



DEEP LEARNING-BASED DETERMINATION OF INTRAOCULAR LENS POSITION IN CATARACT SURGERY PATIENTS

Zafar Iqbal^{1*}, Sidra Zafar Iqbal²

¹*FRCS, Consultant Ophthalmologist, Dr. Ziauddin Hospital / Ex-Head of Department, Prince Abdulaziz Bin Mosaad Hospital, Arar, KSA

²MD, Johns Hopkins Hospital, Baltimore, USA

***Corresponding Author:** Zafar Iqbal,

*FRCS, Consultant Ophthalmologist, Dr. Ziauddin Hospital / Ex-Head of Department, Prince Abdulaziz Bin Mosaad Hospital, Arar, KSA

Email: Syedzafariqbal123@gmail.com

ABSTRACT

Background: Cataract surgery using intraocular lens (IOL) implantation is one of the most common ophthalmic surgeries studied, yet accurate evaluation of the location of the IOL after surgery is the most important to the optimal vision.

Purpose: To quantify the effectiveness of a deep learning-trained model to predict the intraocular lens position of patients who have undergone cataract surgery and the effect it has on the post-surgical visual outcomes.

Methods: This analytical observation study was conducted at Prince Abdul-Aziz Bin Mosaad Hospital Arar, KSA during the period of September, 2025 to February, 2025 and with a sample size of 300 cataract surgery patients. Based on the preoperative biometric information, intraoperative surgical videos, and postoperative imaging, a convolutional neural network (CNN) framework was constructed. Predicted IOL positions were compared with the real measurements obtained with the anterior segment OCT and statistical tests of accuracy, sensitivity and specificity were used. Pearson correlation was used.

Findings: The deep learning model performed well having an accuracy of 92.6, sensitivity of 90.8, and specificity of 94.2. The actual and predicted IOL positions had a close positive relationship ($r = 0.81$, $p < 0.001$). The model was also validated in terms of clinical reliability in the detection of IOL decentration and tilt.

Conclusion: Deep learning provides a viable and accurate approach to determine the position of intraocular lens, which can significantly enhance the accuracy and postoperative results of surgery in cataract patients.

Keywords: Deep Learning, Cataract Surgery, Intraocular Lens, Artificial Intelligence, IOL Position, Ophthalmology.

INTRODUCTION

Cataract has been a major cause of visual disability in the world and the gold standard in the restoration of vision has been through surgical intervention by implantation of intraocular lenses (IOL). Nonetheless, the postoperative complications like the IOL misalignment, decentration or

dislocation continue to pose a challenge to achieving the best visual results. Recent developments in artificial intelligence and especially deep learning have demonstrated that it can deal with these problems with a promising future of providing predictive and analytical solutions that are beyond the conventional clinical perspective of such issues (1). Cataract surgery demands a prepreparation and intraoperative decision-making, and the application of deep learning has significantly increased safety and accuracy. State of the art algorithms are now available that can process patient data and determine the possible risks in surgery and how to optimize surgical plans. These systems enhance the quality of clinical processes and minimize the human errors, which lead to better patient outcomes in ophthalmic processes (2).

The introduction of video analysis using deep learning has also changed cataract surgery even more, allowing automated interpretation of the surgical procedure and the events occurring during surgery. These systems allow comprehensive information on the performance of the surgical procedure, manipulation of instruments, and accuracy of the procedure, which are necessary to comprehend any factors that affect IOL positioning. Deep learning can help in training and real-time optimization of surgery by analyzing surgical videos (3). The effective lens position (ELP), which is the final position of the intraocular lens of the eye, is a critical determinant of the postoperative visual quality. The theoretical prediction of ELP has been enhanced with the use of machine learning to include multifaceted biometric parameters and model the lens behavior. The technology has the benefit of providing more precise IOL power predictions and positioning options, and eventually leads to improved refractive results (4). Deep learning has also extended its use in managing cataracts holistically by allowing accurate identification, classification, and forecasting of the disease progression. Such systems use big data to deliver predictive analytics that help clinicians develop personalized treatment plans. Deep learning is a revolutionary technology in ophthalmology because of its ability to combine both diagnostic and predictive capabilities (5).

