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Review Article

Artificial intelligence in cataract: What's new?

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ABSTRACT

Artificial intelligence (AI) is a technological advancement that provides thinking and processing capacity to machines. It is a complex technology with multiple algorithms and formulas. AI has transformed the face of several industries, including the healthcare sector. Ophthalmology being a highly technology-driven branch of healthcare can benefit vastly from the application of AI. Newer technologies are cropping up with each passing day to enhance our diagnostic and management modalities. From huge machines, now, AI has even come down to applications on the small screen of smartphones. Through this study, we summarise the various AI-driven developments in the world of cataract that have occurred in the past 3 years. Ranging from cataract detection, cataract grading, IOL power calculation, to acting as an aid in the surgical arena, this study intends to cover all recent AI-based innovations and advancements.

Keywords: Artificial intelligence, Cataract, Machine learning, Deep learning

INTRODUCTION

As the realms of technology, computerised algorithms, and big data are expanding with time, artificial intelligence (AI) promises to revolutionise the world as we know it. In simple terms, AI aims to impart intelligence to machines, to create 'thinking machines.' Machine learning (ML) is a component of AI that entails the conversion of rough input into useful output material by means of engineering.[1] ML could be supervised or unsupervised, depending on whether the AI is learning from the 'ground truth' having labelled output. A much advanced subclass of ML is deep learning (DL), which obviates the need for human engineering to make predictions/decisions by forming artificial neural networks. Several industries have begun the utilisation of AI services and the healthcare sector has not been far behind.[2-4] Ophthalmology is a speciality that has enormously benefitted from upcoming imaging and technological advances; thus, AI holds a special potential to transform this field. In the near future, AI is expected to cater to a variety of ophthalmological conditions including cataract which is the foremost cause of blindness worldwide, estimated to affect 40 million people by the year 2025.[5] In addition, a prevalence of 0.32–22.9/10,000 children has been noted for paediatric cataracts.[6] In recent times, the use of AI has been described in cataract detection,[7-15] cataract grading,[5] intraocular lens (IOL)-related calculations[16-23], and even as an aid in cataract surgery.[24-27] The developing countries, where healthcare distribution is not equitable, can greatly benefit from such wide-ranging applications of AI. Even simple AI-based smartphone applications can be of great assistance to primary healthcare givers in rural areas, where resources are scarce. Early diagnosis and timely referrals can reduce future disease morbidity. Further, AI-based surgical assistance or training can prove to be an advantageous tool for the skill development of novice surgeons in remote healthcare centres. COVID-19 pandemic has brought forth an era, where telemedicine practice and AI-based applications are key players in patient management. With frequent travel restrictions and new emerging COVID variants, the healthcare divide between the urban and the rural areas has further widened. In these times, AI through its multiple applications can bridge this divide for patients as well as healthcare givers.

In the present study, we aim to enrich the readers regarding cataract-related AI developments, focussing on recent advances in the past 3 years.

METHODS

For the preparation of the present study on recent AI developments in cataract, we performed an internet search

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of literature databases, including PubMed, Cochrane library, and Google Scholar. Boolean operators 'AND' and 'OR' were used to conduct the search using keywords such as 'artificial intelligence,' 'cataract,' 'machine learning,' 'deep learning' and 'AI,' and literature published in the past 3 years (January 2019–January 2022) was identified. Ninety-six research items in total were identified, out of which only English articles with available full text were selected. Further, relevant articles were added through a manual search on the internet and using a bibliography of already selected articles. Articles were screened thoroughly and studies addressing recent utilisation of AI in cataract in the past 3 years were selected. A total of 34 articles were included to compose this study ([Figure 1] illustrates the article compilation process).

