Artificial intelligence in ophthalmology 2023

Post congress report.

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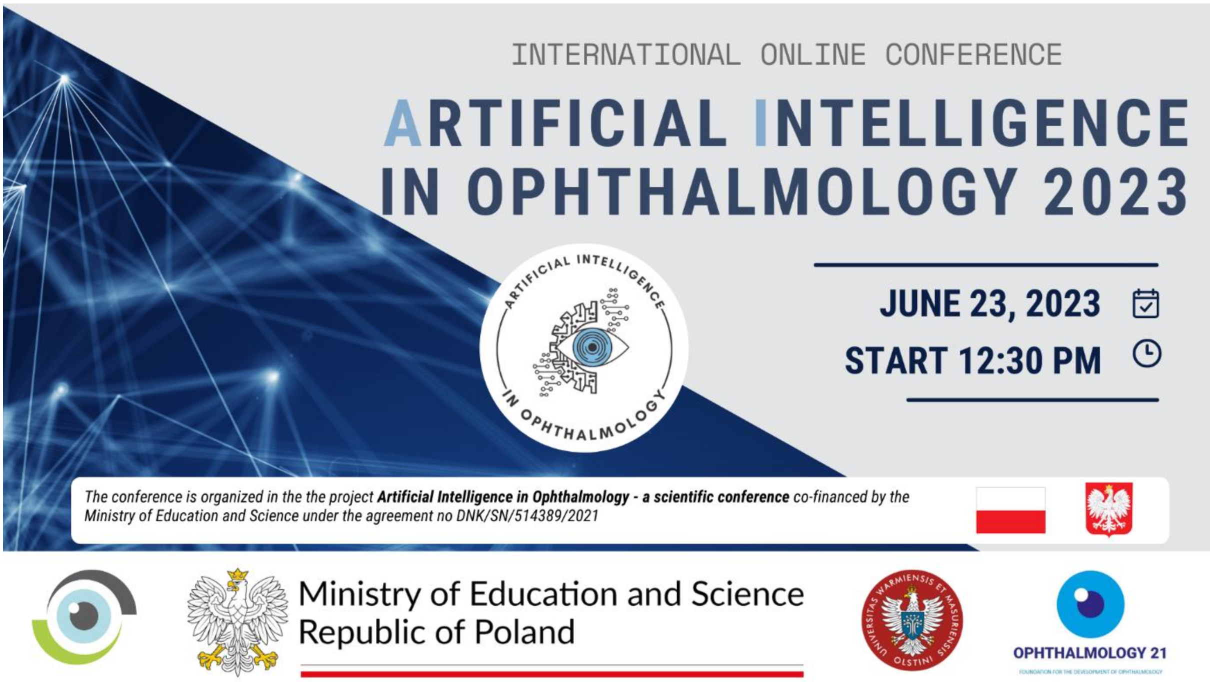
On June 23, a conference entitled "Artificial intelligence in ophthalmology 2023" organized by the Foundation for the Development of Ophthalmology, the Department of Ophthalmology of the University of Warmia and Mazury and the International Society of Artificial Intelligence in ophthalmology thanks to a grant granted by the Ministry of Education and Science as part of the “Perfect Science” (“Doskonała Nauka”) Programme.



The conference consisted of four sessions, two of which presented the latest scientific achievements from the world, and two - the latest scientific achievements from Poland. The conference was attended by 12 lecturers. The detailed program and profiles of the lecturers were presented at https://aiinophthalmology.com/, and the lectures were posted on a special YouTube channel after the conference.

Summaries of the most important lectures are presented below.

Prof. Ryo Kawasaki, MD, PhD, Department of Social Medicine, Osaka University

Retina as a window to see CVD risk.

I. Grading the Severity of Retinal Arterio-venous Crossing Signs & II. Explainable risk profile assessment for cardiovascular disease.