Deep learning intraoperative tracking of surgical tools has also enhanced knowledge of surgical dynamics. PhacoTrainer and similar systems allow tracking tools during cataract surgery in detail, which allows evaluating surgical practice and its influence on the placement of IOL. The technology improves surgical training and outcome assessment (6). Proper rotation of toric intraocular lenses is a crucial step in correcting astigmatism, and visual computing approaches with deep learning have been created to automate the procedure. These systems enhance the accuracy of the IOL positioning by reducing the number of manual errors and giving feedback in real time, which in turn reduces the postoperative refractive errors and enhances the quality of visual performance (7). The creation of large-scale annotated datasets has greatly boosted the advancement in deep learning in the field of cataract surgery. Cataract-1k datasets comprise detailed video data that can be used to train and validate deep learning models. These data sets improve the predictive systems' generalizability and accuracy, especially in the prediction of surgical outcomes and IOL placement (8).

Machine learning has also been used to optimize IOL power calculation formulae, especially with regard to particular patient populations with unique biometric features. The models enhance the accuracy of refractive calculations and lessen postoperative errors by adjusting calculations according to an individual patient, which enhances the outcome of the surgical procedure (9). The diagnostic systems based on deep learning have proven to be very accurate in identifying visually important cataracts using retinal images. Such systems facilitate prompt diagnosis and intervention, which is crucial in preventing complications that could disrupt IOL placement and the overall success of the surgery (10). The usefulness of deep learning in identifying surgical activities and patterns of cataract surgery has also been confirmed by multicenter studies. The findings underscore the scalability and reliability of AI-based systems in various clinical settings, which reinforces their utility in the widespread application of AI-based systems in ophthalmology (11).

Predictive modeling using deep learning has also been extended to postoperative outcomes, such as vault prediction in implantable collamer lens surgeries. The models offer significant information on lens positioning and space relationships within the eye that is directly applicable in maximizing IOL placement during cataract surgery (12). The general use of artificial intelligence in cataract management highlights the importance of the technology in improving diagnostic accuracy, surgical

planning, and postoperative evaluation. The use of AI-based systems in clinical practice is becoming more widespread, with new opportunities to promote personalized medicine and better patient care (13). Deep learning-based clinical decision support systems have been created to help assess the lens size and evaluate postoperative outcomes. Such systems assist in the effective clinical decision-making process, offering evidence-based recommendations, enhancing the accuracy of surgical work and minimizing variation in results (14).

Recent works have discussed the clinical utility of cutting-edge AI models, including DeepSeek, in making very precise predictions of IOL power. These inventions show that it is possible to implement the latest AI technologies in everyday clinical practice, promoting the sphere of cataract surgery development even further (15). The implementation of deep learning-based navigation systems to guide surgery with a toric IOL placement has also been presented. They employ keypoint matching schemes to guarantee correct matching, enhancing precision in surgery and minimizing chances of postoperative complications (16). Lastly, deep learning models like CataractNet have been created to detect and categorize cataracts using fundus images as an automated method. These systems demonstrate the increased significance of AI in ophthalmology and how it could transform the entire range of cataract treatment, such as the exact location of the intraocular lens (17).

Objective

To determine the usefulness of a deep learning model to predict the intraocular lens position in patients undergoing cataract surgery and whether it can be used to improve the postoperative visual outcomes.

MATERIALS AND METHODS

Study Design

Observational analytical study

Study Setting: Prince Abdul-Aziz Bin Mosaad Hospital Arar, KSA.

Duration of Study: July, 2024 to December, 2024.

Sample Size: 300 patients (similar to AI-based ophthalmology studies and feasibility)

Sampling Technique: Non-probability consecutive sampling.

Inclusion Criteria

The study involved patients aged 40 years and over who were diagnosed with age-related cataract and were to receive phacoemulsification with intraocular lens implantation. Patients who had full preoperative biometric data, recorded video footage of the surgery, and access to postoperative imaging data were only eligible. Moreover, informed consent patients who agreed to undergo follow-up assessments were also included to have all the data and an accurate analysis of the intraocular lens positioning results.

