Development of a Cloud-Based Clinical Decision Support System for Ophthalmology Triage Using Decision Tree Artificial Intelligence

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Purpose: Clinical decision support systems (CDSS) are an emerging frontier in teleophthalmology, drawing on heuristic decision making to augment processes such as triage and referral. We describe the development and implementation of a novel cloud-based decision tree CDSS for on-call ophthalmology consults. The objective was to standardize the triage and referral process while providing a more accurate provisional diagnosis and urgency.

Design: Prospective comparative cohort study.

Subjects: On-call referrals to a Canadian community ophthalmology clinic.

Methods: A web-based decision tree algorithm was developed using current guidelines and expert opinion. The algorithm collected tailored information on the patient’s ophthalmic concern, and outputted a provisional diagnosis and urgency before sending an electronic referral to the on-call ophthalmology clinic. Data were described using descriptive statistics. Spearman-rho correlations and Cohen’s kappa coefficient were used to characterize the observed relationships. Post hoc analysis was conducted using analysis of contingency tables and adjusted residuals.

Main Outcome Measures: Diagnostic category, provisional diagnosis, and urgency for the referring provider, CDSS, and ophthalmologist.

Results: Ninety-six referrals were processed. Referring providers included medical doctors (76.0%, n = 73), optometrists (20.8%, n = 20), and nurse practitioners (3.1%, n = 3). The CDSS (κ = 0.5898; 95% confidence interval [CI], 0.4868–0.6928; P < 0.0001) performed equally well with 66.7% agreement in determining category when compared with referring providers (κ = 0.5880; 95% CI, 0.4798–0.6961; P < 0.0001). The CDSS (agreement = 53.1%; κ = 0.4999; 95% CI, 0.4021–0.5978; P < 0.0001) performed better than referring providers (agreement = 43.8%; κ = 0.4191; 95% CI, 0.3194–0.5188; P < 0.0001) in determining a diagnosis. The CDSS (ρ = 0.5014; 95% CI, 0.3092–0.6935; P < 0.0001) also performed better than referring providers (ρ = 0.4035; 95% CI, 0.2406–0.5665; P < 0.0001) in determining urgency. The CDSS assigned a lower level of urgency in 22 cases (22.9%) compared with referring providers in 6 cases (6.3%).

Conclusions: To our knowledge, this is the first cloud-based CDSS in ophthalmology designed to augment the triage and referral process. The CDSS achieves a more accurate diagnosis and urgency, standardizes information collection, and overcomes antiquated paper-based consults. Future directions include developing a random forest model or integrating convolutional neural network-based machine learning to refine the speed and accuracy of triage and referral processes, with emphasis on increasing sensitivity of the CDSS. Ophthalmology Science 2023;3:100231 © 2022 by the American Academy of Ophthalmology. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Ophthalmologists are responsible for providing timely and high-quality vision care. This can be challenging in North America, where ophthalmologists service a vast geographic distribution.1,2 Teleophthalmology can address gaps in access to care, with early data suggesting increased patient and provider satisfaction.2 Clinical decision support systems (CDSS) are emerging as a powerful tool within teleophthalmology3-7 to provide clinicians with tailored information to enhance decision making, particularly during triage and referral processes.8,9 Knowledge-based CDSS extract data directly from the patient, clinician, or electronic health record and filter it through a standardized system of rules—such as a decision tree algorithm—to produce an output that may be used to augment clinical decisions.3

Within the Canadian health care system, cloud-based CDSS represent an opportunity to enhance communication between referring providers and ophthalmologists. This report aims to develop and implement a novel cloud-based decision tree CDSS to improve the accuracy of provisional diagnosis and urgency suggested by referring
providers for on-call ophthalmology consults. The primary objective was to employ heuristic decision making to determine a provisional diagnosis and urgency with minimal, if any, physical exam, thereby increasing accessibility of the CDSS to providers with varying levels of expertise or equipment to conduct an ophthalmic exam. Our CDSS presents an opportunity to address gaps in the triage and referral process by helping to achieve a more accurate diagnosis and urgency, standardizing information collection across referring providers, and replacing antiquated paper-based consults with secure electronic referrals.

