract are increasingly being established. In such settings, routine follow-up assessments—including visual acuity measurement, intraocular pressure evaluation, optic nerve imaging, and visual field testing—are performed by trained personnel or automated devices. The ophthalmologist subsequently reviews the results remotely and determines the appropriate management plan. This model helps reduce the burden of in-person visits while improving patient convenience.

The use of teleophthalmology expanded considerably during the COVID-19 pandemic, when a significant proportion of consultations shifted to remote formats [9–11]. The pandemic acted as a catalyst that accelerated the acceptance of telemedicine among both clinicians and patients. As a result, teleophthalmology has now become a stable component of the modern hybrid model of ophthalmic care delivery.

Glaucoma and Smart Technologies

Glaucoma is a chronic progressive disorder that can ultimately result in irreversible blindness. Because effective management requires both early diagnosis and long-term follow-up, this disease represents an important area for the application of smart medical technologies. Conventional diagnostic approaches—such as measurement of intraocular pressure, assessment of the optic nerve head, and visual field testing—largely rely on physician interpretation and are typically performed at irregular time intervals. This limitation becomes especially evident in patients with insufficient adherence to hypotensive therapy. Modern smart technologies aim to enhance the objectivity of diagnostic procedures and ensure more consistent disease monitoring.

Figure 2 illustrates a multimodal framework for the use of AI in ophthalmology. Input data include clinical parameters such as optical coherence tomography, fundus photography, and visual field metrics. These data are analyzed by deep learning models generating clinically meaningful outputs, including disease detection, risk stratification, and prediction of pathological progression. An additional layer of explainable AI provides reliability assessment and visualization of pathological features, thereby improving clinical decision-making efficiency and trust in these systems.

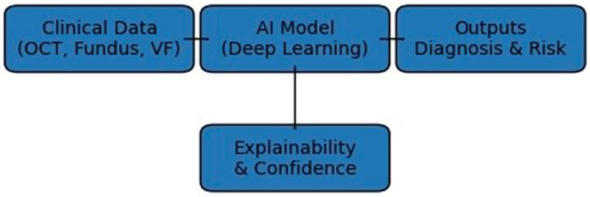

Figure 3 - Conceptual model of AI application in ophthalmology.

Alongside AI –based analytical systems, particular attention has been given to technologies designed for monitoring intraocular pressure (IOP), which remains the principal modifiable risk factor in glaucoma. Since IOP demonstrates circadian variation and may exhibit intermittent spikes, isolated measurements taken during clinic visits provide only limited insight into the true pressure profile. Consequently, recent years have seen the development of novel systems capable of continuous IOP monitoring [12,13].

One such innovation is the implantable sensor Eyemate, produced by the company Implandata in Germany. This device is a miniature electronic sensor designed to measure intraocular pressure directly from within the eye. Clinical investigations have confirmed its feasibility and safety, leading to regulatory approval for clinical use in Europe and recognition by the U.S. Food and Drug Administration through Breakthrough Device designation in 2021.

The sensor can be implanted either in the ciliary sulcus during cataract surgery or positioned in the supraciliary space as part of glaucoma surgery, where it remains permanently. The device operates without an internal battery; instead, it receives power wirelessly

from an external reader placed by the patient near the eyelid. When activated, the sensor transmits current pressure measurements to the external receiver, which then forwards the information to a protected cloud-based database. This system allows clinicians to track the patient's IOP pattern over extended periods—ranging from hours to several months. Physicians can review the data through an online monitoring platform that visualizes pressure fluctuations and long-term trends, with customizable alerts triggered when IOP exceeds predefined thresholds.

Clinical research has demonstrated that prolonged use of Eyemate is safe, and the pressure readings obtained correlate well with measurements from conventional tonometry devices [12,13]. Continuous data collection significantly increases the number of recorded measurements, enabling more accurate detection of nocturnal and episodic pressure elevations and thereby improving assessment of disease progression risk. Furthermore, developers are working on incorporating AI algorithms capable of analyzing large volumes of IOP data alongside clinical variables to support personalized treatment decisions.

Before the introduction of implantable sensors—and still in use today—wearable systems for monitoring intraocular pressure were developed. One notable example is the Sensimed Triggerfish contact lens. This soft contact lens integrates a micro-sensor that detects subtle changes in ocular circumference associated with variations in intraocular pressure. The lens communicates with an antenna positioned around the orbit, which transmits recorded signals to a portable data logger.

This technology enables continuous ambulatory monitoring of the IOP pattern over a 24-hour period, including nighttime measurements, with recordings obtained at five-minute intervals. Although the system does not directly measure absolute pressure values and instead records signals in arbitrary units, the pattern of fluctuations and the timing of pressure peaks provide clinically useful information for identifying patients at greater risk of glaucoma progression [13-15]. Clinical studies have shown that the Triggerfish system is generally well tolerated. Most reported adverse effects are mild and transient, such as tearing or conjunctival hyperemia, and typically resolve after removal of the lens.

