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Current application and future direction of artificial intelligence in optometry

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Artificial Intelligence (AI) is revolutionising optometry by enhancing the identification, diagnosis, and treatment of ocular illnesses. AI-powered tools can help detect age-related macular degeneration (AMD), diabetic retinopathy and glaucoma earlier and more accurately. By facilitating individualised care, lowering myopia, and expanding access to telemedicine, artificial intelligence is revolutionising the healthcare industry. AI-driven platforms are enabling improvements in disease screening and diagnostic imaging, while the rise of innovations like predictive analytics, AI-enhanced contact lenses, and smart gadgets is transforming optometric practices. Some of the issues, like data quality, algorithmic bias, and integration into clinical workflows, have not been resolved by these developments. Accessing AI technologies might be difficult due to their high costs, particularly in settings with limited resources. Even today, ethical issues like correcting prejudices and guaranteeing equal access to healthcare are important. The focus of this review is on the current applications of AI in optometry, including disease detection, diagnostic imaging, and remote care. Prospects in fields like advanced vision therapy, wearables, smart devices, big data, robotics, virtual reality, predictive analytics, and machine learning are also highlighted. It is emphasized that AI can improve clinical outcomes and close healthcare gaps.

Keywords: artificial intelligence; tele-optometry; predictive analytics; personalized medicine; diagnostic imaging; smart devices; algorithmic bias and healthcare accessibility

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Современное применение и перспективы развития искусственного интеллекта в оптометрии

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Искусственный интеллект (ИИ) активно трансформирует оптометрию, улучшая выявление, диагностику и лечение заболеваний глаз. Инструменты на основе ИИ могут помочь на более ранних стадиях и с более высокой точностью диагностировать возрастную макулярную дегенерацию (ВМД), диабетическую ретинопатию, глаукому и миопию, что способствует персонализированному подходу и облегчает доступ к телемедицине, значительно расширяя возможности здравоохранения. Платформы на основе ИИ позволяют улучшить скрининг заболеваний и диагностическую визуализацию, а внедрение таких инноваций, как предиктивная аналитика, контактные линзы с поддержкой ИИ и умные гаджеты, трансформируют оптометрическую практику. Некоторые проблемы, такие как качество данных, ошибки алгоритма и интеграция в клинические рабочие процессы, пока остаются нерешенными. Доступ к технологиям ИИ может быть затруднен из-за их высокой стоимости, особенно в условиях ограниченных ресурсов. Сегодня также важны этические вопросы, юридические неопределенности и обеспечение равного доступа

к медицинской помощи. В настоящем обзоре основное внимание уделяется современному применению ИИ в оптометрии, включая выявление заболеваний, диагностическую визуализацию и дистанционное наблюдение. Рассматриваются также перспективы в таких областях, как передовые методы зрительной терапии, носимые и умные устройства, большие базы данных, робототехника, виртуальная реальность, предиктивная аналитика и машинное обучение. Подчеркивается, что ИИ может улучшить клинические результаты и устранить пробелы в здравоохранении.

Ключевые слова: искусственный интеллект; телеоптометрия; предиктивная аналитика; персонализированная медицина; диагностическая визуализация; умные гаджеты; ошибки алгоритма, доступность медицинских услуг

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Healthcare is being revolutionised by Artificial Intelligence (AI), which opens up new possibilities for identifying, diagnosing and treating diseases. Optimists may find AI to be useful in different fields, such as optometry, which can use AI to analyse large datasets and automate tasks while also providing insights into clinical decision-making [1, 2].