CATARACT DETECTION AND GRADING

Cataract contributes to the major burden of blindness across the globe and delayed detection/presentation is common, especially in the developing world. When we consider the fact that clinical diagnosis and cataract grading require a qualified ophthalmologist and slit-lamp examination, the developing countries and rural communities find themselves lacking in both these aspects. Thus, there is a pressing need to address these shortcomings to reduce morbidity and the burden of blindness. Wu *et al*.[28] established a universal AI model for cataract detection using slit-lamp images, involving multilevel clinical situations and an AI-based referral system to provide a comprehensive management scheme. Their system consists of a methodical three-step algorithm based on deep learning through a residual neural network (ResNet). The first step involves the distinction of slit-lamp images with dilated pupils from those with undilated pupils and of diffuse illumination from slit sections (capture mode recognition stage). In the second step (cataract detection stage), the AI system classifies images as a normal non-cataractous lens, cataractous change, or as post-surgical IOL. The third step includes grading of cataract and management plan to either continue routine follow-up or refer to a higher care centre. This study noted an area under the curve (AUC) exceeding 99% in the first two steps while the third step detected cataracts needing tertiary centre referral with AUC of more than 91%. Paediatric disease involving the visual axis achieved an AUC of 100% for the referral step. The authors noted that in the real-world scenario, this system could increase the provision of services of an ophthalmologist to the population by 10 times. This AI system was further utilised as a pilot project in China, where individuals self-reported complaints of decreased vision on a smartphone application.[7] Such individuals were then asked to report at a primary healthcare centre, where slit-lamp photographs were captured by trained technicians or nurses. The AI processed these images and further decided the necessity to refer to an expert ophthalmologist. This study achieved a specificity of 92% and sensitivity of >83% in the detection of cataract, thus, providing a promising future application of this algorithm, which could potentially shift the primary point of care to community health centres from an ophthalmologist. This would reduce an ophthalmologist's work burden and also make sure that cases needing referral reach the ophthalmologist faster.

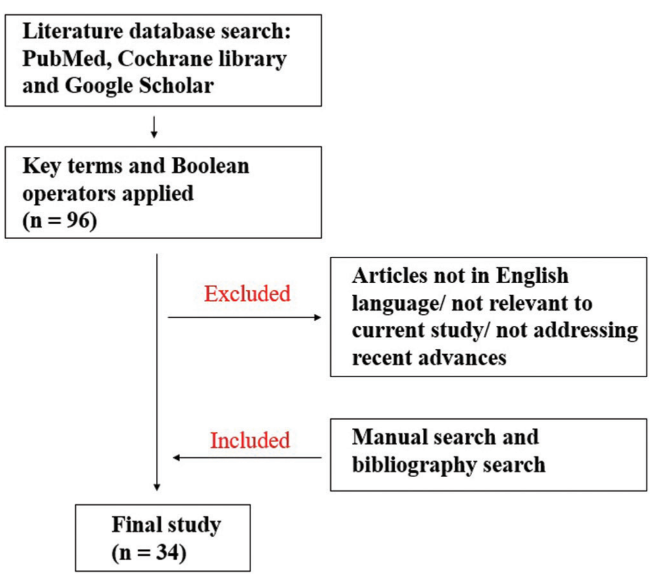

Figure 1: Article inclusion process employed in the study.

Visualisation of the fundus depends on the density of cataract [Figure 2]. Cataract detection from fundus photographs using AI has been described by Pratap and Kokil in their studies, by applying convoluted neural networks (CNNs).[9,29] The CNN is a deep learning programme that was trained beforehand on millions of photographs and refined using 400 retinal photographs. Their AI system, using support vector machine (SVM) and CNN programmes, could categorise images into no cataract, mild cataract, moderate cataract, and severe cataract.[29] The categorisation was based on clarity of fundus photographs and achieved 100% results for cataract detection and >92% accuracy for severity categorisation.[29] Another study of theirs addressed the problem of noisy fundus images interfering with AI-aided cataract diagnosis.[9] They utilised computer-aided cataract diagnosis (CACD) with