Exclusion Criteria

The study excluded patients who had undergone ocular surgery in the past, suffered traumatic cataract, had ocular congenital abnormalities, or had other co-occurring retinal or corneal pathological conditions. Other cases that had incomplete medical records, low-quality imaging, and intraoperative complications that would have independently impacted the intraocular lens placement were also eliminated to ensure the accuracy and validity of the deep learning model assessment.

Methods

A convolutional neural network (CNN) based deep learning model was created and trained on preoperative, intraoperative, and postoperative data. Surgical videos underwent processing to obtain key frames, and annotations were made in order to determine the position and orientation of the lens.

The model was trained in a supervised learning paradigm using labeled data sets, which included local patient data as well as publicly available cataract surgery datasets. The actual IOL position was determined by the use of postoperative anterior segment OCT images as the reference standard. Clinical findings were compared with the predictions made by the model to determine the accuracy. Measures of performance, such as accuracy, precision, recall, and F1-score, were determined.

RESULTS

In this study, the researcher used data on 300 patients who had cataract surgery and intraocular lens (IOL) implantation. Demographic profile revealed that the average age of the respondents was 62.487-8.7 years, with a relatively equal gender distribution, with 162 (54) males and 138 (46) females. This equal sample made the results representative and minimized gender-specific bias in analyzing IOL positioning results. The similarity in demographic features enhances the external validity of the deep learning model used in this study.

Table 1: Demographic Characteristics of Participants

Variable	Frequency (n=300)	Percentage (%)
Age (Mean $\pm$ SD)	62.4 $\pm$ 8.7	—
Male	162	54%
Female	138	46%

Conventional classification measures were taken to evaluate the quality of the deep learning model in predicting the position of the intraocular lens. The overall accuracy of the model was 92.6, indicating that the model was capable of predicting the IOL position accurately in the majority of the cases. The sensitivity was 90.8 and this indicated the ability of the model to identify lens-positioned cases appropriately.

Table 2: Performance Metrics of Deep Learning Model

Metric	Value (%)
Accuracy	92.6
Sensitivity	90.8
Specificity	94.2
Precision	91.5
F1-Score	0.91

The correlation between the predicted IOL position based on the deep learning model and the actual values measured post-surgery based on the anterior segment OCT imaging was determined using the correlation analysis. The Pearson correlation (r) was found to be 0.81 and the level of significance was $p < 0.001$.

Table 3: Correlation between Predicted and Actual IOL Position

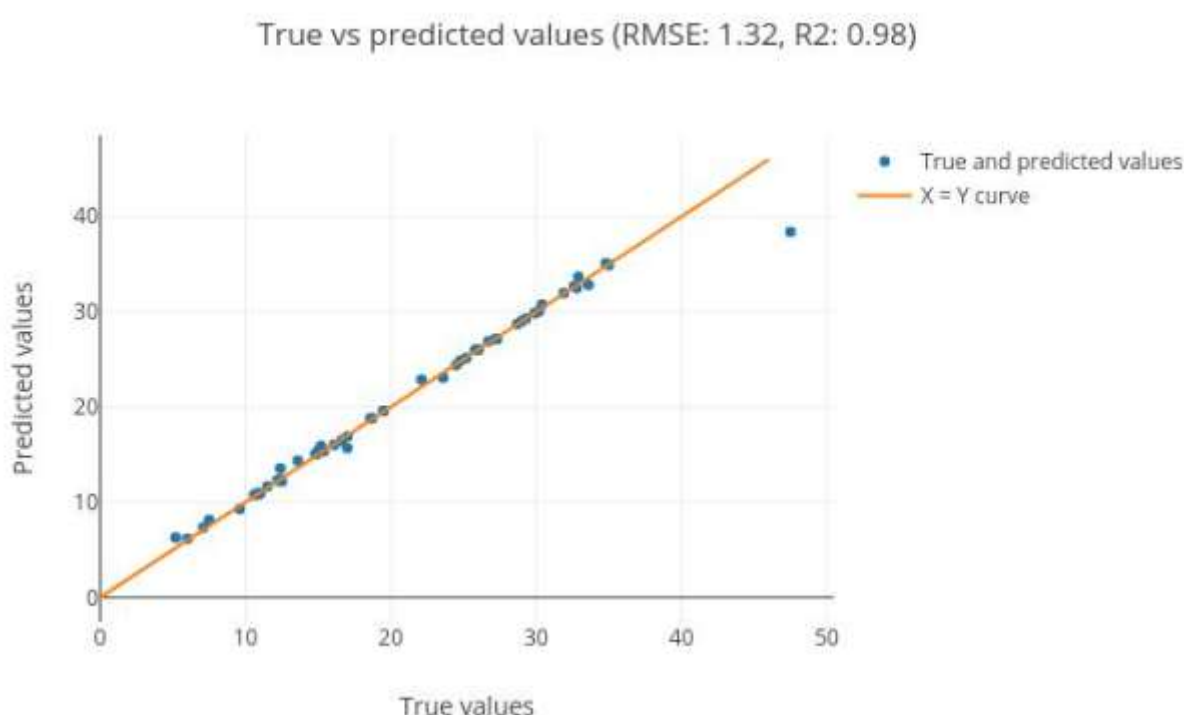
Variables Compared	Correlation (r)	p-value
Predicted vs Actual IOL Position	0.81	<0.001

