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Research Article

Evaluating the Incidence of Glaucoma, Age-Related Macular Degeneration, and Diabetic Retinopathy in Western New York and Assessing the Feasibility of Utilizing Optical Coherence Tomography and Artificial Intelligence for the Timely Identification of these Ocular Diseases

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Abstract

Introduction: Diabetic retinopathy (DR), glaucoma and Age-related Macular Degeneration (AMD) are among the leading causes of blindness worldwide. The global prevalence of each of these ocular pathologies is projected to increase significantly in the coming decades. DR is a microvascular complication of diabetes that damages capillaries of the retina. Glaucoma is a neurodegenerative eye disease of the optic nerve, which causes progressive structural loss of retinal ganglion cells. AMD is a progressive degenerative retina disease of the macula. In each of these diseases, early detection is crucial to preventing or slowing the progression to an advanced stage of irreversible vision loss. Therefore, it is imperative that early detection methods, such as OCT and AI, are adopted to aid in the prevention of severe visual complications of DR, glaucoma, and AMD. **Methods:** An extensive literature review was conducted focused on whether OCT scans can be effectively used to detect and diagnose early changes in DR, glaucoma, and AMD. CDC VEHSS prevalence data was collected from 2015-2019 for various subtypes of DR, glaucoma, and AMD in multiple disease stages at the national (United States), state (New York) and county (Monroe and Erie) level. The data was then stratified by age, gender, race and stage of the disease. This information was analyzed for trends. The intersection of early diagnosis, AI and OCT is then evaluated for possible recommendations to prevent blindness from these diseases. **Results:** The data showed that overall prevalence of AMD of any stage at the national, state and county level increased from 2015 to 2019. Both early and late-stage AMD was most commonly diagnosed in individuals who were non-Hispanic White, female or age 85 or older. For glaucoma of any type, the overall prevalence also increased from 2018 to 2019 at the national, state and county level. Open angle glaucoma was most diagnosed in individuals who were non-Hispanic Black, female, or age 85 or older, whereas severe stage glaucoma was more common diagnosed in non-Hispanic Black, males and age 85 or older. However, the overall prevalence of DR decreased from 2018 to 2019 at the national, state and county level. Non-proliferative DR was most diagnosed in individuals who identified as North American native, male and age 65-84 whereas severe non-proliferative DR was most diagnosed in individuals who were Hispanic, any race, male and age 40-64. **Conclusions:** The CDC data shows an increase in the prevalence all stages and forms of AMD and glaucoma. The data also reveals a decrease in the prevalence of all stages of DR. Furthermore, the data unearths racial health differences particularly for non-Hispanic Blacks, Hispanics and North American natives. Given these visual health outcomes, adoption of early detection measures, including OCT and AI, will be powerful tool in mitigating racial disparities related to disease progression and blindness worldwide.

Keywords: Glaucoma; Diabetes; Age related macular degeneration; Health equity; AI; Social determinants of health; Teleophthalmology

Introduction

Glaucoma, Age-related Macular Degeneration (AMD), and Diabetic Retinopathy (DR) rank among the top five primary factors contributing to blindness and significant visual impairment in individuals aged 50 years and above globally. Glaucoma is the leading cause of irreversible blindness globally. Its worldwide prevalence is estimated to be 112 million by 2040 [1]. AMD is the most common cause of blindness in developed countries, with an expected global prevalence of 288 million by 2040 [2]. DR is the most common cause of preventable blindness in working-age adults, as the global prevalence is expected to rise to 161 million by 2045 [3]. Collectively, these ocular diseases caused more than 6 million blind adults and 13 million adults aged 50 and older with moderate to severe visual impairment in 2020. Overall, global age-standardized prevalence of blindness from all causes has decreased from 1990 and 2020. However, a notable expectation to this trend was blindness from DR, which saw region-specific increases, particularly in sub-Saharan Africa, Asia and high-income North America [4].

Glaucoma is a neurodegenerative disease affecting the optic nerve, resulting in visual field impairment and potential blindness if left untreated. Timely detection and proper treatment are essential in reducing the likelihood of visual impairment and vision loss [5,6]. Glaucoma is the leading cause of irreversible blindness around the world. Significant risk factors include older age, non-white race, family history and elevated intraocular pressure. Notably, glaucoma is the leading cause of irreversible blindness in Black individuals, who are at two times greater risk of disease than white individuals [7]. Glaucoma, a collection of optic neuropathies which result from chronic progressive degeneration of retinal ganglion cells. It is categorized into two main categories: Primary Open Angle Glaucoma (POAG) and Primary Angle-Closure Glaucoma (PACG) based on the anatomy of the angle. POAG is the most common form of glaucoma (90% of cases), which occurs when there is increased resistance to flow of aqueous humor through the trabecular meshwork. PACG is characterized by narrow or closed angle of aqueous humor drainage, causing obstruction through the uveoscleral pathway [8,9].

AMD is a multifactorial progressive degenerative retinal disease triggered by retinal deposits, termed drusen, which result in central vision loss predominately in adults over the age of 60. Pertinent risk factors include older age, cigarette smoking, hypertension, and hyperlipidaemia [10]. There are two broad categories: non-neovascular or “dry” AMD and neovascular or “wet” AMD. Non-neovascular AMD is the more common subtype (85-90% of cases), which has a more favourable visual prognosis [11]. Non-neovascular AMD is typified by geographic macular atrophy at the center of the fundus. Neovascular AMD is the less common subtype but has a poorer visual prognosis, accounting for 80% of vision loss for individuals with AMD. In neovascular AMD, choroidal neovascular membranes form because of angiogenesis by vascular endothelial growth factor (VEGF) release, which causes haemorrhage and exudation in the retina [12].