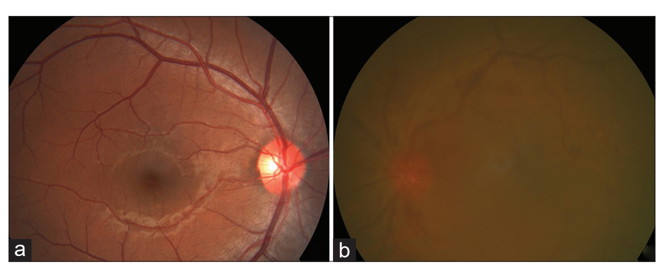

Figure 2: (a) Fundus image of a patient with early cataract and (b) fundus image of a patient with dense cataract.

the addition of artificial noise (Gaussian noise) in their AI system. Their CNN algorithm then extracted characteristics from the fundus photographs to detect cataract under various noise levels. The researchers demonstrated higher efficiency of their CNN-based CACD in cataract recognition under noisy environments when compared to presently available AI systems. While newer technologies are cropping up for cataract detection, researchers also trying to better the prevailing grading systems. Xu *et al.*[5] have developed a hybrid CNN model incorporating global as well as local neural networks to improve the existing AI-based cataract grading systems. This research combined CNN with a deconvolution system to perform a layered study of cataract characterisation. The research was conducted on 3000 fundus images and involved four stages. Pre-processing (Stage 1) was followed by a second stage, which included extracting features from fundus photographs using deep CNN. The third stage involved identifying the required features and the final stage included a combination of global and local features. At the end of the study, the authors were able to achieve a useful understanding of the hybrid system, which can potentially improve grading systems in the future.

Askarian *et al.*[11] proposed a novel smartphone-based cataract detection system. This AI application uses the phone camera to capture photographs of the eye and then crops out the lens. The AI system removes the surrounding noise and extracts the characteristics of the lens image, using 'pixel brightness algorithm.' At the next step, SVM is utilised to diagnose and classify cataract. The authors concluded that their system was 96% accurate and 93% specific in detecting cataract. This system carries an additional advantage of adjusting for different types of sensors in smartphone cameras, as well as camera angles and shooting distances, thus, making it independent of technical variations in capturing images with different cameras. Hu *et al.*[13] proposed a DL-based AI system that could grade cataract in real time from videos. Incorrect diagnosis is a potential limitation of automatic cataract grading from a single slit lamp or fundus image. To overcome this drawback, the authors put forward a method that uses iSpector Mini system, a smartphone slit lamp to capture videos of the patient's eye. You only look once (YOLO) algorithm was used for proper positioning to identify the crystalline lens. Colour space inversion was subsequently performed to grade the cataract. The authors attained an accuracy of 94% and an AUC of 98.8% in this study. High efficacy and rapid cataract detection were seen, with the detection per frame accomplished in just 29 microseconds. Cataract diagnosis using smartphones can prove to be an easy and cheap method compared to expensive imaging devices. Such modalities will find particular use in rural and poor regions for rapid detection and referral of patients with cataract.

AI-based cataract detection has also been elucidated for paediatric cataracts in a few recent studies. A cloud-based system, known as 'CC-Cruiser,' has been utilised to diagnose and grade paediatric cataracts.[30] After processing slit-lamp images, the system uses three different CNNs for three different components: Cataract detection, cataract grading, and advising treatment. Although studies have demonstrated lower performance of this system than trained ophthalmologists in cataract diagnosis and advising further management, the overall patient satisfaction has been adequate with regard to rapid screening of congenital cataract. Lin *et al.*[14] developed an ML-based screening model for congenital cataracts utilising the 'random forest (RF)' and 'adaptive boosting' technologies. This model was constructed using 11 different factors, including medical, family, and environmental influences. The authors demonstrated an AUC of 82% for unilateral disease and 91% for bilateral disease. This AI system could distinguish cataract cases from healthy children with good accuracy. Long *et al.*[31] designed an AI system termed 'CC-Guardian' that can personalise prediction of congenital cataract and also advise follow-up based on telemedicine system. This AI technology created using DL and Bayesian algorithms has shown good sensitivity and specificity in validation tests. The CC-Guardian system can be accessed through a smartphone and can be integrated with cloud technology. AI systems have shown great promise in detecting adult as well as paediatric cataracts. A great social and economic burden on society can be alleviated by detection and management of paediatric cataracts in the crucial vision development age group.