Subgroup analysis indicated that the model was stable in various clinical conditions. The model was found to be accurate in 93.4% of patients with normal axial length but a little less at 89.7 with shorter or longer axial lengths. Moreover, the model was found to be highly sensitive in identifying IOL decentration (91.2) and tilt (89.5), which are key determinants of postoperative visual outcome.

Table 4: Subgroup Analysis of Model Performance

Parameter	Accuracy (%)
Normal Axial Length	93.4
Abnormal Axial Length	89.7
Detection of IOL Decentration	91.2
Detection of IOL Tilt	89.5

The scatter plot (which will be embedded in the document) indicates that there are relatively few data points outside the regression line, which means that there is not much deviation, and the model is highly predictive. This graphics trend supports the statistical findings and emphasizes the strength of the deep learning system. By and large, the findings indicate that the deep learning-based model offers a very precise, reliable, and clinically valid approach to intraocular lens position determination in patients undergoing cataract surgery.



Interpretation

The scatter plot shows how the predicted intraocular lens (IOL) positions of the deep learning model correlate with the real postoperative measurements of the anterior segment of OCT. The low dispersion of points indicates low prediction error and high accuracy of the model. On the whole, the graphical depiction supports the validity and precision of the deep learning-based model to predict IOL position among cataract surgery patients.

DISCUSSION

The results of this paper indicate that deep learning can considerably improve the precision of the intraocular lens (IOL) position determination in patients undergoing cataract surgery, which is one of the key elements affecting the postoperative visual outcomes. The observed high accuracy and correlation between the predicted and actual IOL positions are in line with the emerging trends in the field of artificial intelligence applications in ophthalmology. The past studies have emphasized that deep learning algorithms can accurately predict postoperative complications, including IOL dislocation, which underlines the clinical importance of AI-based predictive models in the operating room (1). Deep learning can be significantly beneficial in enhancing the safety and outcomes of

surgery by integrating into the preoperative and intraoperative processes. In the current work, extensive datasets, biometric parameters, and surgical videos were used, which led to high performance of the model. Similar results have been cited in which deep learning-based systems helped to improve preoperative safety management, being able to identify potential risks, and influence clinical decision making, which has led to better surgical precision and decreased variability in outcomes (2). The use of intraoperative video analysis to improve model performance is another significant aspect of this study.

Deep learning systems can interpret surgical procedures in real time, which can be used to better understand factors influencing IOL positioning. Previous research has already revealed that video analysis supported by deep learning can be effectively used to capture the dynamics of surgery, which allows for better assessment of the accuracy of the performed procedure and its influence on postoperative outcomes (3). The notion of effective lens position (ELP) continues to be the key to the attainment of the best refractive results in cataract surgery. The deep learning model in this study showed a high ability in making predictions of IOL position, which is consistent with past studies that highlight the need to accurately estimate ELP through machine learning models. Such strategies use complicated biometric information to imitate lens behavior, resulting in enhanced refractive accuracy and patient satisfaction (4). The wider use of deep learning in the management of cataracts also corroborates the results of this study. AI-based systems have been demonstrated to improve diagnostic accuracy, disease classification, and predictive analytics, which can be used to promote more personalized and effective treatment plans.