**Methods**

**Technical Development**

A combination of literature review and expert opinion were used to determine the most common on-call referrals in a community-based ophthalmology clinic. Referrals were considered based on whether they were related to new ophthalmic symptoms or a previous (i.e., known) ophthalmic diagnosis. New ophthalmic concerns were categorized into 10 symptom-based categories as follows: 1) visual disturbance, i.e., blurry, hazy, or cloudy vision; 2) eye discomfort with no redness, including mild symptoms of watery discharge, irritation, or blurry vision; 3) red eye(s); 4) diplopia; 5) eyelid concern; 7) rash characteristic of herpes zoster; 8) recent injury or trauma to the eye; 9) recent history of ocular surgery or injections; and 10) other concerns. Previous ophthalmic diagnoses were categorized into 10 diagnosis-based categories as follows: 1) age-related macular degeneration; 2) diabetic retinopathy; 3) cataract; 4) post-operative cataract extraction; 5) corneal diagnosis; 6) glaucoma, including glaucoma suspect; 7) hydroxychloroquine use; 8) retinal tear or detachment; 9) uveitis; and 10) other diagnosis. Similarly, level of urgency was stratified into 7 categories as follows: 1) emergent, within 1 to 2 hours; 2) very urgent, within 24 to 48 hours; 3) urgent, within 1 week; 4) semi-urgent, within 1 month; 5) non-urgent, within 2 to 3 months; 6) referral of unspecified urgency; and 7) no referral required.

The algorithm was constructed on Zingtree (Applian Technologies). An introductory decision tree was developed to collect standard information included in a typical consult or referral. Information collected at this stage included the name and discipline of the referring provider (i.e., family physician, emergency physician, nurse practitioner, optometrist, or other); the referring provider’s provisional diagnosis and urgency, and basic information about the patient including past ophthalmic history, eye involvement, symptom duration, and whether the referral was for a new ophthalmic concern or a previously diagnosed condition.

The introductory decision tree subsequently branched into 10 categorical diagnosis trees (Fig 1). The categorical decision trees inquired about increasingly specific details regarding the patient’s condition. The algorithm was designed to elicit most information through the history; however, some nodes required rudimentary physical examination findings such as visual acuity, extraocular movements, anterior segment slit-lamp exam (i.e., fluorescein staining), and posterior segment funduscopic exam (i.e., presence of red reflex or gross hemorrhage).

The categorical decision trees eventually culminated in a provisional diagnosis and urgency before prompting the referring provider to provide demographic information about the patient to complete the referral. Notice of the completed referral was subsequently transmitted to the referring provider and the ophthalmology clinic via a secure Health Insurance Portability and Accountability Act compliant email, whereby further details could be accessed by logging in to the decision tree platform using single sign-on authentication. The referral was processed electronically through the CDSS such that there were no paper-based forms required and the referral request was processed immediately by the ophthalmology clinic.

All nodes in the decision tree algorithm provided an option to communicate directly with the on-call ophthalmologist if needed. If the referring provider disagreed with the provisional diagnosis or urgency, they were prompted to contact the on-call ophthalmologist via telephone prior to completing the referral. The decision tree algorithm also included several opportunities for the referring provider to provide free-text information that was not explicitly requested to ensure that all pertinent information was captured.

**Data Collection**

The CDSS was developed and implemented in a community-based ophthalmology practice in St. John’s, Newfoundland and Labrador, Canada. Data were collected prospectively from on-call ophthalmology referrals between November 2020 and December 2021. For data analysis, 10 diagnostic categories were developed: 1) corneal and conjunctival pathology; 2) inflammatory pathology; 3) lens or refractive pathology; 4) lid and lacrimal system pathology; 5) neuro-ophthalmologic pathology, including intraocular pressure disturbance and strabismus; 6) postoperative complication; 7) traumatic pathology; 8) vitreoretinal pathology; 9) unspecified; and 10) examination within normal limits (Table 1). Primary outcome measures included the category, diagnosis, and urgency for the referring provider, CDSS, and comprehensive ophthalmologist. All data were collected by a single member of the research team (S.T.) and all on-call patient assessments were conducted by a single comprehensive ophthalmologist (C.J.). The ophthalmologist’s final diagnosis and urgency, elicited after a complete ophthalmologic examination, were the ground truth. The provincial health research ethics board determined that this project was quality improvement and approval was not required for this study; however, regional health authority approval and verbal consent from participants were obtained. The described research adhered to the tenets of the Declaration of Helsinki.