AI IN IOL-RELATED TECHNOLOGIES

Pre-surgical estimation of the IOL power to be used is a key determinant of post-surgical outcome in cataract surgery. Over decades, newer formulas and technologies have emerged to refine this IOL power prediction process. Newer variables such as anterior chamber depth, corneal shape, and lens thickness are now considered in IOL power calculations. In the recent past, AI has taken over this burden of devising even more accurate formulas for predicting the most suitable IOL power for a patient. Clarke and Kapelner[14] introduced an advanced AI-based model for IOL power calculations. Their system collected data from 5331 eyes of 3276 individuals and consisted of four broad steps. The first step included a collection of a large dataset over a 3-year time period, including diverse IOLs. In the second step, an ML-based algorithm termed 'BART' that is, Bayesian Additive Regression Trees was utilised. BART consists of several decision trees that have high predictability and accuracy. Third, effective lens position (ELP) was predicted from pre-existing formulas and conversion of ELP to IOL power was performed. The last step included noting the difference between the calculated IOL power and an axial lengthadjusted IOL power (calculated using SRK/T formula) using the BART system, to further improve accuracy. This system was compared to five pre-existing formulas: Radial basis function 1.0, SRK/T, Hoffer-Q, Holladay I, and Haigis. The authors concluded that their formula was 3 times more accurate than the existing described studies and carried an overall median error of only 0.204 dioptres. A recent study compared multiple IOL calculating formulas using swept source optical coherence tomography (SS-OCT) in terms of calculated and actual post-operative refractive results.[18] The authors utilised SS-OCT through the 'ANTERION Cataract App' to determine pre-operative biometry measurements, including detailed corneal parameters, depth of aqueous chamber, the thickness of the lens, and axial length. This SS-OCT-based application was used to determine IOL powers using eight different formulas that included vergence formulas, AI-based formulas, and combined formulas. SS-OCT has the advantage of measuring the total power of the cornea by taking into account the central 3 mm of both the front and back of the cornea. Accurate prediction of ELP is another plus point of the SS-OCT system. This study concluded that SS-OCT-based IOL power calculation using the Haigis formula was the most precise among all the different formulas. Langenbucher *et al.*[19] used supervised ML process to predict the axial location of IOL and depth of anterior chamber after cataract surgery, based on pre-operative calculations performed using IOLMaster 700 and Casia 2 OCT. They applied a total of 17 different ML algorithms for the same, after taking a variety of pre-operative measurements. The authors noted that for the prediction of the above two parameters, the Gaussian Process Regression Model performed the best out of the 17 algorithms. However, the study concluded that the utility of supervised ML was very limited in everyday scenario as compared to the standard regression formulas. Liu *et al.*[20] employed ML algorithms for predicting the depth of focus post-cataract surgery in patients receiving Tecnis Symfony IOL. The authors enrolled 182 eyes and employed four AI prediction methodologies, namely multivariable logistic regression, Extreme Gradient Boost, LASSO penalised regression, and RF. Depth of focus is the range of IOL power where an acuity of 20/32 or better can be maintained. It is a vital parameter in lens design and a value equal to or better than 2.5 dioptres is defined as a good depth of focus. The authors achieved a precision of >70% using this ML system. Factors associated with a good depth of focus post-surgery were as follows: Lower depth of anterior chamber, small pupil, the axial length between 21 and 23 mm, low astigmatism, intraocular pressure below 12 mmHg, and targeted refractive error between −0.25 and −0.5 dioptres. Nemeth *et al.*[21] compared three AI-based formulas (Hill RBF 2.0, Kane formula, and Pearl-DGS method) to a vergence-based Barrett Universal II formula for IOL power calculations. Data from 114 eyes were used for calculating the differences between post-surgical manifest and objective refractions with the predicted values of refraction. This study found that the Hill RBF 2.0 formula had a superior accuracy in the prediction error range of ±0.5 dioptres to ±1 dioptres as compared to the Barrett formula. The other two formulas were found to have a comparable precision with the Barrett formula. A novel study proposed tailoring the design of the IOL haptic to the patient's individual characteristics in cataract surgery.[22] This study used two deep neural network-based prediction systems for the same. The first AI system predicted the mechanical stability of IOLs with C-loop while the second AI system was used to envisage a haptic design that could fit any chosen biomechanical response. A standard test for gauging mechanical characteristics of IOLs was used in the study (ISO 11979-3 compression test). The study noted that various IOL designs could elicit similar biomechanical responses and the AI system had a high accuracy in determining the biomechanical properties of IOLs. This study provides a futuristic insight, where IOL manufacturers and operating surgeons can customise and hand-pick IOLs based on individual patients' characteristics. Carmona González and Palomino Bautista[23] have recently devised a new AI-based IOL formula that uses a variety of ML algorithms. This new formula collects parameter predictions from several formulas and combines them into one. In addition, it considers white-to-white distance, central lens thickness, and the ratio of front: back corneal surfaces. When compared to regression formulas, vergence formulas, and existing AI-based formulas, this new model was found to have the most precise IOL power prediction, with the lowest prediction error. AI has made significant strides in attempting to create precise most formulas with the least errors. We are not far from the day when the surgeon will be able to choose individualised IOLs for patients as per their distinct characteristics and parameters.