Diabetes is a condition that inhibits the production of insulin (type 1) or the absorption of sugars (type 2). It can be a persistent, lifelong illness that impacts various organs in the body, with the eye being among them. DR is the most common microvascular complication of diabetes mellitus, occurring in 30-40% of diabetic individuals [13]. Major risk factors of DR include longer duration of diabetes diagnosis, greater levels of hyperglycaemia and hypertension. The pathogenesis of diabetic retinopathy is marked by hyperglycaemia-induced vascular abnormalities of the retina. It is categorized into two stages: Non-Proliferative Diabetic Retinopathy (NPDR) and Proliferative Diabetic Retinopathy (PDR). NPDR is an early-stage DR, which is characterized by microaneurysms, retinal haemorrhages and hard exudates. PDR is a late-stage DR, and is defined by neovascularization, vitreous haemorrhage, and retinal detachment [14].

This study seeks to investigate the prevalence of glaucoma, AMD and DR in western New York and assess whether any significant health disparities exist with regards to age, gender, and race. Furthermore, this study aims to explore the current literature on screening modalities for glaucoma, AMD and DR. Specifically, we seek to understand whether Artificial Intelligence (AI) algorithms and Optical Coherence Tomography (OCT) data sets can be used for the early detection diagnosis of glaucoma, AMD and DR. Earlier diagnosis will increase treatment and thus prevent the loss of vision from these diseases.

Methods

Literature Review

An extensive literature search was conducted via PubMed of peer-reviewed articles related to the topics of AI and/or OCT for screening of glaucoma, AMD and DR. A total of 152 abstracts were reviewed and assessed for relevance.

Data source

To compare prevalence of AMD, glaucoma and DR within Monroe and Erie counties in comparison to New York State and the US, this study utilized data from the Vision and Eye Health Surveillance System (VEHSS) – a program developed by the Center of Disease Control and Prevention (CDC) Vision Health Initiative (VHI). The VEHSS aims to assess the burden of vision loss and ocular disorders and the eye care infrastructure in the United States. In addition, it aims to inform health professionals, researchers, policy makers and patients on the existing disparities [15]. The VEHSS includes retrospective data analyses from multiple data sources to generate composite prevalence scores that estimate the disease burden across the national, state and, occasionally, county level using Medicare as the primary data source. These analyses include de-identified information such as enrolment, eligibility, service use, diagnoses, and payments in Medicare [15]. The VEHSS reports this anonymized, publicly available data and permits its publication without any explicit consent [15].

Study Population

Patients enrolled in Medicare with AMD, Glaucoma and DR diagnosed between 2014 and 2019 were included. We compared diagnoses at the level of US national, New York State, Monroe, and Erie counties. The national and state-wide prevalence of all three diseases is reported and is further stratified by age and gender for all years between 2014 and 2019. Data stratified by racial/ethnic groups (Asian, Black/African American, Hispanic, Native American, and White) is reported for 2019 only as county level race data is not available for years prior to 2019.

Using census data estimates from 2020, the national US population was 331,464,948 with New York state having a population estimate of 20,202,320. Monroe and Erie counties had populations of 759,430 and 954,231, respectively [16]. Monroe county has diverse ethnic groups (68.9% White alone, not Hispanic or Latino; 16.6% Black or African American; 9.9% Hispanic or Latino; 3.9% Asian; 0.4% North American Native). Erie county has a similar distribution of racial and ethnic groups (73.5% White alone, not Hispanic or Latino; 14.1% Black or African American; 6.1% Hispanic or Latino; 4.8% Asian; 0.8% North American Native) [16].

Results

The prevalence of AMD in 2019 for patients enrolled in Medicare was 9.37% (N=29,607,800), 11.18% (N=1,549,100), 6.61% (N=32,500), and 9.56% (N=49,300) for US National, New York State, Monroe and Erie counties, respectively. For glaucoma, the prevalence in 2019 was 13.6%, 19%, 11.71%, and 13.05% for US National, New York State, Monroe and Erie counties, respectively. Finally, the prevalence of DR was 3.11%, 3.55%, 3.01%, and 2.97% for US National, New York State, Monroe, and Erie counties, respectively. These results along with trends across years 2014 to 2018 are summarized in Supplementary Table 1. In general, the prevalence of AMD and glaucoma increased across all locations while the prevalence of DR decreased across all locations between 2014 and 2019.