**Statistical Analyses**

All statistics were performed using Stata 16.1 (StataCorp LLC). Data were described using basic and descriptive statistics. Pearson’s chi-squared test was used to examine associations between the referring provider versus (vs.) CDSS, referring provider vs. ophthalmologist, and CDSS vs. ophthalmologist for category, diagnosis, and urgency. Spearman-rho correlations were performed to measure the strength of association for the urgency provided by the referring provider vs. ophthalmologist and CDSS vs. ophthalmologist. Cohen’s kappa coefficient was used to quantify the agreement congruity for diagnoses between the referring provider vs. ophthalmologist and CDSS vs. ophthalmologist; referring providers were further assessed based on their discipline (i.e., medical doctor, optometrist, or nurse practitioner). Post hoc analysis was conducted using analysis of contingency tables and adjusted residuals.

**Results**

Ninety-six referrals were processed during the study period with 59 unique diagnoses. Most referring providers were medical doctors (76.0%, n = 73), with representation from...
optometrists (20.8%, n = 20) and nurse practitioners (3.1%, n = 3) as well.

The most frequent referring categories were “vitreoretinal pathology” (37.5%, n = 36), “traumatic pathology” (16.7%, n = 16), and “unspecified” (14.6%, n = 14). Similarly, the most frequent CDSS categories were “vitreoretinal pathology” (37.5%, n = 36), “unspecified” (15.6%, n = 15), and “traumatic pathology” (14.6%, n = 14). The most frequent ophthalmologist categories were “vitreoretinal pathology” (37.5%, n = 36), “traumatic pathology” (17.7%, n = 17), and “examination within normal limits” (13.5%, n = 13). The agreement for categories was 66.7% between the referring provider and ophthalmologist (κ = 0.5880; 95% confidence interval [CI], 0.4798–0.6961; P < 0.0001) as well as the CDSS and ophthalmologist (κ = 0.5898; 95% CI, 0.4868–0.6928; P < 0.0001). For optometrists, the agreement was 85.0% (κ = 0.7561; 95% CI, 0.4866–1.0256; P < 0.0001); whereas for all other providers (i.e., medical doctors and nurse practitioners), the agreement was 61.8% (κ = 0.5407; 95% CI 0.4224–0.6591; P < 0.0001). A correlation matrix for categories using adjusted residuals for the referring provider and CDSS is provided in Figures 2 and 3, respectively.

The most common referring diagnoses were “description of a sign or symptom” (20.8%, n = 20), “retinal detachment” (12.5%, n = 12), and “corneal foreign body, corneal rust ring, or acute trauma of the conjunctiva” (11.5%, n = 11). The most common CDSS diagnoses were “posterior vitreous detachment” (22.9%, n = 22), “corneal foreign body, corneal rust ring, or acute trauma of the conjunctiva” (10.4%, n = 10), and “tree failure” (7.3%, n = 7). Instances of tree failure are depicted in Table 2. The most common ophthalmologist diagnoses were “posterior vitreous detachment” (17.7%, n = 17), “examination within normal limits” (13.5%, n = 13), and “corneal foreign body, corneal rust ring, or acute trauma of the conjunctiva” (10.4%, n = 10). The agreement for diagnoses was 43.8% between the referring provider and ophthalmologist (κ = 0.4191; 95% CI, 0.3194–0.5188; P < 0.0001), compared to 53.1% between the CDSS and ophthalmologist (κ = 0.4999; 95% CI, 0.4021–0.5978; P < 0.0001). Upon analyzing by discipline, optometrists had a 75.0% agreement (κ = 0.7319; 95% CI, 0.5378–0.9260; P < 0.0001) whereas all other providers had a 35.5% agreement (κ = 0.3271; 95% CI, 0.2252–0.4289; P < 0.0001).

Referring providers correctly assigned 45 cases (46.9%) as the same level of urgency that the ophthalmologist determined. Among the remaining 51 cases (53.1%) assigned with the incorrect level of urgency by referring providers, 6 cases (6.3%) were assigned a lower level of urgency and 45 cases (46.9%) were assigned a higher level of urgency compared to the ophthalmologist. The CDSS correctly assigned 66 cases (68.8%) as the same level of urgency.
Table 1. Categories and Diagnoses Encountered During the Study