AI IN ELECTRONIC MEDICAL RECORD (EMR) SYSTEMS

The focus of medical records maintenance has shifted from papers to computers and many health facilities are now adopting an electronic system of medical records maintenance. Ophthalmological EMR is particularly complex as it contains several fields such as typed words, clinical drawings, imaging data, and prescriptions to name a few [Figure 3]. With a continuous collection of data, manual processing of such a huge amount of collected data becomes a herculean task. AI can process complex data in a short time and lead the way towards better detection of disease as well as predicting risks or prognosis, thus improving overall patient care. Lin *et al.*[32] reviewed studies that had used three types of AI techniques to process EMR data to create organised data for analysis. The research work included 11 studies with ML use, three studies with DL use, and two studies that had used

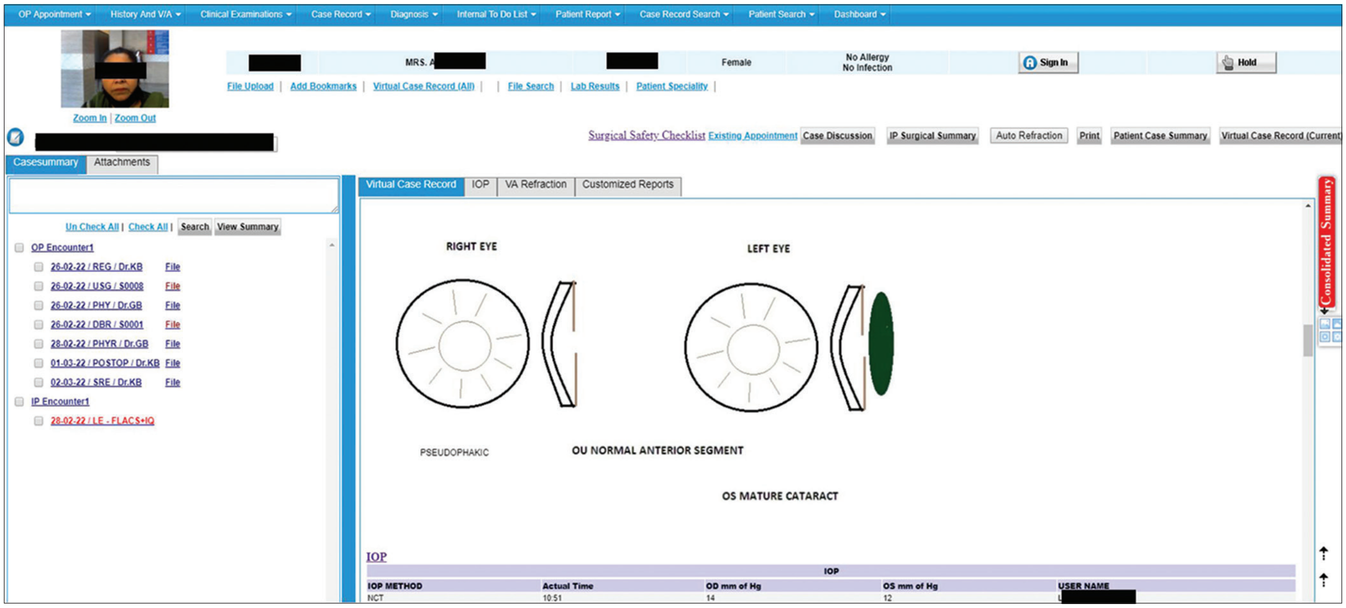

Figure 3: Electronic medical record system of the authors' institute showing diagrams, text and computerised entries.

natural language processing (NLP). NLP has the ability to convert text-based data into an appropriate format that can be utilised by ML algorithms. For EMR processing of cataract patients, the authors noted that AI could identify cataract patients based on arranged data, free text notes and scanned images from complex EMR information. ML algorithms could predict post-surgical and intraoperative complications based on recognition of risk factors, with moderate accuracy (AUC being only 65%). Alalawi *et al*.[8] attempted to distinguish sociodemographic factors and the influence of climate in relation to ophthalmic diseases in South India. Data of nearly 0.9 million patients over 8 years were retrieved from the EMR system of a specialised ophthalmology hospital network. These data were clubbed with climatic influences to study the association between climate changes and ophthalmic disorders. The authors used 'Cynefin framework' system, which steers experts toward choosing a suitable path on the basis of 'emerging patterns.' The authors concluded that cataract had a high prevalence in all climate seasons and it was higher in the rural regions of Telangana state. The older age group was most affected by cataract and areas receiving more rainfall had a higher prevalence of cataract. Application of AI in EMR system can help gain an understanding of the intricacies of association between the environment and disease causation. This can further prepare us to devise suitable awareness and preventive strategies.

AI IN SURGICAL TRAINING AND AS A SURGICAL AID