Introduction: Retinal vascular signs serve as end-organ damage indicators and are manifestations of cardiovascular risks and metabolic abnormalities like hypertension or diabetes. Among these, arterio-venous (A-V) crossing signs are particularly prominent, reflecting chronic hypertension and arteriolosclerosis. Although these signs relate to cardiovascular risks, their utilization in clinical or screening settings has been limited due to the complexity of consistent grading. Recent technological advancements such as deep learning have revolutionized this field. This lecture is divided into two parts focusing on grading the severity of A-V crossing signs and assessing the cardiovascular disease (CVD) risk profile.

Part I: Grading the Severity of Retinal Arterio-venous Crossing Signs

Methods: A combination of deep learning models was created to imitate the assessment process of medical specialists, including identifying vessels, distinguishing arterioles, and venules, locating crossing points, and grading the overall severity.

Study Group: 684 participants from the Ohasama study, focusing on hypertension and cardiovascular disease.

Imaging Process: Retinal images were captured at 5184 × 3456 pixels using the Canon CR-2 AF Digital Non-mydriatic Retinal Camera.

Model Construction

Vessel Segmentation Model: IterNet (https://github.com/conscienceli/IterNet)

Artery/Vein Classification Model: SeqNet (https://github.com/conscienceli/SeqNet)

A-V Crossing Point Detection: Employed skeletonized vessel map for precise detection.

Annotation on A-V Crossing: Images were meticulously reviewed and graded by an experienced ophthalmologist.

A-V Crossing Point Severity Grading Model: Data was divided into training, validation, and test sets.

Data Augmentation: A total of 11 operators were utilized for enhancing the deep learning models' performance.

Multi-diagnosis Team Network (MDTNet): Introduced to tackle label ambiguity and distribution imbalance.

Results: The method validated crossing points with precision and recall of 96.3% each. The agreement between the specialist's grading and the estimated score was highly commendable (kappa value: 0.85, accuracy: 0.92).

Discussions: The innovative multi-diagnosis team network (MDTNet) improved the model's accuracy. This pipeline emulates the retina specialist's grading process without needing specific feature extractions. The code availability ensures reproducibility.

Implications: This method can be integrated into current CVD risk screening programs, enabling A-V crossing sign analysis without additional human task burden.

Part II: Explainable Risk Profile Assessment for Cardiovascular Disease

Methods: This section delves into CVD risk profiling using deep learning models, leveraging a dataset from the UK Biobank, containing 52,297 entries with retinal images and traditional CVD risks.

Models

"xMACE" Model: A two-stage deep learning model that first estimates individual CVD risk factors and then assesses the Major Adverse Cardiovascular Events (MACE).

"xMACE+" Model: This model integrates traditional CVD risk factors and retinal images.

Results: The proposed models showcased promising capabilities. The xMACE model exhibited remarkable accuracy (ROC-AUC 0.738 [95%CI 0.710-0.766]), outshining traditional score-based models like SCORE (0.682 [0.640-0.719]). It was also comparable to neural network models grounded on traditional CVD risk factors.

Discussion: The xMACE+ model, utilizing both CVD risk factors and retinal images, performed the best. Nevertheless, the standalone xMACE model showed remarkable precision in estimating CVD risks and 5-year MACE, outperforming traditional models and aligning with neural network models relying on standard CVD risk factors.

Implications: In circumstances where blood testing for CVD risk assessment is inaccessible, retinal imaging alone can furnish a comprehensive CVD risk profile, indicating the primary risks contributing to the increased threat.