US National | All ages, genders, and races				
Year	**Sample Size**	**Crude Prevalence [95% CI] (%)**		
		AMD	**Glaucoma**	**DR**
2014	29,974,000	8 (7.9 - 8)	12.7 (12.7 - 12.7)	3.5 (3.5 - 3.5)
2015	30,028,300	8.4 (8.4 - 8.4)	12.9 (12.9 - 12.9)	3.4 (3.4 - 3.4)
2016	30,424,200	9.1 (9.1 - 9.1)	13 (13 - 13)	3.1 (3.1 - 3.1)
2017	30,239,200	9.1 (9.1 - 9.1)	13.1 (13.1 - 13.2)	3.2 (3.1 - 3.2)
2018	29,909,000	9.2 (9.2 - 9.2)	13.3 (13.3 - 13.3)	3.2 (3.2 - 3.2)
2019	29,607,800	9.37 (9.36 - 9.38)	13.6 (13.59 - 13.61)	3.11 (3.1 - 3.11)
New York | All ages, genders, and races				
Year	**Sample Size**	**Crude Prevalence [95 % CI] (%)**		
		AMD	**Glaucoma**	**DR**
2014	1,619,700	9.1 (9 - 9.1)	17.8 (17.8 - 17.9)	4.4 (4.4 - 4.5)
2015	1,604,000	9.8 (9.8 - 9.8)	18.1 (18.1 - 18.1)	4.3 (4.2 - 4.3)
2016	1,618,200	10.7 (10.7 - 10.8)	18.1 (18.1 - 18.2)	3.6 (3.6 - 3.7)
2017	1,589,000	10.9 (10.8 - 10.9)	18.3 (18.3 - 18.4)	3.6 (3.6 - 3.6)
2018	1,566,100	11 (10.9 - 11)	18.6 (18.6 - 18.7)	3.6 (3.6 - 3.7)
2019	1,549,100	11.18 (11.13 - 11.23)	19 (18.94 - 19.06)	3.55 (3.52 - 3.58)
Monroe County | All ages, genders, and races				
Year	**Sample Size**	**Crude Prevalence [95 % CI] (%)**		
		AMD	**Glaucoma**	**DR**
2014	36,000	5 (4.8 - 5.2)	11.2 (10.9 - 11.5)	5.1 (4.9 - 5.4)
2015	36,700	5.4 (5.2 - 5.6)	11 (10.7 - 11.3)	4.7 (4.5 - 5)
2016	35,800	6.1 (5.8 - 6.3)	10.9 (10.6 - 11.3)	2.7 (2.5 - 2.9)
2017	35,600	6.3 (6 - 6.5)	11.2 (10.9 - 11.5)	2.7 (2.6 - 2.9)
2018	33,600	6.4 (6.1 - 6.7)	11.4 (11 - 11.7)	3.1 (2.9 - 3.2)
2019	32,500	6.61 (6.34 - 6.88)	11.71 (11.36 - 12.06)	3.01 (2.83 - 3.21)
Erie County | All ages, genders, and races				
Year	**Sample Size**	**Crude Prevalence [95 % CI] (%)**		
		AMD	**Glaucoma**	**DR**
2014	57,900	7.6 (7.4 - 7.9)	11.5 (11.2 - 11.8)	4.3 (4.1 - 4.5)
2015	57,900	8.3 (8.1 - 8.5)	11.7 (11.4 - 12)	4.1 (4 - 4.3)
2016	56,700	9.4 (9.1 - 9.6)	12 (11.7 - 12.3)	3.1 (3 - 3.3)
2017	54,900	9.2 (9 - 9.5)	12.3 (12 - 12.5)	3.1 (2.9 - 3.2)
2018	50,900	9.3 (9 - 9.5)	12.6 (12.3 - 12.9)	3 (2.8 - 3.1)
2019	49,300	9.56 (9.3 - 9.82)	13.05 (12.76 - 13.35)	2.97 (2.83 - 3.13)

Supplementary Table 1: Trends across US National, New York state, Monroe county and Erie county for Age-related macular degeneration (AMD), glaucoma and Diabetic Retinopathy (DR) between 2014 and 2019 for all ages, genders and races.

Prevalence by Age and Sex

Between 2014 and 2019, the prevalence of AMD increased with age and individuals 85 and older had a higher prevalence of AMD in Monroe County than Erie County as seen in Figure 1a. Figure 1b shows that females had a higher prevalence for AMD than males in both Monroe and Erie counties. In addition, Erie County had a higher prevalence of females with AMD than Monroe County. Trends for glaucoma showed increased prevalence in age in both Monroe and Erie counties with both counties having similar prevalence values as seen in Figure 2a. Similarly, both counties showed increased prevalence of glaucoma in females as seen in Figure 2b. DR had a higher prevalence in both Monroe and Erie counties for individuals aged 65 to 84 with Monroe County having a higher prevalence than Erie County as seen in Figure 3a. There were no differences between males and females for prevalence of DR in both Monroe and Erie counties as shown in Figure 3b.