Among the various utilities of AI, an important one for surgeons, trainees and students is its application as a teaching tool or as a useful aide in the operating room. Wu *et al*.[24] explored the use of AI as a pedagogy tool in ophthalmology clerkship. They divided 38 clerkship students into two groups: One group was taught about the diagnosis and management of congenital cataracts through problem-based learning by the use of the CC-Cruiser platform while the other group learnt the same through lectures delivered by the same teachers. CC-Cruiser can detect and categorise congenital cataracts from slit-lamp images, and can advise further management. Each group had to attempt a test before and after the lectures. The improvement in scores of the after lecture test compared to the before lecture test was significant in both groups but the overall scores in the second test were higher in the group that had received AI-mediated teaching. The study concluded that while AI is not an immediate substitute for experienced teachers, it can certainly improve the performance and satisfaction of students. Lanza *et al*.[25] developed an AI system to assess ocular as well systemic influences that could lead to complications in cataract surgery. This retrospective study collected extensive data pertaining to ocular and systemic factors in 1229 patients. AI-mediated processing was performed encompassing a total of 1.25 billion simulations and recording 73 complications in the study. The results of this study indicated that complications in cataract surgery were most commonly associated with three factors: The surgeon, axial length of the operative eye, and the IOL power used. The algorithm was also capable of predicting the time of surgery on the basis of analysed parameters. This AI model could be used to design customised models for different ophthalmic surgical facilities to minimise complications and predict the surgical time for better time management. Yoo *et al*.[26] and his team designed smart speakers that utilise DL to confirm the site before the start of cataract surgery. The authors trained a deep CNN system in certain keywords such as 'right,' 'left,' 'cataract' and 'intraocular lens' to confirm the correct site and surgical details during a surgical time out. Review and confirmation of patient details may not be possible due to lack of appropriate surgical time out or inability of the surgeon to manually do it himself, due to sterility of his hands after surgical scrubbing. Keeping in mind such situations, the smart speakers can act as surgical assistants having a hands-free interaction with the surgeon. To train the system, target words with different accents, tones, and speeds were used through a text-to-speech tool. This DL system attained an accuracy exceeding 93%, tested for 200 time-out speeches. Accuracy as regards the procedure and surgery was 100%. The authors concluded that smart speaker-based systems could add to the safety of the patients by preventing wrong site cataract surgery. This could also be a step forward toward the creation of smart operation rooms and future integration of speaker devices into the EMR system.