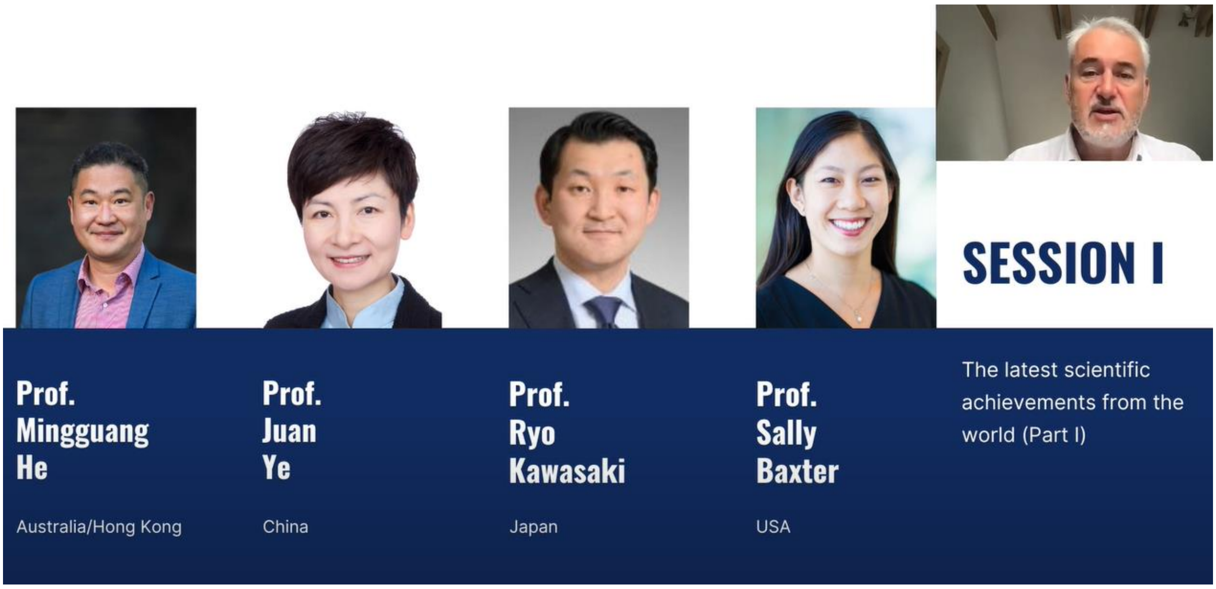
Conclusion: The exploration of retinal vascular signs or retinal images themselves offers an exciting avenue in cardiovascular risk assessment and modification. The non-invasive assessment using retinal images could uniquely serve as a biomarker, reflecting the risk profile, and paving the way for more personalized and targeted preventive measures. The synergistic approach of traditional CVD risk factors and retinal imaging, coupled with deep learning models, provides a robust tool for understanding and managing cardiovascular risks. The potential of retinal signs as a window to perceive CVD risks highlights the significance of integrating modern technology with clinical expertise, creating an agile, precise, and practical healthcare solution.

Prof. Sally Baxter, MD, MSc, University of California San Diego

Current initiatives and efforts in AI education in ophthalmology

The rapid advancement of AI in medicine has led to increased opportunities for training and education. Clinicians in eye care and researchers in visual sciences must understand the development and deployment of AI models, along with their benefits and limitations. Ethical considerations are crucial due to data misuse and unintended consequences seen in other industries. Educational opportunities in AI are expanding, particularly in ophthalmology. Ophthalmology residents in the US and Europe have traditionally used the American Academy of Ophthalmology (AAO) Basic and Clinical Science Course (BCSC) for education. The AAO is now incorporating AI-related chapters into the BCSC curriculum, covering AI principles and its impact on ophthalmology. Specialized fellowship training and degree programs in AI, supported by organizations like the US National Library of Medicine (NLM), offer in-depth expertise in AI, including clinical deployment and decision support. For established ophthalmologists and vision scientists, short-term educational opportunities are available. The American Medical Informatics Association offers "10x10" courses on AI integration into clinical workflows. Additionally, conferences like the AAO and ARVO have courses and symposia on AI, discussing cutting-edge research. The AAO has collaborated with the

American College of Radiology to develop ophthalmology-specific AI modules on the AI-LAB platform, which allows users to engage in medical imaging use cases. In conclusion, there is a growing array of AI educational opportunities across different career stages.