| Category | Diagnosis |
|----------|-----------|
| 1 Corneal and conjunctival pathology | Keratitis, herpes simplex virus | Keratitis, herpes simplex virus, previous diagnosis |
| | Keratitis, marginal |
| | Keratitis, ultrasclerotic |
| | Recurrent epithelial erosion |
| | Keratoconus, previous diagnosis |
| | Dry eye |
| | Conjunctivitis, allergic |
| | Conjunctivitis, bacterial |
| | Pterygium |
| | Foreign body granuloma |
| 2 Inflammatory pathology | Episcleritis |
| | Scleritis |
| | Uveitis, anterior |
| | Uveitis, anterior, previous diagnosis |
| | Uveitis, intermediate |
| | Acute retinal necrosis |
| | Dermatomyositis |
| 3 Lens and refractive pathology | Cataract |
| | Refractive error |
| 4 Lid and lacrimal system pathology | Chalazion or stye |
| | Dacryocystitis |
| | Lid papilloma |
| | Entropion |
| 5 Neuro-ophthalmologic pathology, including intraocular pressure disturbance and strabismus | CNVI palsy |
| | Arteritic ischemic optic neuropathy |
| | Non-arteritic ischemic optic neuropathy |
| | Herpes zoster ophthalmicus |
| | Optic neuritis |
| | Idiopathic intracranial hypertension |
| | Ocular migraine |
| | Glaucoma, primary open angle |
| | Decompensated esotropia |
| 6 Post-operative complication | Corneal graft failure |
| | Tarsorrhaphy failure |
| | Postoperative dry eye or allergic conjunctivitis |
| 7 Traumatic pathology | Corneal foreign body, corneal rust ring, or acute trauma of the conjunctiva |
| | Corneal abrasion |
| | Chemical injury |
| | Nonpenetrating or blunt ocular trauma |
| 8 Vitreoretinal pathology | Retinal detachment |
| | Retinal detachment, previous diagnosis |
| | Retinal tear |
| | Retinal tear, previous diagnosis |
| | Retinal tear, vitreous hemorrhage |
| | Complications of diabetic retinopathy (i.e., vitreous hemorrhage, macular edema) |
| | Macular edema, wet age-related macular degeneration |
| | Macular edema, wet age-related macular degeneration, previous diagnosis |
| | Macular edema, retinal vein occlusion |
| | Macular edema, unspecified etiology |
| | Retinal vein occlusion |
| | Macular hole |
| | Intraocular candidiasis |

Table 1. (Continued.)

| Category | Diagnosis |
|----------|-----------|
| 9 Unspecified | Pathology of the retina or optic nerve and/or mild media opacity |
| | Non-specific cause of reduced vision |
| | Pathology of peripheral retina |
| | Description of sign or symptom |
| | Tree failure |
| 10 Examination within normal limits |

CNVI = Cranial nerve VI.
ophthalmologist’s urgency ($r = 0.6324$; 95% CI, 0.4629–0.8019; $P < 0.0001$).

**Discussion**

**Summary of Findings**

We designed a cloud-based decision tree CDSS to codify the heuristic decision making during triage and referral processes in a community ophthalmology practice. Our objectives were threefold: improve the accuracy of on-call ophthalmology triage by making current best practices accessible to clinicians, standardize triage and referral across various primary care settings, and replace paper-based referrals with an electronic system.

Our findings suggest that the CDSS performed equally well in determining the category when compared to referring providers (agreement = 66.7%), although subgroup analyses demonstrated that optometrists (agreement = 85.0%) performed better than both the CDSS and all other providers (agreement = 61.8%). When determining provisional diagnosis, the CDSS (agreement = 53.1%) performed better than referring providers (agreement = 43.8%); subgroup analyses similarly demonstrated that optometrists (agreement = 75.0%) performed better than the CDSS and all other providers (agreement = 35.5%). Finally, the CDSS (correlation = 0.5014, moderate positive) performed better than referring providers (correlation = 0.4035, weak positive) for determining urgency; in contrast to category and diagnosis, performance was better for all other providers (correlation = 0.4211, weak positive) compared to optometrists (correlation = 0.3600, weak positive). A summary of findings is provided in Table 3. These findings support the hypothesis that our CDSS may improve the accuracy of on-call ophthalmology triage and referral processes in a community ophthalmology practice.