Another use of AI that has been demonstrated in relation to cataract surgery is a method based on DL that enables the annotation of surgery videos.[27] The authors put forward a system to help in the annotation process by utilising a pre-recognition mechanism. The algorithm for helping in the annotation of surgical steps was based on CNNs. A 50-video dataset known as 'CATARACTS' was used in the study, which was 'down-sampled' to create a dataset of 100 thousand images. Non-professionals performed the annotation of cataract surgery phases and surgical steps in two groups: With and without the aid of AI. It was noted that the individuals using AI assistance for annotation were 10 min quicker than the other group. It was concluded that AI showed good accuracy and shorter duration in the annotation of surgery videos. Annotation is a cumbersome process that entails having in-depth knowledge of the procedure involved. If AI can be trained with DL for assisting in annotation, it will make even a complex annotation procedure simpler. Xia and Jia[33] proposed an AI-based system to recognise steps and phases from cataract surgery videos, to better the quality of surgery. This process termed 'workflow recognition' has the potential to create a computer-assisted surgical system in the future. The researchers in the mentioned study utilised 'contrastive learning' as a means to rectify 'spatial-temporal' inconsistencies in surgical videos. The AI system extracted spatial characteristics from the video and contrastive learning was used to discriminate surgical frames with identical features in various surgical steps from those which had significant differences in the same surgical steps. The AI system could successfully correct the unclear frames that occurred among steps of surgery due to incongruity in the spatial-temporal relationship. Workflow recognition can be of great utility to surgeons in training by aiding them in surgical procedures and preventing the risk of complications.

AI IN SPACE: TO INFINITY AND BEYOND

Since the 1st time, a man was able to venture into space, discovering and perhaps even visiting destinations beyond the Earth has been a dream for scientists. While the Moon has already been 'conquered,' efforts are underway to send human beings to Mars. Such an arduous journey through millions of kilometres will not come without substantial challenges. An important challenge will be the provision of adequate healthcare to space travellers. Deep space and zero gravity can affect the body in various capacities and returning to the Earth for seeking healthcare in the midst of space travel is not a viable option. Ionising radiations in space will be much more perilous beyond the safety of the earth and could lead to cataract development. AI is a feasible solution to such problems, with its ability to detect and provide management from a remote location. With ever-emerging recent advancements in AI, the day is not far away when surgery for cataract will be possible from distant locations. Even the untrained might be able to conduct the procedure with assistance from AI and the guidance of experts from far-off places.

CONCLUSION

This study has attempted to highlight the various applications of AI technology in the field of cataract in the past 3 years. As AI transforms the world around us, we as ophthalmologists must keep ourselves updated with the latest developments so as to improvise patient care, surgical techniques, patient satisfaction and ensure equitable distribution of ophthalmic care.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Conflicts of interest

There are no conflicts of interest.

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