Prof. Andrzej Grzybowski, MD, PhD, University of Warmia and Mazury in Olsztyn; Institute for Research in Ophthalmology, Poznań

Fundus-based AI algorithms for ophthalmic and non-ophthalmic applications

The lecture presented a thorough examination of the latest advancements in the application of artificial intelligence (AI) to ophthalmic fundus images. It reviewed spotlighted the utilization of diverse AI algorithms for a range of tasks, including their application in both ophthalmic and non-ophthalmic disorders. The integration of AI algorithms for the interpretation of retinal images offers an inventive solution, exhibiting notably higher accuracy in the detection of ophthalmic and non-ophthalmic disorders in comparison to clinical experts. In recent times, the surge in medical data has paved the way for the integration of AI and deep learning, enabling immediate analysis. This convergence holds the potential to revolutionize healthcare by enhancing precision, speed, and workflow efficiency, while simultaneously reducing costs and expanding accessibility. Moreover, it holds promise in minimizing errors and transforming the landscape of healthcare worker education and training.

Khalid Saeed, DSc, PhD, Bialystok University of Technology, Universidad dela Costa, Barranquilla

Iris and retina biometrics, impact of eye diseases on human recognition by biometric methods. Ophthalmologist-Informatics relationship and AI in various ophthalmic aspects

Traditional means of automatic authentication are either of possession-based type using something we have (credit card, smart card, passport, ID card, etc.) or of knowledge-based type and use something we know (password, PIN). However, there is another way of user authentication, not traditional, but becoming more and more popular. It is a Biometrics-based type (biometrics identifier) and uses something relying on what we are. Actually, it is the drawbacks of the traditional authentication methods that had given birth to *BIOMETRICS*.
Biometrics Categories:

1. Physiological (*Cognitive Biometrics*)

Physiological biometrics traits measure the distinct traits that people have, usually (but not always or entirely) dictated by their genetics. They are based on measurements and data derived from direct measurement of a definite part of the human body. Fingerprints, Iris (the coloured part of the eye), face, odor, retina, ear, vascular pattern, lips, hand geometry, and DNA are all examples of the physiological biometrics category.

2. Behavioral (*Behaviometrics*)

Behavioral biometrics traits measure the distinct actions of the people and are generally very hard to copy from one person to another. They measure the characteristics of the human body indirectly. Examples of such traits are speech and speaker recognition, signature and hand writing, keystroke dynamics, mouse dynamics, gait (the way of our walking), and many other traits. Some behavioural traits may even not come to mind, like eye blinking or finger movement.

Iris Biometrics - human recognition by iris information code

Iris is one of the most popular and used in practice biometrics features. The highly used algorithms are those belonging to Daugman, Wildes and Ma. Within my biometrics team, we also have our achievements using our own methodologies for iris image processing. As an example, the reader can refer to the publication: *"Iris segmentation using harmony search algorithm and fast circle fitting with blob detection." K. Malinowski and K. Saeed, Elsevier 2022.*

The iris recognition algorithms are, however, affected by the eye diseases as they cover or occlude and hence cause to lose part of the necessary information causing the identifying methods not to work effectively or at least with high accuracy.

Methodology: Biometrics uses distinctive and measurable characteristics of the image collected from the human retina or iris and then transform the information into a code that is understandable by the recognition system. In all my studies and research direction, the main goal has been to find and deal with a simple, easily implemented way for biometrics image description. This is an important and basic stage within biometrics image processing. In the image classification stage for biometrics object recognition, artificial intelligence methods have been employed and are continuously improved and developed.

One of our artificial intelligent-based algorithms idea used by me and my team to obtain measurable features and prepare the medical image for a better digital description and classification is the principle of transforming noise into a group of points with a definite arrangement (*Saeed K. Applied Numerical Mathematic 2014*) or the earlier Neural Network based algorithms described in the publication (*Saeed et al.* IEEE Transactions on Industrial Electronics 2007).