The use of AI in optometry is highly beneficial, given its critical need for accuracy and early detection. Diagnosis is often delayed or inconsistent, and clinician expertise differs from traditional diagnostic methods. AI helps to overcome these issues by providing measurable and actionable outcomes. In certain cases, machine learning models have been more effective than human experts in identifying retinal pathologies due to their high sensitivity and specificity [3]. Beyond just diagnosing, AI is revolutionising everything from personalised medicine to patient monitoring. CLINICS is utilising predictive analytics to predict disease progression, and AI-based tele-optometry platforms are increasing accessibility to care in areas that have been traditionally reserved for medical research [4]. Additionally, AI is making it possible for smart devices – like contact lenses – to assess intraocular pressure and administer medication to people who have symptoms or illnesses, which is upending the conventional optometric practice [5, 6]. Even though it might be a fantastic idea, there are several issues with integrating AI into optometry. The need for legal frameworks, algorithmic bias, and data quality concerns are just a few of the major obstacles that still need to be addressed. AI is a vital tool in optometric treatment, and its capacity to solve a variety of issues is only expected to grow as technology develops. The evaluation looks at how AI can be used in optometry now, ascertains its potential for the future, and pinpoints the challenges that need to be overcome before it is generally adopted. Knowing the revolutionary effects and possibilities of AI will help researchers and optometrists get ready for a time when AI will be used both within and outside of therapeutic settings.

Clarification on Terminology. While this article focuses on the field of optometry, the discussed applications of AI extend well beyond optometric practice into broader ophthalmic, visual science, and healthcare domains. The term 'optometry' is thus used inclusively to represent innovations applicable to the entire spectrum of vision care and ocular diagnostics.

Current Applications of AI in Optometry

Disease detection and screening. AI is making accurate and effective diagnosis and treatment of eye illnesses easier. Retinal scans are being analysed using DeepMind, an AI platform created by Google, to treat diabetes. Skilled eye doctors have determined that these methods are effective [1, 2]. Furthermore, Eye Art has received FDA approval, proving their efficacy in self-directed

DR screening [4]. Regarding glaucoma to avoid permanent visual loss, glaucoma must be detected early. Convolutional neural networks (CNNs) and other AI-driven optical coherence tomography (OCT) platforms can detect structural alterations in the optic nerve head and retinal nerve fibre layer before functional damage even happens [7]. To better identify age related macula dystrophy (AMD) symptoms and provide individualised treatment, patients can be divided into various phases with the aid of machine learning algorithms. This makes it possible to implement more focused therapies [8]. Researchers can identify keratoconus symptoms at subclinical stages by using AI to analyse corneal topography and tomography, which improves the results of corneal cross-linking treatments [9].

Diagnostic imaging. AI-based systems can detect keratoconus at subclinical levels by examining corneal topography and tomography [10]. AI models that use artificial neural networks to segment retinal layers and find biomarkers for diseases like AMD and diabetic macular oedema (DME) improve the efficiency of OCT analysis [11]. Real-time analysis of posterior segment diseases and visual anomalies can be accomplished with the integration of Ultrasound Imaging AI in ophthalmic ultrasound systems, improving diagnostic precision [12].

Contact lens design and fit. Using AI-driven tools, contact lens fitting becomes more efficient by analysing the corneal shape and the dynamics of tear films. These lenses are then fed into advanced algorithms that assess the topography of the eye and recommend the most suitable parameters for scleral lens treatment, reducing the amount of time spent experimenting and increasing patient comfort [13]. Using Multifocal Contact Lenses AI, the visual performance of multifocal lenses can be predicted by considering individual refractive errors and pupil dynamics, which may help in the management of pre-decompensation.

Myopia control. The global rise in myopia prevalence has prompted innovative AI solutions for its management. AI models predict myopia progression using datasets that include genetic, environmental, and lifestyle factors. This information guides interventions such as orthokeratology and low-dose atropine therapy [14]. Environmental monitoring: AI-powered wearables track outdoor activity and near-work duration, providing real-time feedback to mitigate myopia risk factors [15].

Tele-optometry. Telehealth applications are being enhanced with AI to provide accessible and high-quality eye care. Remote screening AI-enabled platforms allow for remote screening of conditions such as diabetic retinopathy (DR), AMD, and refractive errors, expanding access to care in underserved areas [1]. Virtual Refraction AI algorithms are now integrated into smartphone-based refraction systems, providing accurate

prescriptions for eyeglasses and contact lenses [16]. Real-Time Consultation AI-powered tele-optometry systems facilitate real-time consultations by analysing patient data and generating actionable insights for optometrists [17].