Another technological direction in glaucoma management is the development of home-based tonometry. In recent years, portable tonometers that allow patients to independently measure intraocular pressure outside the clinic have been introduced. One example is iCare HOME, which enables repeated IOP measurements in everyday conditions. New research efforts are focused on making these systems easier to use and less dependent on the patient's technical skills.

An example of such innovation is the IOPerfect device, designed as a compact module mounted on the patient's forehead. This prototype measures intraocular pressure using a non-contact technique: a brief air pulse is directed toward the cornea, while a built-in video camera captures the biomechanical response of ocular tissues. The system does not require topical anesthesia and is designed to reduce the influence of corneal thickness on measurement results. Additionally, the collected data can be automatically transmitted to the treating physician through an internet connection. Although the IOPerfect system is still in the experimental stage, it demonstrates the current trend in device development—creating practical tools that enable regular home monitoring of glaucoma.

Smart technologies are also beginning to play a role in glaucoma therapy. While fully autonomous therapeutic smart systems remain relatively rare, several devices combining treatment delivery with digital monitoring capabilities are under investigation. For instance, experimental smart implants capable of releasing antiglaucoma medications within the eye in a controlled manner are being explored. These systems may incorporate microchips that allow remote regulation of drug dosage.

Another technological solution aimed at improving treatment adherence involves electronic sensor caps attached to eye-drop bottles. These devices register the exact time when medication is instilled, allowing clinicians to track patient compliance. In addition, they can synchronize with mobile applications that send reminders to patients regarding scheduled instillations. Although such technologies are not yet widely implemented in routine clinical practice, they illustrate a future model of glaucoma care in which digital connectivity enables closer monitoring of therapy and more rapid adjustments to treatment strategies.

Overall, smart technologies are gradually being integrated into all stages of glaucoma care—from early identification of the disease and continuous monitoring of its progression to individualized treatment planning and control of medication adherence. As these innovations continue to develop and become more widely adopted, they have the potential to significantly reshape traditional glaucoma management strategies, shifting the focus toward proactive prevention of irreversible visual impairment.

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MyGlaucoma app

Poor treatment adherence remains one of the principal factors contributing to disease progression in patients with glaucoma. Numerous studies have demonstrated that inadequate compliance with prescribed hypotensive therapy is common among individuals with this chronic condition. Reported adherence rates vary widely, ranging from approximately 30% to 80%, depending on the population studied and the methods used to assess compliance [16,17]. Such variability reflects the complex and multifactorial nature of patient behavior in long-term therapy.

A variety of determinants influence adherence to glaucoma treatment. These include patient-related factors such as forgetfulness, limited understanding of the disease, low health literacy, and personal beliefs about the necessity or effectiveness of therapy. Socioeconomic factors—including medication cost, access to healthcare services, and social support—also play an important role. In addition, clinical characteristics such as the presence of comorbidities, age-related limitations in manual dexterity or vision, and the complexity of treatment regimens may further reduce the likelihood that patients will follow the prescribed therapeutic plan. Collectively, these barriers highlight the need for strategies that support patients in maintaining consistent long-term therapy [18].

In response to these challenges, specialists from the Kazakh Research Institute of Eye Diseases developed a mobile application designed to improve adherence to glaucoma treatment. The initial version of the application, known as Glaucoma App, was introduced in 2018 as a digital tool intended to assist patients in managing their therapy and maintaining regular communication with their ophthalmologists. Following several years of practical use and user feedback, the application underwent further development, and an updated version—MyGlaucoma App—was finalized in 2025.

The MyGlaucoma App is available for download through major mobile platforms, including the App Store and Google Play, and supports three languages: Kazakh, English, and Russian (Figure 4). The application is structured into several functional sections designed to provide both educational and practical support for patients living with glaucoma.

The first section contains educational materials aimed at improving patients' understanding of the disease. This component includes seven short informational videos created by ophthalmologists from the Kazakh Research Institute of Eye Diseases. The videos present clear and accessible explanations of glaucoma symptoms, risk factors, diagnostic methods, and treatment principles, helping patients better understand the importance of regular monitoring and consistent therapy.

The second section focuses on treatment management. It allows users to create an individualized schedule for the administration of prescribed eye drops and provides reminders to ensure that medications are used at the correct times each day. Such reminder systems are particularly valuable for patients who require multiple medications or complex dosing regimens.

Another important feature of the application is the ability to record and store clinical information. Patients can enter and retain the results of ophthalmological examinations, including measurements of intraocular pressure and other relevant clinical parameters. The application also provides space to document the patient's medical history, previous treatments, and changes in therapy over time, enabling more structured long-term disease monitoring.