Hence, with the aid of AI method (Machine Learning type), we can extend the iris and retina processing algorithms to apply on big data collected from varieties of human eyes to examine for the aim of human recognition. However, there still are problems with obtaining such data, namely, the human recognition by retina is impractical for two main reasons: discomfort and small data for comparison and classification. The discomfort comes from the fact that we feel as if we were at the ophthalmologists, where they use stationary devices. Also, it is NOT EASY to collect huge data under such conditions. This is why human recognition by retina is limited to some special cases (*RETINA ROOM IN AIRPORTS is an example*). From the other side, and what indeed is promising, the technology level is allowing for more and more comfortable checking and data collection devices. The available big data would allow for advanced AI-based approches to apply and give an accurate and fast decision. This is what nowadays is the case - retina image can be collected by a portable *fundus camera*. What is more! Mobile phone can be used for data collection and transmitting to the ophthalmologist for healthy retina checking or to the appropriate authorities for other applications.

Prof. Andrzej Jankowski, PhD; University of Warmia and Mazury in Olsztyn

Predicting Children's Myopia Risk: A Monte Carlo Approach to Evaluating the Trustworthiness of Machine Learning Models

Addressing the global rise in children's myopia, this study introduces a novel approach for predicting myopia risk through trustworthy machine learning models developed by the Myopia Risk Calculator Consortium (MRC). Utilizing data from 3989 children [1], we focused on the trustworthiness of machine learning models, specifically their effectiveness and robustness. MRC employed a machine model development and assessment methodology, adjusting it to project needs using Monte Carlo and cross-validation [2,3]. The combination of classifiers and regression models yielded promising results for myopia risk prediction. Future research will explore incorporating image and synthetic data to enhance predictive accuracy through transfer-learning techniques.

The co-authors of the study include prof. Andrzej Grzybowski, Foundation for Ophthalmology Development & University of Warmia and Mazury), Poland; Prof. Mohammad Hassan Emamian, Ophthalmic Epidemiology Research Center, Shahroud University of Medical Sciences, Shahroud, Iran; Prof. Olavi Pärssinen, Gerontology Research Centre and Faculty of Sport and Health Sciences, University of Jyväskylä, Finland; Prof. Carla Lanca Lisbon School of Health Technology, Portugal; Dr. Shiva Mehravaran Morgan State University, USA; Klaus Nordhausen, Gerontology Research Centre and Faculty of Sport and Health Sciences, University of Jyväskylä, Finland; Prof. Piotr Artiemjew, UWM, and Krzysztof Ropiak, UWM; Radosław Cybulski, UWM; Cezary Morawski, UWM; Andrzej Jankowski, UWM; Mateusz Śliwiński, UWM; Andrzej Strzeszewski, UWM; Adam Jankowiak, UWM; Michał Domian, UWM; Paweł Budziński, UWM; Bartosz Ćwiek, UWM; Jakub Przyborowski, UWM, and Jakub Kasjaniuk, UWM.

References

1. Emamian MH, Hashemi H, Khabazkhoob M, Malihi S, Fotouhi A. Cohort Profile: Shahroud Schoolchildren Eye Cohort Study (SSCECS). Int J Epidemiol. 2019;48(1):27-27f. doi: 10.1093/ije/dyy250.
2. Robert, C. P., & Casella, G. (2013). Monte Carlo Statistical Methods. Springer.
3. Kohavi, R. (1995). A Study of Cross-Validation and Bootstrap for Accuracy Estimation and Model Selection. In IJCAI (Vol. 14, No. 2, pp. 1137-1145).

Dr. Agnieszka Zbrzezny, PhD, University of Warmia and Mazury in Olsztyn; Institute for Research in Ophthalmology, Poznań