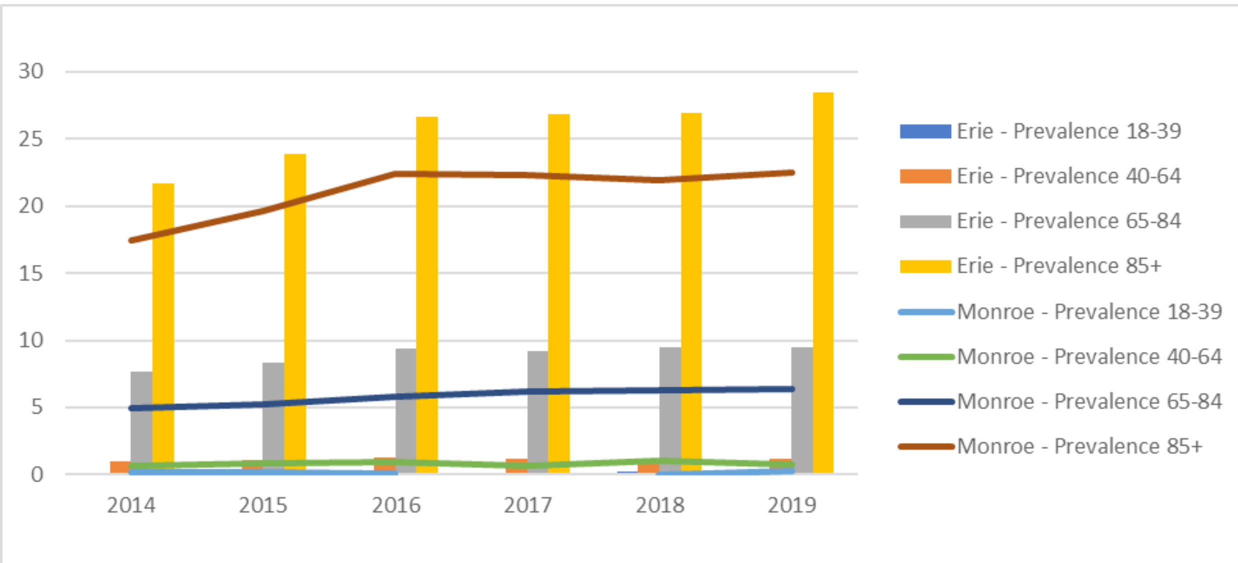

Figure 1a: Prevalence of Age-related Macular Degeneration (AMD) across age between 2014 and 2019 for Erie and Monroe counties.

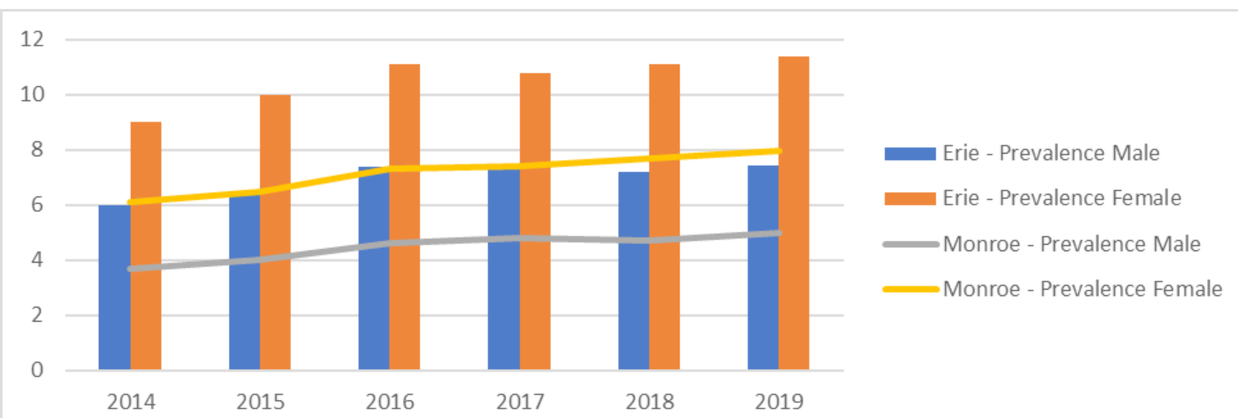

Figure 1b: Prevalence of Age-related Macular Degeneration (AMD) across genders between 2014 and 2019 for Erie and Monroe counties

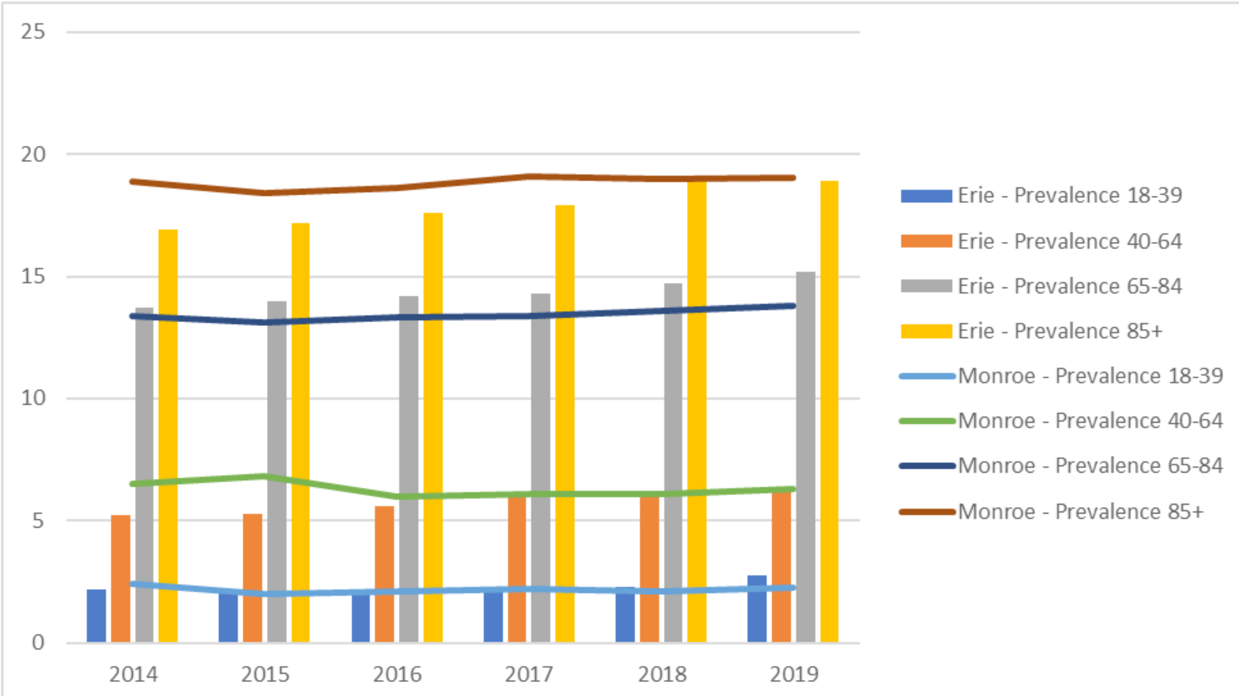

Figure 2a: Prevalence of Glaucoma across age between 2014 and 2019 for Erie and Monroe counties.