**Review of Literature**

Clinical decision support systems are gaining traction in teleophthalmology and other specialties such as emergency medicine, infectious diseases, and outpatient pharmacy. Our CDSS was inspired by the 2013 Scottish Eyecare Integration Project, which integrated over 50 paper-based referral forms into 5 categorical electronic forms. The Scottish health care system increased the efficiency and accuracy of referrals with significant improvements to patient satisfaction and wait times for sight-saving procedures. However, this solution relied on the concerted participation of optometrists, general practitioners, nurses, and ophthalmologists as patient care flowed through this pipeline before a diagnosis and urgency were ultimately decided. Interprofessional collaboration in Canadian eye care is highly variable across jurisdictions with few concerted shared-care models. As a result, referrals to ophthalmology may originate from physicians, optometrists, nurse practitioners, and other allied health professionals lending to significant variability in the caliber of consults.

In 2018, Docherty et al demonstrated a 67.0% agreement rate for diagnostic category between referring providers and ophthalmologists at a Canadian institution—mirroring our

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**Table 3**

| Referring provider | Corneal and conjunctival pathology | Inflammatory pathology | Lens and refractive pathology | Lid and lacrimal system pathology | Neuro-ophthalmologic pathology | Post-operative complication | Traumatic pathology | Vitreoretinal pathology | Exam within normal limits |
|--------------------|---------------------------------|------------------------|-------------------------------|----------------------------------|-------------------------------|--------------------------|---------------------|----------------------|------------------------|
| Corneal and conjunctival pathology | 7.3960 | -0.9570 | -0.4600 | 0.6330 | -0.8840 | -0.4600 | -0.5450 | -2.4410 | -1.2470 |
| Inflammatory pathology | 0.4630 | 7.2850 | -0.4010 | -0.7090 | -0.7710 | -0.4010 | -0.2460 | -2.1280 | 0.0800 |
| Lid and lacrimal system pathology | -0.7390 | -0.4790 | -0.3350 | 8.8650 | -0.6440 | -0.3350 | -1.0550 | -1.8790 | -0.0800 |
| Neuro-ophthalmologic pathology | 0.4630 | -0.5750 | -0.4010 | -0.7090 | 2.2490 | -0.4010 | -1.2750 | -2.1280 | 3.5010 |
| Post-operative complication | -0.4600 | -0.2980 | -0.2080 | -0.3690 | -0.4010 | 9.7860 | -0.0630 | -1.1070 | -0.0660 |
| Traumatic pathology | -1.4090 | -0.9140 | 1.2780 | -1.1310 | -1.2290 | -0.6390 | 8.7280 | -3.3940 | -1.7340 |
| Vitreoretinal pathology | -2.4410 | -1.5830 | 0.3690 | -1.9600 | -0.5070 | -1.1070 | -3.5210 | 6.7500 | -0.0390 |
| Unspecified | -1.3020 | -0.8440 | -0.5910 | -1.0450 | 2.2010 | -0.5910 | -1.8780 | 1.0450 | 1.7780 |

Figure 2. Correlation matrix using adjusted residuals for categories by the referring provider versus ophthalmologist.
66.7% observed agreement. The most common diagnosis, posterior vitreous detachment, was shared between our studies. Similarly, many cases were referred as a description of a sign or symptom, and Docherty et al\textsuperscript{16} attributed this observation to gaps in ophthalmology education throughout medical training. Reintegrating ophthalmology into medical education is an upstream approach to improving the assessment and management of vision concerns in primary care settings.\textsuperscript{17} Our CDSS represents a turnkey solution that is readily implemented and customized for diverse practice settings to address gaps arising from limited exposure to ophthalmology during medical training.

In 2021, Khou et al reviewed referral forms in an Australian hospital-based ophthalmology clinic. The authors found that most referrals were incomplete and identified poor referral quality as contributory to inaccurate triage and lengthy waitlists.\textsuperscript{18} Interpretation of referrals is a learned skillset, and the administrative burden of triage and wait-list management may be alleviated by CDSS. A cloud-based referral platform was demonstrated to yield a more efficient care delivery pipeline from optometrists to ophthalmologists in a retrospective cohort study by Kern et al\textsuperscript{4} based in the United Kingdom, reinforcing the value of a standardized referral process. Similar administrative burdens may be alleviated by our CDSS, which ensures completeness by standardizing data collection and referral delivery while also providing a provisional diagnosis and urgency.