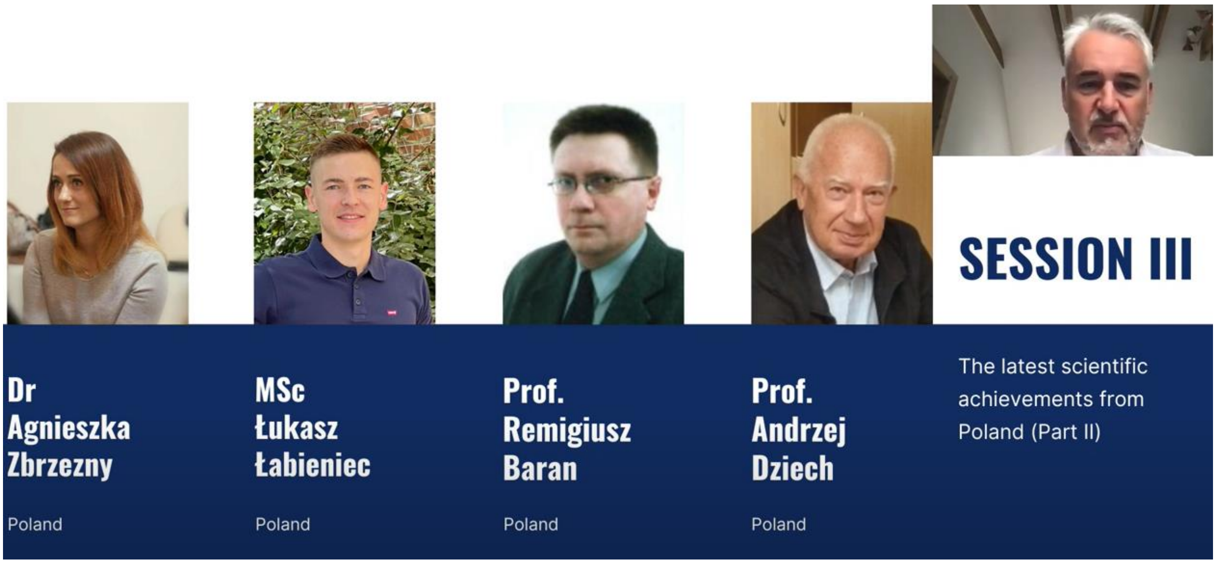
Deceptive tricks in artificial intelligence: adversarial attacks in ophthalmology

The artificial intelligence (AI) systems used for diagnosing ophthalmic diseases have significantly progressed in recent years. The diagnosis of difficult eye conditions, such as cataracts, diabetic retinopathy, age-related macular degeneration, glaucoma, and retinopathy of prematurity, has become significantly less complicated because of the development of AI algorithms, which are currently on par with ophthalmologists in terms of their level of effectiveness. However, in the context of building AI systems for medical applications such as identifying eye diseases, addressing the challenges of safety and trustworthiness is paramount, including the emerging threat of adversarial attacks. Research has increasingly focused on understanding and mitigating these attacks, with numerous articles discussing this topic in recent years. We provide examples of unique attack strategies for medical images. Unfortunately, unique algorithms for attacks on the various ophthalmic image types have yet to be developed. It is a task that needs to be performed. As a result, it is necessary to build algorithms that validate the computation and explain the findings of artificial intelligence models. We focus on adversarial attacks, one of the most well-known attack methods, which provide evidence (i.e., adversarial examples) of the lack of resilience of decision models that do not include provable guarantees. Adversarial attacks have the potential to provide inaccurate findings in deep learning systems and can have catastrophic effects in the healthcare industry, such as healthcare financing fraud and wrong diagnosis.

Łukasz Łabieniec, MSc, University of Bialystok

Can artificial intelligence assess neuropathy based on magnetic resonance images?

Diffusion-weighted MRI imaging of the human optic nerve and optic tract is technically challenging due to the small size of this structure, the inherent strong signal generated by the surrounding fat and CSF, and due to motion artifacts and signal distortion due to eddy currents and magnetic susceptibility. For economic reasons, the technical capabilities of scanners are often limited, and the acquisition time is minimized, which results in low quality diffusion-weighted images. The challenge for current tractography methods is both the assessment of continuity and the exact tracking of the direction of the optic fibers so that they correspond to the known anatomy. Despite technical limitations and low image resolution, a new procedure for visualizing human visual pathways using diffusion tensor mapping was presented and a quantitative measurement of optic nerve atrophy based on the analysis of these data was proposed. This approach can be considered complementary to the standard diffusion-weighted magnetic resonance imaging method.