Future Directions of AI in Optometry

A schematic representation of future directions of AI in optometry is presented in the Figure.

Personalized medicine and predictive analytics. AI can completely transform disease management and prevention through the use of big data-driven predictive models. These can be used by the models to determine who is susceptible to diseases like myopia, AMD, or glaucoma by taking environmental, lifestyle, and genetic factors into account. Predictive analytics can be used to create customised treatment regimens that include lifestyle changes or medication therapies [3, 18]. AI algorithms may be able to predict how children's myopia will develop and recommend certain therapies, such as low-dose atropine therapy or orthokeratology (Table).

Advanced vision therapy tools. The combination of AI and virtual reality (VR) is opening up new possibilities in vision therapy [3]. These tools promise to boost patient adherence, shorten treatment duration, and enhance therapeutic efficacy.

While the combination of AI and VR is advancing rapidly and holds significant promise for vision therapy, a clear medical consensus regarding its clinical safety has yet to be established. There remain unverified concerns about visual discomfort, binocular vision strain, and other possible side effects. Therefore, rigorous studies are essential to assess the safety and long-term effects of VR-based interventions before widespread clinical implementation.

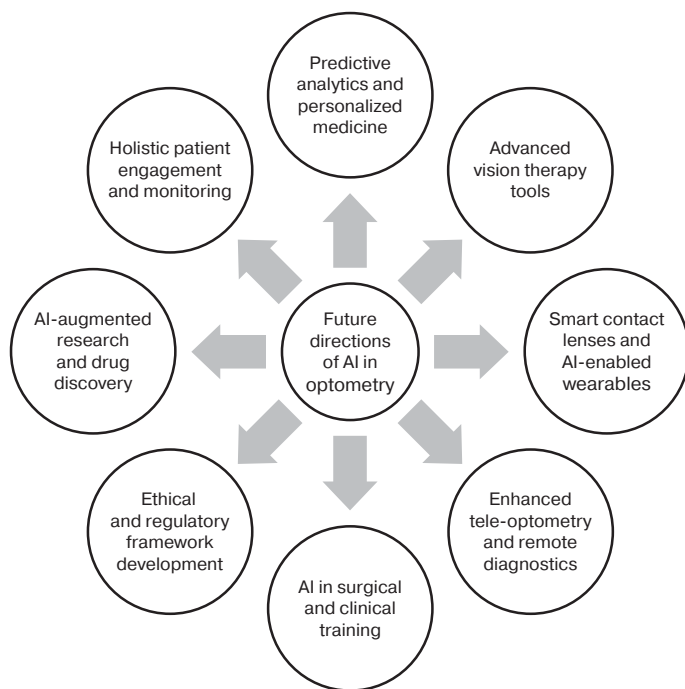


Figure. A schematic representation of future directions of AI in optometry. The diagram highlights key applications, including predictive analytics, advanced vision therapy tools, AI-enabled wearables, tele-optometry, AI in clinical training, ethical frameworks, AI-driven research, and patient engagement. **Рисунок.** Схема будущих направлений развития ИИ в оптометрии. На диаграмме выделены ключевые области применения, включая предиктивную аналитику, передовые инструменты зрительной терапии, носимые устройства с поддержкой ИИ, телеоптометрию, ИИ в клиническом обучении, нормативно-этические рамки, исследования с применением ИИ и взаимодействие с пациентами

Wearables with AI capabilities and smart contact lenses. Smart devices will likely influence optometric care in the future. AI-enhanced contact lenses with micro-sensors could be used to dispense drugs, create biomarkers, or monitor intraocular pressure in glaucoma patients [5, 6]. Artificial intelligence in wearable technology, such as smart glasses, may make it possible to track visual behaviours like screen time and near-work, offering important insights to lessen digital eye strain and other eye conditions. Companies like Sensel are investigating smart lenses that can track intraocular pressure to help in glaucoma early detection [18]. Wearables with Activity Tracking AI could use artificial intelligence to track kids' reach activity in the garden and give parents timely feedback on how much time they've spent outside, which could lower risk factors for myopia progression [15].