Prager et al explored the ethics of virtual triage during the coronavirus disease 2019 (COVID-19) pandemic in

| Referring Diagnosis | Ophthalmologist Diagnosis | Reason for Tree Failure |
|---------------------|---------------------------|------------------------|
| Keratitis, ultraviolet | Keratitis, ultraviolet | Clinical presentation not included in CDSS |
| Dacryocystitis | Dacryocystitis | Clinical presentation not included in CDSS |
| Idiopathic intracranial hypertension | Examination within normal limits | Clinical presentation not included in CDSS |
| Corneal foreign body, corneal rust ring, or acute trauma of the conjunctiva | Corneal abrasion | Clinical presentation not included in CDSS |
| Retinal tear | Retinal tear | Asymptomatic clinical presentation on routine optometric exam |
| Intraocular candidiasis | Examination within normal limits | Clinical presentation not included in CDSS |

CDSS = Clinical decision support systems.

Figure 3. Correlation matrix using adjusted residuals for categories by the clinical decision support system versus ophthalmologist.
scenarios where in-person assessment may be delayed. Ethically appropriate triage was identified as prioritizing patient safety and minimizing risks associated with delayed access to care, underscoring the importance of an appropriately triaged urgency. The authors recommended triaging based on standardized scoring criteria in addition to clinical judgment, both of which were integrated into our CDSS.18

Our CDSS demonstrated a moderate positive correlation with the ophthalmologist for urgency; while this was stronger than the weak positive correlation demonstrated by referring providers, there exists an opportunity to improve the accuracy of risk stratification for timeline of urgency. As per our findings, referring providers erroneously assigned a higher level of urgency (i.e., false positive) in 45 cases (46.9%) compared with the CDSS 8 cases (8.3%), whereas the CDSS assigned a lower level of urgency (i.e., false negative) in 22 cases (22.9%) compared with referring providers’ 6 cases (6.3%). Indeed, the risk of false negatives (i.e., assigning a lower level of urgency, such as an urgent clinical scenario stratified as non-urgent) in teleophthalmology triage outweighs the risk of false positives (i.e., assigning a higher level of urgency, such as a non-urgent clinical scenario stratified as urgent). As identified in a 2022 study by Meshkin et al., a framework is needed to define the objective ground truth or gold standard for urgency to facilitate more accurate teleophthalmology triage, prioritizing a high-sensitivity model to minimize false negative results.

**Future Directions**

Our pilot study demonstrates a proof-of-concept for the utility of a prototypal CDSS to improve the triage and referral experience. The 7.3% tree failure rate is a testament to the narrow range of diagnostic possibilities encompassed in our CDSS, which was designed for common on-call presentations. Future directions include broadening the scope of clinical scenarios by increasing the number of decision trees, which may eventually be constructed into a random forest model, yielding improved prediction accuracy for diagnosis and urgency.19 Although the time efficiency of the CDSS was not evaluated in our study, a feature selection algorithm may help to reduce the time needed to complete the triage and referral process by optimizing the number of input variables.20 Machine learning models have been successfully applied in emergency medicine with superior ability to predict clinical outcomes,10 and counterfactual diagnostic algorithms utilizing causal machine learning have been shown to perform at the level of expert clinical accuracy in general medicine.21 Optical character recognition to extract data from paper charts or health care insurance cards may also be integrated to improve usability and efficiency; natural language processing with techniques such as named entity recognition may be further implemented to help classify and interpret these data. Further research is needed to evaluate the time- and cost-efficiency of using CDSS in a community ophthalmology practice, in addition to the utility of CDSS to support the integration of a network of providers to improve interprofessional communication and collaboration. The CDSS skeleton may also be deployed with best practices to enhance triage and referral processes in other areas of clinical medicine and surgery.

**Strengths and Limitations**

Strengths of our pilot study include that it is among the first to assess a CDSS designed for and implemented within a community ophthalmology practice. The study included referrals from various practice providers rather than clinical vignettes used to test and train many other decision tree algorithms. Our CDSS was tested in the unique practice and
referral patterns in this setting, and future iterations may also be customized to their respective practice settings.

Although our study was designed to deliver a proof-of-concept, the small sample size limited our ability to draw conclusions based on specific diagnoses and referring provider discipline. A more extensive prospective observational study would be beneficial to support ongoing quality improvement of this CDSS. Additionally, the study was not blinded to participant, personnel, or outcome assessment which may introduce detection or performance bias. The study was conducted during the COVID-19 pandemic which resulted in lower patient volumes and may introduce selection bias.