Prof. Remigiusz Baran, DSc, The University of Computer Engineering and Telecommunications in Kielce and Prof. Andrzej Dziech, PhD, AGH University of Krakow

The system for automatic diagnosis of diseases based on the analysis of fundus images made in optical coherence tomography OCT, based on Artificial Intelligence

Presentation concerned the current results of the INDOK R&D project with the same title. The results presented during it included, among others: data relating to the accuracy of different types of lesion detectors developed within the project, performing the above-mentioned detection in the so-called OCT B-scans based on artificial intelligence algorithms (mainly neural networks). Among them, the highest accuracy (accuracy of at least 95%) has binary detectors of such changes as: sensory retinal detachment, retinal edema, cysts, vitreomacular traction. The HS-vs-Rest algorithm was also presented, distinguishing (with an accuracy exceeding 95%) "healthy" scans - without lesions from "sick" scans - containing such lesions. These and other algorithms, including the full-thickness macular hole classifier (accuracy 99%), became the basis for the organization of an expert system capable of automatically diagnosing diseases. This system, depending on the underlying architecture (fuzzy systems and/or decision trees), is able to diagnose with high accuracy, e.g. exudative (96%) and non-exudative (93.4%) macular degeneration (AMD), central serous chorioretinopathy (93.9%), and diabetic retinopathy (92.9%).

Prof. J. Peter Campbell, MD, MPH, Oregon Health & Science University

Applications of AI in retinopathy of prematurity

Retinopathy of prematurity (ROP) is a leading cause of childhood blindness worldwide, despite the fact that treatment is available, and blindness can be prevented in most cases. Primary prevention is effective by reducing the risk factors that cause ROP, such as improving oxygen monitoring. Secondary prevention is effective by developing systems of care to ensure all at risk babies receive eye examination. Tertiary prevention ensures that timely and accurate diagnosis of treatment-requiring ROP leads to effective treatment and identification of disease resolution. Multiple potential indications for use (IFUs) have been proposed for ROP AI algorithms that could impact all three levels of ROP prevention. Previous work has demonstrated that AI-based assessment of ROP severity can identify differences in ROP epidemiology between hospitals. Quantitative assessment of ROP through the development of a vascular severity score may have applications not only for ROP screening, but also quantitative diagnosis, monitoring, risk prediction, and identification of disease reactivation following treatment. In this session, I review the multiple potential IFUs including some of the translational challenges in implementation.

References:

1. Sabri K et al. Retinopathy of Prematurity: A Global Perspective and Recent Developments. Pediatrics 2022;150.
2. Ting DSW et al. Artificial intelligence and deep learning in ophthalmology. Br J Ophthalmol 2018:bjophthalmol–2018–313173.
3. Campbell JP et al. Applications of Artificial Intelligence for Retinopathy of Prematurity Screening. Pediatrics 2021.
4. Coyner AS et al. External Validation of a Retinopathy of Prematurity Screening Model Using Artificial Intelligence in 3 Low- and Middle-Income Populations. JAMA Ophthalmol 2022;140:791–798.
5. deCampos-Stairiker MA et al. Epidemiologic evaluation of retinopathy of prematurity severity in a large telemedicine program in India using artificial intelligence. Ophthalmology 2023.

The Congress gathered 370 participants from 55 countries around the world: Poland (155), China (36), USA (15), Germany (12), United Kingdom (12), India (11), Ukraine (10), Italy (6), Argentina (5), Pakistan (5), Hong Kong (4), Japan (4), Venezuela (4), Saudi Arabia, Czech Republic, Spain, Peru, Romania, Australia, Austria, Bangladesh, Belgium, Finland, France, Greece, Iran, Israel, Mexico, Moldova, Nepal, Portugal, Switzerland, Turkey, Bolivia, Chile, Egypt, Irland, Indonesia, Latvia, Nigeria, South Africa, Uganda, Taiwan, The Netherlands, Ecuador, Kenya, Philippines, South Korea, Slovakia, Thailand, Canada, Sweden, Central African Republic, Singapore, and Kuwait.

The report was developed as part of the project ***"Artificial intelligence in ophthalmology" - scientific conference*** co-financed by the Ministry of Education and Science as part of the "Perfect Science" ("Doskonała Nauka") Programme.