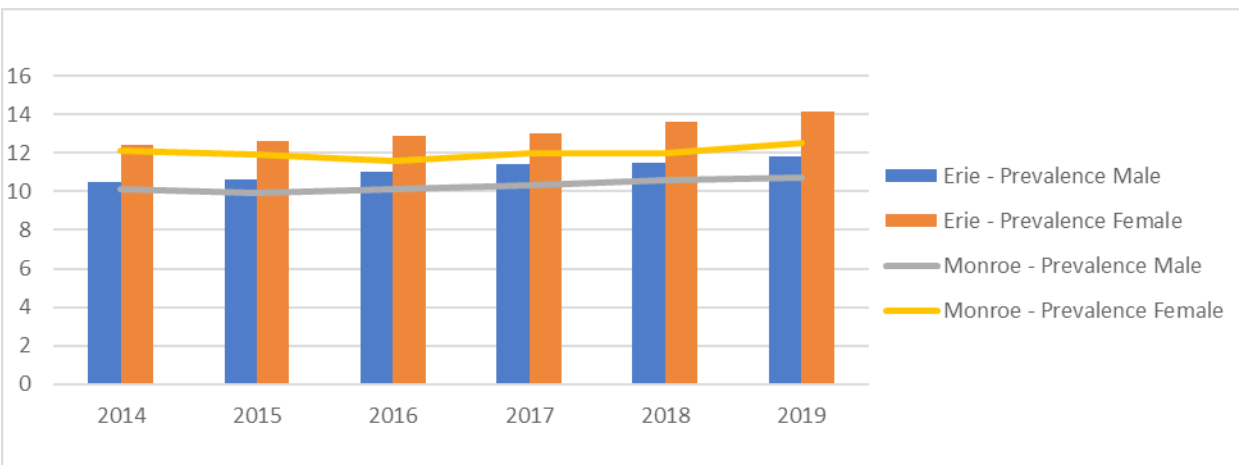

Figure 2b: Prevalence of Glaucoma across genders between 2014 and 2019 for Erie and Monroe counties.

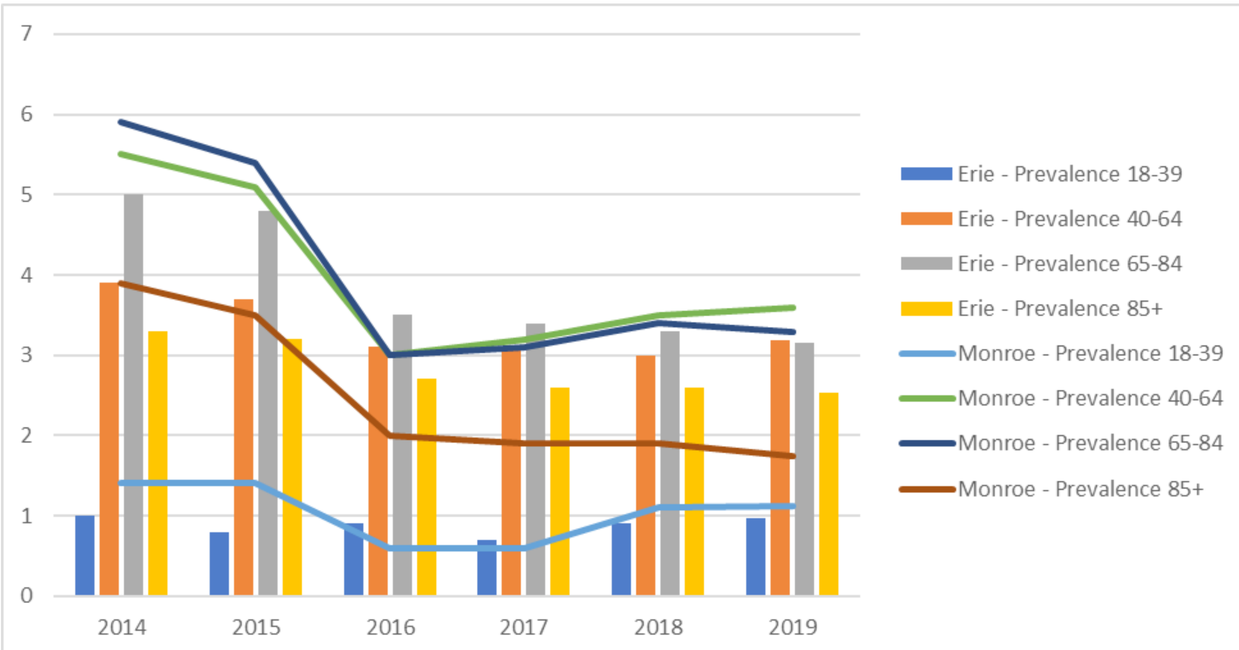

Figure 3a: Prevalence of Diabetic Retinopathy (DR) across age between 2014 and 2019 for Erie and Monroe counties.