### Footnotes and Disclosures

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**Abbreviations and Acronyms:**

- CDSS = clinical decision support systems
- CI = confidence interval
- HIPAA = Health Insurance Portability and Accountability Act

**Keywords:**
Clinical decision support system, Decision tree algorithm, Triage and referral, Teleophthalmology, Artificial intelligence.

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### References

1. Bellan L, Buske L, Wang S, Buys YM. The landscape of ophthalmologists in Canada: present and future. *Can J Ophthalmol*. 2013;48(3):160–166.
2. Wedekind L, Sainani K, Pershing S. Supply and perceived demand for teleophthalmology in triage and consultations in California Emergency Departments. *JAMA Ophthalmol*. 2016;134(5):537–543.
3. Scanzera AC, Chang AY, Valikodath N, et al. Assessment of a novel ophthalmology tele-triage system during the COVID-19 pandemic. *BMC Ophthalmol*. 2021;21(1):1–9.
4. Kern C, Fu DJ, Kortuem K, et al. Implementation of a cloud-based referral platform in ophthalmology: making telemedicine services a reality in eye care. *Br J Ophthalmol*. 2020;104(3):312–317.
5. Chen Y, Ismail R, Cheema MR, et al. Implementation of a new telephone triage system in ophthalmology emergency department during COVID-19 pandemic: clinical effectiveness, safety and patient satisfaction. *Eye*. 2021;36:8–10.
6. Meshkin RS, Armstrong GW, Hall NE, et al. Effectiveness of a telemedicine program for triage and diagnosis of emergent ophthalmic conditions. *Eye (Lond)*. 2022;1–7.
7. Vinny PW, Takkar A, Lal V, et al. Mobile application as a complementary tool for differential diagnosis in neuro-ophthalmology: a multicenter cross-sectional study. *Indian J Ophthalmol*. 2021;69(6):1491–1497.
8. Sutton RT, Pincock D, Baumgart DC, et al. An overview of clinical decision support systems: benefits, risks, and strategies for success. *NPJ Digit Med*. 2020;3(1):1–10.
9. Bali J, Bali O. Artificial intelligence in ophthalmology and healthcare: an updated review of the techniques in use. *Indian J Ophthalmol*. 2021;69(1):8–13.
10. Raita Y, Goto T, Faridi MK, et al. Emergency department triage prediction of clinical outcomes using machine learning models. *Crit Care*. 2019;23(1):1–13.
11. Khosavanna RR, Kareko BW, Brady AC, et al. Clinical symptoms of dengue infection among patients from a non-endemic area and potential for a predictive model: a multiple logistic regression analysis and decision tree. *Am J Trop Med Hyg*. 2021;104(1):121–129.
12. Tanner L, Schreiber M, Low JGH, et al. Decision tree algorithms predict the diagnosis and outcome of dengue fever in the early phase of illness. *PLoS Negl Trop Dis*. 2008;2(3):e196.
13. Stämple D, Winkler BA, Vilei SB, Burden AM. Assessment of minor health disorders with decision tree-based triage in community pharmacies. *Res Social Adm Pharm*. 2022;18(5):2867–2873.
14. Hall HN. Electronic referrals and digital imaging systems in ophthalmology: a global perspective. *Asia Pac J Ophthalmol (Phila)*. 2017;6(1):3–7.
15. Beck D, Ellis H, Dhillon B. Digital ophthalmology in Scotland: benefits to patient care and education. *Clin Ophthalmol*. 2019;13:277–286.

16. Docherty G, Hwang J, Yang M, et al. Prospective analysis of emergency ophthalmic referrals in a Canadian tertiary teaching hospital. *Can J Ophthalmol*. 2018;53(5):497–502.

17. Shah M, Knoch D, Waxman E. The state of ophthalmology medical student education in the United States and Canada, 2012 through 2013. *Ophthalmology*. 2014;121(6):1160–1163.

18. Khou V, Ly A, Moore L, et al. Review of referrals reveal the impact of referral content on the triage and management of ophthalmology wait lists. *BMJ Open*. 2021;11(9):1–8.

19. Prager KM, Dagi Glass LR, Wang M, et al. Ophthalmology and ethics in the COVID-19 Era. *Am J Ophthalmol*. 2021;224:158–162.

20. Darcy AM, Louie AK, Roberts LW. Machine learning and the profession of medicine. *JAMA*. 2016;315(6):551–552.

21. Richens JG, Lee CM, Johri S. Improving the accuracy of medical diagnosis with causal machine learning. *Nat Commun*. 2020;11(1):3923.