The final section of the application includes practical tools to facilitate ongoing interaction with healthcare providers. It contains the contact information of the treating ophthalmologist and integrates a calendar function that allows patients to plan future visits and receive reminders about upcoming appointments. By combining educational resources, medication reminders, and tools for storing clinical information, the MyGlaucoma App aims to support patients in maintaining consistent treatment and active participation in the management of their disease.

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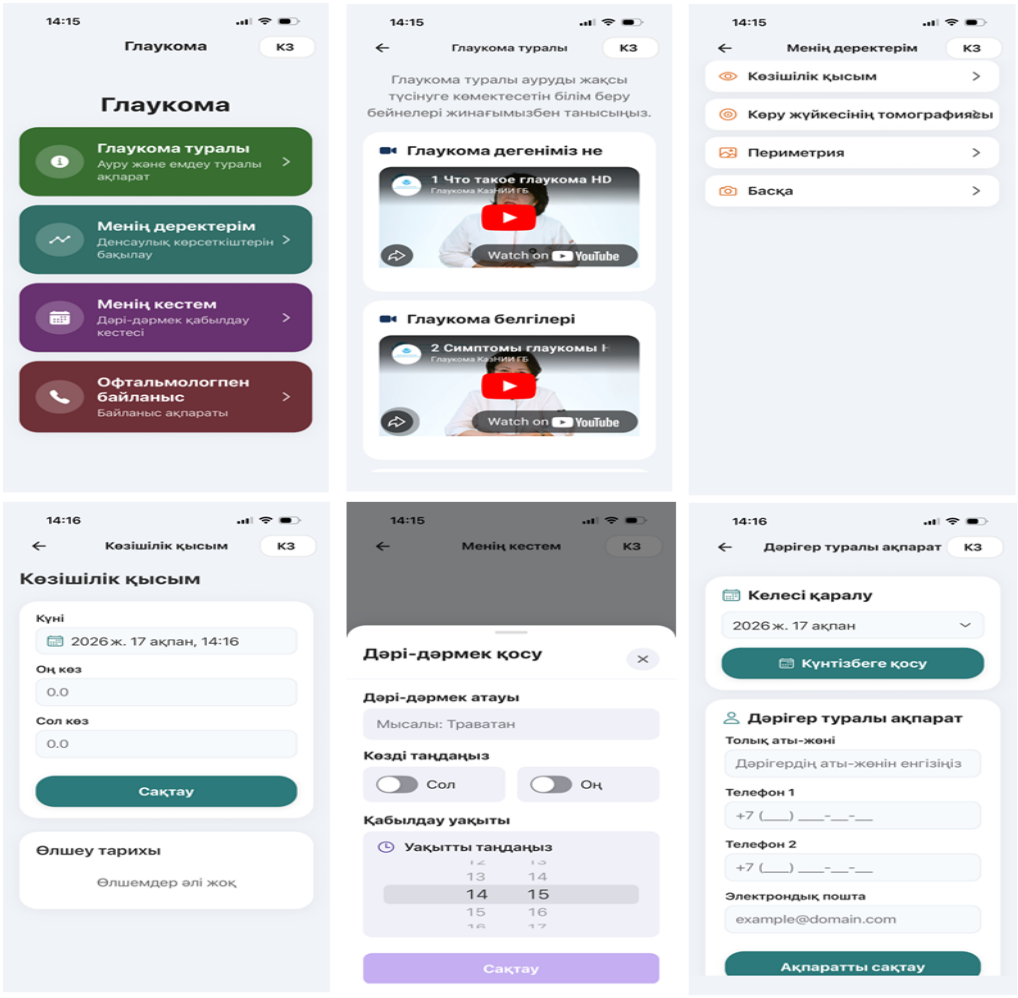

Figure 4 - MyGlaucoma App interface

4. Discussion

Any AI model is trained on a specific dataset, and its performance may decline when transferred to another population, a different type of camera, or an alternative imaging protocol. The quality of input data (blurred images, cataract, media opacities) also affects accuracy: some images become non-informative and require specialist evaluation. Bias is another important issue: if the training data are insufficiently representative, the algorithm may perform worse in certain ethnic or age groups. Therefore, multicenter studies and independent validation are necessary.

Organizational barriers also exist: implementation of telemedicine and AI requires funding, infrastructure, staff training, and integration with electronic medical records. In addition, digital inequality must be considered: not all patients possess smartphones, stable internet access, or the skills to use applications. Consequently, smart technologies should function not as the sole but as an additional channel of care delivery in settings where access to the traditional healthcare system is limited.