Enhanced tele-optometry and remote diagnostics. The integration of AI with telehealth platforms is set to redefine remote eye care. AI algorithms could be used to analyse images and data from slit lamps, OCT devices, or fundus cameras, facilitating comprehensive remote diagnostics. For instance, Virtual Clinics (AI-powered virtual clinics) could conduct detailed exams, including refraction and anterior/posterior segment evaluations, providing patients with nearly in-clinic accuracy [3]. **Real-Time Decision Support:** AI could assist optometrists during live teleconsultations by generating differential diagnoses and recommending management plans, improving care delivery in rural or underserved areas [19].

AI in surgical and clinical training. The use of AI-powered simulation platforms is gaining popularity among optometrists and ophthalmologists to improve surgical techniques and diagnostic skills. Those same tools will provide real-time feedback, allow progress and identify areas for improvement so that clinicians are better equipped to deliver their clinical competency. By using AI-driven simulators, cataract surgery trainees can practice without any potential risks to their patients, as demonstrated by some cases where they face challenging situations [9].

Ethical and regulatory framework development. The development of strong ethical and regulatory structures is crucial as AI becomes more prevalent [1]. In the future, research priorities will include addressing biases in AI algorithms that may impact underrepresented populations, setting international standards for their integration into clinical workflows, and ensuring safety and consistency across healthcare systems.

AI-augmented research and drug discovery. Biomedical research is already being revolutionised by AI, and its potential use in optometry-based drug discovery is noteworthy. By utilising machine learning models, researchers could uncover novel therapeutic potentials for eye disorders or expedite the progress towards creating new treatments. By utilising AI, genetic datasets can be analysed to identify connections between specific mutations and ocular diseases. Additionally, artificial screening could reduce the time and expense of developing drugs through virtual screening using machine learning [16].

Holistic patient engagement and monitoring. AI systems in the future could expand beyond diagnostics and treatment to include full patient engagement platforms. Why? By integrating information from wearables, electronic health records and patient-reported outcomes, these platforms could provide insights into a centralised system for monitoring the condition of the eyes. The utilisation of Natural Language Processing (NLP) could enhance the communication between patients and clinicians, resulting in more personalised care [11].

Integration of large language models (LLMs) in optometric AI. Recent advancements in AI have been largely driven by LLMs, such as GPT-based systems, which have transformed data interpretation,

Table. Future Directions of AI in Optometry: Key Areas and Advancements
Таблица. Перспективы ИИ в оптометрии: ключевые направления и достижения