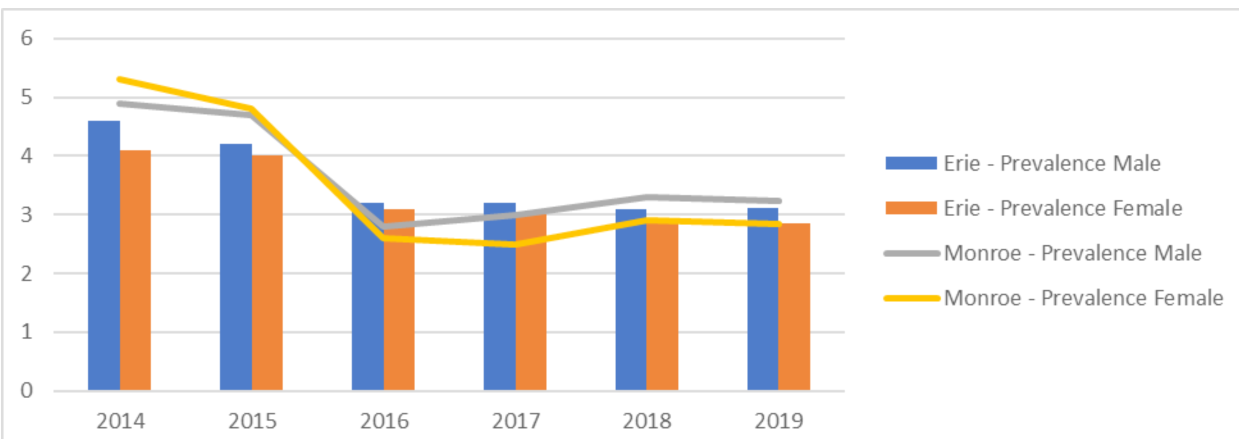

Figure 3b: Prevalence of Diabetic Retinopathy (DR) across gender between 2014 and 2019 for Erie and Monroe counties.

Prevalence by Race

Differences between racial groups in 2019 show that the highest prevalence of AMD was among White non-Hispanics while the lowest prevalence was in Black non-Hispanics. Across all races, prevalence for AMD was higher in Erie County compared to Monroe County with the exception of North American Natives as seen in Figure 4a. Similarly, Glaucoma had a higher prevalence in Erie County compared to Monroe County across all races except North American Natives. Asian and Black non-Hispanic groups had the highest prevalence of Glaucoma in Erie County compared to other racial groups as seen in Figure 4b. White non-Hispanics had the lowest prevalence of DR among all racial groups with no difference between counties. Black non-Hispanics and Hispanics had similar rates of DR across both counties as seen in Figure 4c.

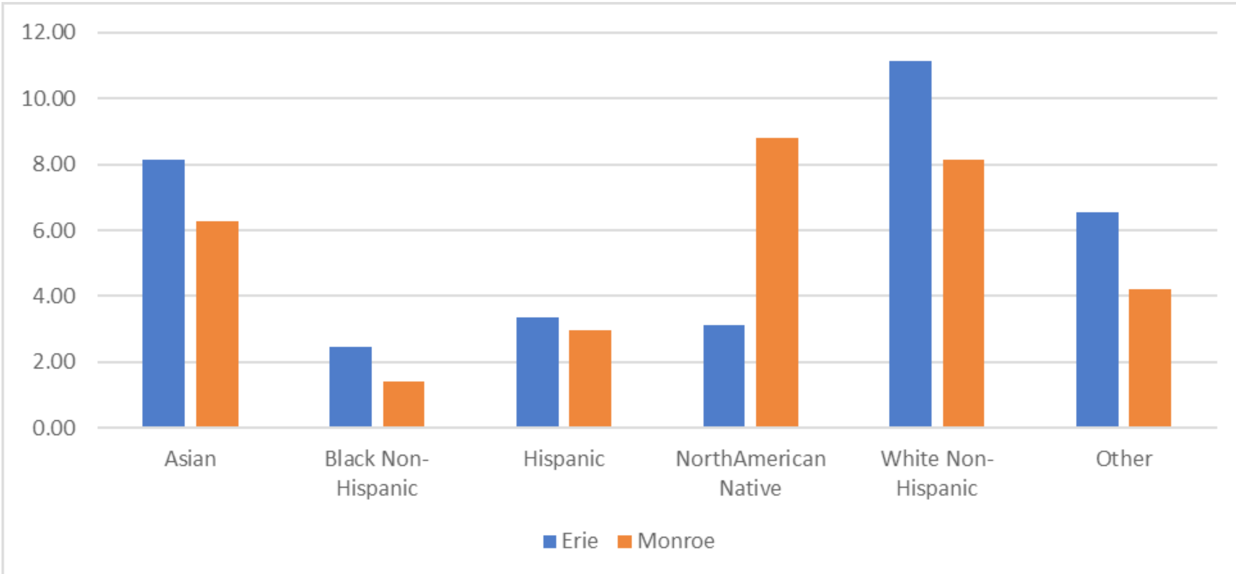

Figure 4a: Prevalence of Age-related Macular Degeneration (AMD) across racial groups in 2019 for Erie and Monroe counties.