Despite the challenges, the prospects are highly favorable. The future lies in multimodal systems that integrate imaging, electronic health record data, genetics, and biomarkers to generate individualized risk predictions and recommendations for each patient. The development of large registries and real-world data analytics will enable faster identification of risk factors, population-level assessment of treatment effectiveness, and refinement of clinical guidelines.

In practical terms, routine screening and primary interpretation tasks are expected to be partially performed by algorithms, while the physician's role will shift toward information integration, final decision-making, communication, and performance of complex interventions.

5. Conclusion

Contemporary ophthalmology is experiencing a period of intensive digital advancement. A range of smart technologies—including AI, mobile health applications, wearable and implantable sensors, telemedicine solutions, and cloud-based data platforms—have already proven their practical value and continue to develop rapidly. AI tools have enhanced the ability to identify ocular diseases at early stages, broadened the reach of screening programs, and achieved automated diagnostic performance approaching that of experienced specialists. At the same time, mobile health technologies and telemedicine services have improved access to ophthalmic care and made long-term monitoring more convenient for patients living with chronic eye disorders.

As larger volumes of clinical data become available, clinical protocols become more standardized, and regulatory environments adapt to technological progress, further incorporation of smart technologies and remote monitoring systems into routine ophthalmic practice is anticipated. Despite these technological advances, the primary goals remain constant: facilitating earlier detection of eye diseases, enabling prompt and effective treatment, preventing avoidable vision loss, and ultimately enhancing patients' quality of life.

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Офтальмологиядағы смарт-технологиялар: Қазіргі жағдайы және даму перспективалары

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Түйіндеме

Сандық технологиялардың қарқынды дамуы офтальмологияны қоса алғанда, денсаулық сақтаудың көптеген салаларын айтарлықтай өзгертті. Ақылды технологиялар ауруларды анықтауды, бақылауды және басқаруды жақсарту үшін офтальмологиялық тәжірибеге барған сайын интеграцияланууда.

Бұл зерттеу офтальмологияда қолданылатын заманауи ақылды технологияларды жүйелеуге және олардың клиникалық қолданылуын, артықшылықтарын және қазіргі шектеулерін бағалауға бағытталған.

Талдау офтальмологиядағы ақылды технологияларды үш негізгі топқа бөлуге болатынын көрсетті: жасанды интеллектке негізделген диагностикалық жүйелер, телемедицина және медициналық көмекке қолжетімділікті кеңейтуге арналған мобильді денсаулық сақтау шешімдері. Олардың ішінде жасанды интеллектке негізделген кескінді талдау құралдары торлы қабық аурулары мен глаукоманы анықтауда ерекше жоғары диагностикалық көрсеткіштерге қол жеткізді. Телеофтальмологиялық платформалар мен смартфонға негізделген бейнелеу технологиялары қашықтықтан скрининг жүргізуге, науқастар мен мамандар арасындағы байланысты жеңілдетуге және географиялық тұрғыдан шалғай аудандарда денсаулық сақтауға қолжетімділікті жақсартуға мүмкіндік береді. Сонымен қатар, имплантацияланатын көзішілік қысым сенсорлары мен киілетін контактілі линзаларға негізделген жүйелерді қоса алғанда, жаңа бақылау құрылғылары ауруға байланысты параметрлерді үздіксіз бағалауға мүмкіндік береді, бұл әсіресе глаукоманы басқаруда маңызды.

Түйін сөздер: сандық технология, офтальмология, мобильді қосымша, жасанды интеллект.

Смарт-технологии в офтальмологии: Текущее состояние и перспективы развития

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Резюме

Быстрое развитие цифровых технологий значительно изменило многие области здравоохранения, включая офтальмологию. Интеллектуальные технологии все чаще интегрируются в офтальмологическую практику для улучшения выявления, мониторинга и лечения заболеваний.

Цель настоящего исследования — систематизировать современные интеллектуальные технологии, используемые в офтальмологии, и оценить их клиническую применимость, преимущества и существующие ограничения.

Анализ показывает, что интеллектуальные технологии в офтальмологии можно условно разделить на три основные группы: диагностические системы на основе искусственного интеллекта, телемедицина и мобильные решения для здравоохранения, предназначенные для расширения доступа к медицинской помощи. Среди них инструменты анализа изображений на основе ИИ достигли особенно высокой диагностической эффективности в выявлении заболеваний сетчатки и глаукомы. Платформы телеофтальмологии и технологии визуализации на основе смартфонов позволяют проводить дистанционный скрининг, облегчают общение между пациентами и специалистами и улучшают доступность медицинской помощи в географически удаленных районах. Кроме того, новые устройства мониторинга, включая имплантируемые датчики внутриглазного давления и носимые контактные линзы, позволяют непрерывно оценивать параметры, связанные с заболеванием, что особенно актуально при лечении глаукомы.

Ключевые слова: цифровые технологии, офтальмология, мобильное приложение, искусственный интеллект.

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