Future directions of AI in optometry Будущее ИИ в оптометрии	Description Описание	References Литература
Predictive analytics and personalized medicine Предиктивная аналитика и персонализированная медицина	By analysing genetic, lifestyle, and environmental factors, AI creates predictive models that identify potential risks for conditions such as glaucoma or myopia. Customized treatment plans can be created through the use of orthokeratology or low-dose atropine therapy Анализируя генетические факторы, образ жизни и влияние окружающей среды, ИИ создает прогностические модели, которые выявляют потенциальные риски таких состояний, как глаукома или миопия. Индивидуальные планы лечения могут быть созданы с помощью ортокератологии или терапии низкими дозами атропина	[3, 16]
Advanced vision therapy tools Передовые инструменты вижн-терапии	By integrating VR with AI for vision therapy, treatment is adjusted dynamically through real-time feedback. Applications include amblyopia, binocular vision dysfunction and post-traumatic vision syndrome Интегрируя VR с ИИ для вижн-терапии, лечение динамически корректируется через обратную связь в реальном времени. Области применения включают амблиопию, нарушения бинокулярного зрения и посттравматический зрительный синдром	[10]
Smart contact lenses and AI-enabled wearables Умные контактные линзы и носимые устройства с поддержкой ИИ	The intraocular pressure is monitored by smart lenses, while biomarkers and drugs are delivered through these devices. Внутриглазное давление контролируется умными линзами, биомаркеры и лекарства контролируются через эти устройства	[5, 6]
Enhanced tele-optometry and remote diagnostics Улучшенная телеоптометрия и дистанционная диагностика	The use of AI in telehealth platforms allows for remote diagnosis through image analysis and virtual clinics, providing real-time decision support during a whirlwind of onsite consultations Использование ИИ в телемедицинских платформах позволяет проводить удаленную диагностику с помощью анализа изображений и виртуальных клиник, обеспечивая поддержку принятия решений в реальном времени во время проведения консультаций на месте	[3, 4, 10]
AI in surgical and clinical training ИИ в хирургическом и клиническом обучении	Optometrists can train with AI simulation platforms that offer real-time feedback and case-based learning for surgical techniques, as well as diagnostics, to ensure clinical competency Оптометристы могут обучаться с помощью симуляционных платформ ИИ, которые обеспечивают обратную связь в реальном времени и обучение хирургическим методам, а также диагностику для повышения клинической компетентности	[3, 17, 19]
Ethical and regulatory framework development Разработка этической и нормативной базы	Ethical and regulatory policies that prioritize the protection of data, algorithmic transparency, and equal access to AI technology. Studies are aimed at reducing biases and aligning AI adoption into clinical processes Этические и нормативные меры обеспечивают защиту данных, алгоритмическую прозрачность и равный доступ к технологиям ИИ. Исследования направлены на снижение предвзятости и внедрение ИИ в клинические процессы	[1]
AI-augmented research and drug discovery Исследования с поддержкой ИИ и разработка лекарств	Drug discovery is facilitated by AI, which pinpoints potential therapeutic targets and simplifies treatment development Создание лекарств с помощью ИИ, который определяет потенциальные терапевтические цели и упрощает разработку методов лечения	[10]
Holistic patient engagement and monitoring Комплексное взаимодействие с пациентами и мониторинг	The integration of data from wearables, health records, and patient-reported outcomes into centralized systems through AI employs NLP to enhance patient-clinician communication and personalized care Интеграция данных из носимых устройств, медицинских карт и результатов, сообщаемых пациентами, в централизованные системы с помощью ИИ использует NLP для улучшения коммуникации между пациентом и клиницистом и персонализированного подхода	[16]

clinical documentation, and patient communication. LLMs can process vast medical literature, summarize diagnostic findings, and provide decision support in real-time, thereby augmenting clinical efficiency. In optometry and ophthalmology, these models can assist in drafting clinical reports, generating automated patient summaries, and interpreting multimodal imaging outputs when integrated with classical AI systems. The hybrid combination of image-based AI and LLMs is emerging as a powerful tool, enabling automated analysis alongside natural language reasoning. This synergy broadens the application of AI in clinical settings and enhances accessibility by facilitating human-machine communication in tele-optometry and educational contexts.

Challenges and Limitations

Data quality and bias. The quality and diversity of the datasets used to train AI models are crucial factors in their performance

for optometry. If the data used by the AI system is poor or biased, it may cause clinical decision-making to be affected. The preparation of AI systems for optometry involves processing medical images – retinal images, OCT scans and visual field images – just like how eye exam data is breached. How is this done? The AI algorithm will need well-annotated, organised, and exhaustive images for its predictions to be correct. Otherwise, if the images are not sufficient, the diagnostic classes are misclassified, or there is sparse data, the cost of diagnostics becomes too high. Some crucial characteristics needed for making a diagnosis of diabetic retinopathy or macular degeneration might be covered up with poor-quality retinal images. It has been noted that there is a discrepancy between the datasets employed for training AI models and the populations intended to be served. Such conclusions provide unfavourable results and, in some cases, may lead to disparity in healthcare. One of the problems

in healthcare is the failure to capture specific demographic groups like older patients, rural populations, or ethnic minorities into the datasets that are used to train the AI models. For example, AI that is trained on data from a single ethnic group may not work as well for patients of other ethnicities [2]. Health disparities are a result of this, as individuals from underprivileged groups may not receive the same level of care.