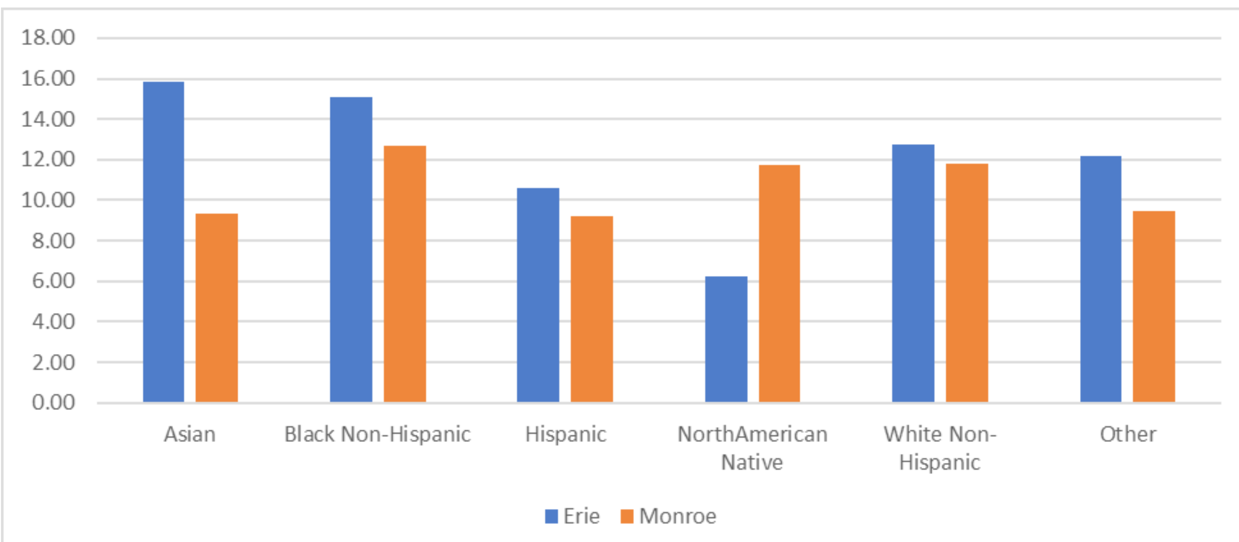

Figure 4b: Prevalence of Glaucoma across racial groups in 2019 for Erie and Monroe counties.

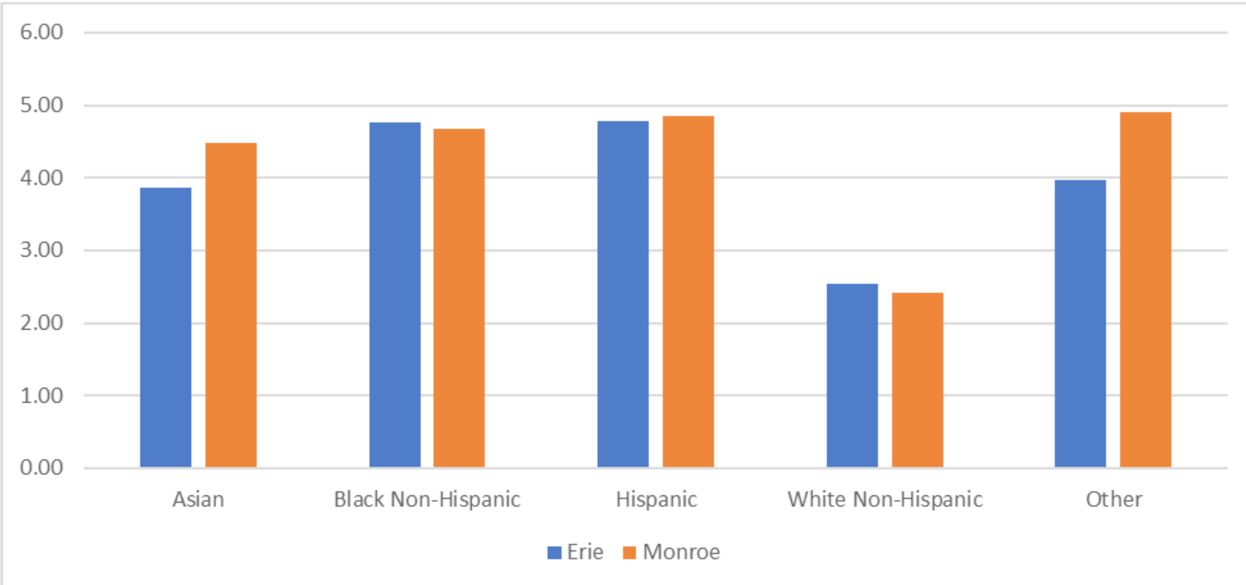

Figure 4c: Prevalence of Diabetic Retinopathy (DR) across racial groups in 2019 for Erie and Monroe counties.

Based on the review of literature, advancements in the field of ophthalmology have incorporated Artificial Intelligence (AI) algorithms in the analysis of fundus photos and Optical Coherence Tomography (OCT) data sets for the early detection of glaucoma, AMD, and DR [17-19].

OCT is a non-invasive imaging modality that can capture Retinal Nerve Fiber Layer (RNFL) degeneration, findings which may preclude other structural pathology before the disease becomes clinically visible [13]. Researchers have developed AI algorithms which extract pertinent features from OCT images to predict the existence of glaucoma damage [20]. A recent meta-analysis to assess AI performance on glaucoma diagnosis found that OCT-based AI algorithms had a high degree of accuracy, with a 96% area under the curve. However, this meta-analysis found that most authors reviewed did not undergo external data validation, meaning that these AI models may not be applicable to a real-world clinical setting [21].

Furthermore, a systematic review analyzing AI algorithms in the screening of diabetic retinopathy found that most of the studies reviewed had a high degree of sensitivity and specificity for diagnostic performance, 80%-100% and 84%-99%, respectively, which exceeds the suggested performance requirement for a screening measurement [22]. Additionally, AI algorithms have also shown promise for detection of AMD. For example, recent studies have found that AI-OCT methods demonstrated good performance in identifying early macular atrophy in AMD. However, most of the studies were limited by small sample sizes and lack of diversity in study populations for development of AI models [23].