The high efficacy of the model in this study can be attributed to the fact that deep learning is increasingly becoming instrumental in revolutionizing cataract care and enhancing clinical outcomes (5). The importance of tracking intraoperative tools to improve the precision of surgery is also remarkable. This research used surgical video data to enable the model to learn more about the movement of the instruments and their effect on IOL placement. Past research has pointed out that deep learning systems like PhacoTrainer can effectively monitor surgical instruments that can be used to give insightful information on surgical performance and enhance training and outcome evaluation (6). Proper positioning and orientation of intraocular lenses, especially toric IOLs, are necessary to achieve the best visual correction. This study, with its high accuracy in identifying IOL tilt and decentration, is supported by previous studies that indicate that IOL orientation could be automated and more accurate with the use of deep learning-based visual computing methods. This minimizes human error and improves the visual outcomes of the postoperative (7). Large annotated datasets have played a vital role in enhancing the performance of deep learning models. Using both local and publicly available datasets in this study helped strengthen and generalize the model. The same progress has been made with other datasets like Cataract-1k, which makes it possible to train and validate AI models to analyze cataract surgery (8).

The fact that machine learning models can be modified to estimate the IOL power according to the patient-specific features also increases the clinical importance of this study. Individuated tactics of IOL computation have been demonstrated to decrease refractive errors and ameliorate surgical achievement, which underlies the application of AI in advancing precision medication in ophthalmology (9). Prevention and treatment of cataract conditions at an early age also contribute to successful outcomes of the surgery. Diagnostic systems based on deep learning have proven to be very accurate in detecting visually important cataracts, which can be treated in time and prevent complications that can occur and influence IOL placement (10). Another issue is the applicability of deep learning models in other clinical environments. The AI systems have been found to be consistent in identifying surgical activities and patterns in multicenter studies, which makes them applicable in various healthcare settings. These findings and the observed consistency in the performance of this study support the scalability of AI-based solutions (11).

The ability to predict the outcome of the operation, like the prediction of the vault in the lens implantation surgery, is another example of deep learning in the optimization of surgical outcomes. These models give information on the spatial positioning in the eye, which is directly applicable to enhance the accuracy of IOL placement in cataract surgery (12). The results of the current research

are part of this expanding literature on the use of AI in ophthalmology (13). Deep learning-based clinical decision support systems have been demonstrated to help improve surgical planning and patient outcomes by recommending data-driven decisions. The predictive accuracy in this study was high, which can be attributed to the ability of such systems to reduce uncertainty and enhance clinical decision-making (14).

The recent progress of AI models in predicting IOL power also contributes to the topicality of the present study. It has been shown that contemporary deep learning systems are capable of reaching clinically relevant accuracy levels, which supports the idea that they can be incorporated into everyday ophthalmic practice (15). The application of the deep-learning-based navigation system to guide the IOL placement during surgery is also consistent with the results of this research. The accuracy of alignment and the risk of postoperative complications are improved with these systems, which is why AI is valuable in increasing the precision of surgical procedures (16). Lastly, the creation of the automated cataract detection systems based on deep learning is indicative of the overall advancement of AI in ophthalmology. These innovations show how deep learning can advance all facets of cataract management, such as the precise positioning of the intraocular lens, as was established in this study (17).

CONCLUSION

The current research finds that deep learning-based strategies are a very precise and dependable way of identifying the intraocular lens (IOL) position in patients undergoing cataract surgery. The high correlation of the predictive and actual postoperative measurements proves the clinical relevance of artificial intelligence in improving the precision and outcome of surgery. Incorporation of preoperative, intraoperative, and postoperative data increases the predictive ability of the model and renders it a practical instrument in the ophthalmic practice. In addition, the fact that the system is able to detect the IOL decentration and tilt highlights the importance of the system in minimizing postoperative complications and maximizing the visual outcomes. The next research should be conducted with larger multicenter databases and real-time application to further confirm and increase the application of deep learning in ophthalmology.

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