Integration into clinical workflows. Despite the potential of AI as a tool to improve optometric care, its integration into everyday clinical practice is difficult due to technical, logistical, and human challenges. Problems of Technical Levels: it is not always possible to use AI tools in clinical settings without a sophisticated hardware/software infrastructure; integration into existing systems can be expensive and difficult. Large quantities of data must be processed by AI systems in real-time, requiring significant computational power. For instance, this can put pressure on the infrastructure of smaller clinics or private practices, which may not have enough funding to invest in such improvements. Additionally, Electronic Health Record (HER) systems and diagnostic devices in optometry, including fundus cameras, OCT devices, and visual field analysers, must integrate with AI tools. Various systems may not have consistent data formats or interoperability, which can make integration and workflow challenges [19]. The integration of AI tools into the clinical workflow can cause both logistical and workflow challenges. New methods for evaluating patients through AI-generated recommendations or diagnoses may require the adaptability of optometrists. Clinicians and administrative staff may face a learning curve due to this. Also, the use of AI tools may cause additional steps in the workflow, such as uploading data for analysis or waiting for results from an AI system, which could lead to a decrease in patient care, particularly in busy clinics. Among the challenges of using AI in clinical practice is clinician trust and acceptance, which remains a significant issue. Optimists are trained to use their clinical judgement and may have reservations about the effectiveness or accuracy of AI systems. Trust in AI can only be established through robust clinical validation, clear evidence that AI tools perform better or as good as human practitioners, and extensive training for healthcare providers. AI tools may not be utilised or rejected by clinicians without this trust [19].

Cost and accessibility. Despite its potential benefits, the high initial and ongoing costs of AI technologies in optometry may limit their adoption in low-resource settings. This is particularly true for AI. Challenges often come in the form of private or public institution licenses and the cost for new training staff along with AI technology maintenance. Regular AI updates are essential because it relies on immense databases that is paired with strong systems, which is why the expense is so high for clinics worldwide, especially in middle-tier earning countries. Implementation, support and correct infrastructure are the backbone of AI so it can function as it was meant to. The proper AI tools are crucial for optometry services, which is why a stable clinic is sometimes unable to function without them. However, because of the increased spending from state-of-the-art equipment and poor internet along with electricity, the weaker core countries are unable to acquire them which brings us to the AI catching-22 zone. While remote areas that are lacking aid would love to have profound access to AI, the core issue is always going to be the cost. If it is too out of reach it causes larger gaps to formulate between people and distance after all, the hybrid cities are the most accessible and affordable. Small practices that choose AI solutions may struggle to fully benefit from their investment, as a limited patient base and inadequate funding can impede their capacity to sustain such advanced technology.

CONCLUSION

AI is bringing an absolute paradigm shift in optometry through not only customisable care but also early diagnosis and authentic testing. The increased app-based technology in optometry can help in enhancing cooperation with staff and thus can result in the best possible outcomes for patients. However, to derive the maximum benefit from this, we will have to face ethical, legal, and accessibility problems. According to AI, the process of optometry is essential to the public, but already on the way to a breakthrough, diseases and the delivery of properly treated patients will be founded on the reality of the proposed methods. AI means reducing the speed at which the disease is spreading, sensitively portraying the patient's health and adjusting to personal health needs. Also, by letting them do the most tedious stuff and providing conclusive insights, they can now focus more on the patient side. Despite the dearth of resources, novel solutions are becoming more common with the use of tools like predictive analytics, AI-enabled contact lenses, and remote diagnosis. However, Tele-optometry is on the rise, and it merges the gap between patient coverage. Nevertheless, a number of perils are there: algorithmic bias, data quality concerns, and the lack of ethical and regulatory frameworks are not dealt with properly that might cause the opposite results. In case these obstacles can be surpassed, AI could be a full-fledged tool of current optometry, thus enhancing results of therapy and patient reception as well as staying.

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