Discussion

Ultimately, adopting AI algorithms and OCT data to screen for the most common ocular diseases that cause blindness may be an effective method to mitigate health disparities in visual health outcomes. For example, in western NY, diabetic retinopathy has the highest prevalence among Black and Hispanic patients. If AI algorithms and OCT data are widely adopted to screen for this condition, timely intervention may impede the progression to severe stage disease of irreversible blindness, preventing further exacerbation of racial health disparities. However, before these measures are employed, further research is necessary to ensure that AI models are reflective of the United States general public with large, diverse sample sizes. By doing so, AI and OCT based screening methods will be better suited to detect glaucoma, AMD, and DR in demographic groups with the highest prevalence of disease.

Health equity frameworks are critically important to the success of emerging AI technologies within the field of ophthalmology. Health equity is defined as the state in which every individual has a fair chance of obtaining optimal health. By ensuring that vulnerable populations with the highest burden of eye diseases can be appropriately managed, screening tools must be adept at identifying disease in these individuals. Furthermore, intentional efforts from hospital systems, ophthalmology departments and researchers must prioritize making the screening tools more equitable so that every patient can have their best visual health [24].

Notably, social determinants of health can have a devastating impact on an individual's disease status or prognosis. According to the US Department of Health and Human Services, these are the societal, political, or structural factors that influence one's health such as economic stability, education access and quality, health care access, neighbourhood and built environment, and the social and community context [25,26]. For example, multiple studies have shown that increased poverty and lower socioeconomic levels are associated with an increased risk of glaucoma and greater disease severity [27]. Given that underserved communities are more adversely impacted by the social determinants of health with worse disease prognosis, AI utilization could be profoundly useful particularly for marginalized groups to prevent irreversible blindness.

Additional considerations to advance health equity in vision care includes teleophthalmology, which is a telecommunication tool which can be used either synchronously or asynchronously to aid in the screening, diagnosis, and treatment of various eye diseases. Teleophthalmology offers the ability for specialists to collaborate over geographical distance using digital images and videos to aid in patient care management. These modalities have been shown to be clinically efficacious in multiple settings [28]. Importantly, this modality can increase vision care to marginalized communities and in rural and remote areas with historical barriers to high-quality vision care. Collectively, these efforts may mitigate the widespread disparities in vision outcomes for glaucoma, AMD and DR.

Moreover, endeavours to promote inclusivity within the ophthalmology profession can contribute to the reduction of racial disparities in the prevalence of glaucoma, AMD, and DR. This ongoing initiative has proven to be highly effective. Countless studies have shown the multiple benefits of diverse professional groups including increased cultural competency, knowledge base and care for underserved populations in underserved areas. Despite these numerous benefits, there is still more work to be done is order to achieve an ophthalmology workforce that is representative of the United States population. As of 2021, only 2.7% of all US practicing American Academy of Ophthalmology Members identified as Black, compared to 12.1% of Black people in the general US population. However, initiatives such as the Rabb-Venable Excellence in Ophthalmology Research Program (RV) and the Minority Ophthalmology Mentoring (MOM) program are both examples of successful efforts to increase representation of underrepresented minorities within the field of ophthalmology.

Additional methods to mitigate health disparities in visual outcomes include ensuring adequate health literacy for patients. According to the US Government's Health People 2030 initiative, health literacy is defined as the degree to which individuals can find, understand, and use information and serves to make health-related decisions. In the field of ophthalmology, low health literacy is associated with increased rates of diabetic retinopathy and lower medication adherence in patients with glaucoma. The average American adult reads at an eighth-grade reading level. When coupled with the complexity of medical terminology, this makes understanding treatment plans exceedingly difficult for many patients. Therefore, to ensure proper health literacy, clinicians must be attentive to patient needs and distribute health information in a meaningful way. Examples include tailoring health information to the intended population, keep reading materials to a fourth to sixth grade reading level, and educate patients about online education resources and social media [29]. By employing these methods, a greater reduction in eye health disparities can be achieved.

Diversity in clinical research is another approach to mitigate racial disparities in visual health outcomes. Clinical trials are regarded as the "gold standard" to evidence-based healthcare delivery are one of the primary ways of trailblazing medical innovation. However, studies have shown that there is a dearth of diversity among clinical trial participants. For example, African Americans comprise only 15% of clinical trial participants. Multiple factors have been identified that explain the lack research engagement: perceived personal risk and fear, distrust in the medical community, relationship with primary care provider, diversity in healthcare, time commitment and cost of participation. With these barriers in mind, researchers can develop initiatives and programming to address and overcome these obstacles to greater diversity in clinical trials. With increased diversity, research findings may become more generalizable to the American public [30] as Munroe county is a great example of most large cities.

Limitations

This study has several limitations. Firstly, it relied solely on Medicare data, which imposed restrictions on the subset of numbers that could be analyzed. Additionally, the study focused exclusively on Monroe County and did not encompass the entirety of Western New York or New York State. Furthermore, the evaluation of suitable services for patient care, zip code, employment and income levels were not conducted.

Conclusion

This study reveals that based on the current literature, AI and OCT holds significant promise for the early detection of glaucoma, AMD and DR. Studies have shown that AI algorithms and OCT methods demonstrate high diagnostic performance for the detection of glaucoma, AMD and DR. However, limitations of these studies include small sample size and lack of study participant diversity in the generation of AI models, impeding the generalizability of the study findings. It is crucial to implement and explore early detection techniques like OCT and AI to assist in the prevention, early detection, and management of glaucoma, diabetes, and age-related diabetic retinopathy. Additionally, addressing social determinants of health, promoting health equity in our research and treatment efforts, and incorporating health literacy in patient care and education are equally essential.

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