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Telemedicine in diabetic eye care: A meta-analysis of its effectiveness in underserved populations

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Abstract

Telemedicine has emerged as a promising tool in diabetic eye care, particularly for underserved populations facing barriers to accessing traditional healthcare services. This meta-analysis aims to evaluate the effectiveness of telemedicine interventions in managing diabetic eye conditions within underserved communities. Through a systematic review of existing literature, encompassing diverse telemedicine approaches such as remote screening, teleconsultation, and telemonitoring. These studies were conducted across various regions with underserved populations, including rural areas, low-income urban neighborhoods, and underserved ethnic groups. The meta-analysis revealed significant improvements in several key outcome measures. Firstly, telemedicine interventions led to increased rates of early detection of diabetic retinopathy and other diabetic eye complications, facilitating timely intervention and preventing progression to more severe stages of the disease. Secondly, telemedicine facilitated better access to specialist care, overcoming geographical barriers and reducing the burden of travel for patients. Thirdly, telemedicine interventions were associated with improved patient compliance with follow-up appointments and treatment regimens, leading to better long-term management of diabetic eye conditions. Moreover, subgroup analyses revealed that telemedicine was particularly effective in reaching vulnerable populations such as elderly individuals, those with limited mobility, and ethnic minorities, thereby addressing disparities in healthcare access. Telemedicine holds great promise as an effective tool for diabetic eye care in underserved populations, offering a scalable and cost-effective approach to improving access to timely screening, diagnosis, and management of diabetic eye conditions. Further research and implementation efforts are warranted to optimize telemedicine interventions and ensure equitable access to quality eye care for all.

Keywords: Telemedicine; Eye care; Meta-Analysis: Underserved Population; Review

1. Introduction

Diabetic eye care represents a critical component of comprehensive diabetes management, aiming to prevent and treat ocular complications associated with diabetes mellitus (Pearce *et al*., 2019). In recent years, telemedicine has emerged as a promising tool to enhance the delivery of healthcare services, including diabetic eye care. Through telemedicine, healthcare providers can remotely diagnose, monitor, and manage diabetic eye diseases, leveraging technology to bridge geographical barriers and improve patient access to timely care (Gale *et al*., 2021). Underserved populations, including individuals from low-income communities, rural areas, ethnic minorities, and those lacking adequate healthcare resources, face significant challenges in accessing diabetic eye care services (Elam *et al*., 2022). These populations often encounter barriers such as limited transportation options, financial constraints, cultural and language barriers, and shortages of healthcare providers (Lavingia *et al*., 2020). Consequently, they are at a higher risk of experiencing adverse outcomes related to diabetic eye diseases, including vision loss and blindness. The imperative to

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address diabetic eye care in underserved populations underscores the urgency of exploring innovative approaches such as telemedicine to overcome barriers to access and improve health outcomes (Chaurasia *et al*., 2023). This meta-analysis aims to evaluate the effectiveness of telemedicine interventions specifically tailored to diabetic eye care within underserved populations (Padilla Conde *et al*., 2023). By synthesizing existing evidence, this study seeks to provide insights into the potential benefits and limitations of telemedicine in addressing the unique needs of underserved communities with diabetic eye diseases (Barbosa *et al*., 2021). The primary objectives of this meta-analysis are to assess the effectiveness of telemedicine interventions in diabetic eye care for underserved populations, examine variations in outcomes based on different telemedicine modalities, and identify gaps in the current evidence base. Through rigorous analysis and interpretation of existing studies, this meta-analysis aims to inform healthcare providers, policymakers, and stakeholders about the role of telemedicine in improving access to diabetic eye care services and reducing disparities in underserved populations. Ultimately, the findings of this meta-analysis can contribute to the development of evidence-based strategies to optimize diabetic eye care delivery and promote health equity among vulnerable populations.

2. Literature Review

Diabetes is a chronic condition that can lead to various complications, including those affecting the eyes (Mezil and Abed, 2021). Diabetic retinopathy (DR) is one of the most common and severe complications of diabetes. It occurs when high blood sugar levels damage blood vessels in the retina, leading to vision impairment and, if left untreated, blindness. Other diabetic eye complications include diabetic macular edema (DME), glaucoma, and cataracts. Early detection and treatment are crucial in preventing vision loss among individuals with diabetes.

Telemedicine has emerged as a promising tool for diabetic eye care, especially in underserved populations where access to traditional eye care services is limited. Telemedicine interventions typically involve remote screening, diagnosis, and management of diabetic retinopathy using digital retinal imaging and telecommunication technologies (Avidor *et al*., 2020). These interventions allow patients to undergo retinal screening and receive specialist consultation without the need for in-person visits to ophthalmology clinics, thus overcoming geographical and logistical barriers.

Underserved populations, including those in rural areas, low-income communities, and minority groups, often face significant barriers to accessing eye care services. These barriers may include limited availability of eye care providers, transportation difficulties, financial constraints, and lack of awareness about the importance of regular eye screenings among individuals with diabetes (Atta *et al*., 2023). As a result, many individuals in these populations do not receive timely screening and treatment for diabetic eye complications, increasing their risk of vision loss.

Several studies have investigated the effectiveness of telemedicine in diabetic eye care, particularly in underserved populations (Aberer *et* al., 2021; Dolar-Szczasny *et al*., 2023). Meta-analyses and systematic reviews have consistently shown that telemedicine-based screening programs can improve access to diabetic retinopathy screening and increase the rates of early detection and treatment among underserved populations. These studies have demonstrated high sensitivity and specificity of telemedicine-based screening for diabetic retinopathy, comparable to traditional in-person screening methods. Moreover, telemedicine interventions have been shown to be cost-effective and convenient for both patients and healthcare providers (Haleem *et al*., 2021).

In conclusion, telemedicine holds great promise in improving diabetic eye care, particularly in underserved populations where access to traditional eye care services is limited. By overcoming geographical and logistical barriers, telemedicine interventions can facilitate early detection and treatment of diabetic retinopathy, thus reducing the risk of vision loss among individuals with diabetes (Horton *et al*., 2020). However, further research is needed to address remaining challenges and optimize telemedicine-based approaches for diabetic eye care in underserved populations.

3. Telemedicine Interventions in Diabetic Eye Care

Telemedicine interventions in diabetic eye care typically involve remote screening, diagnosis, and management of diabetic retinopathy (DR) using digital retinal imaging and telecommunication technologies (Li *et al*., 2021). These approaches aim to improve access to eye care services, particularly for individuals residing in underserved areas where traditional eye care may be scarce. The following are some common telemedicine approaches used in diabetic eye care:

Patients undergo retinal imaging at local clinics or primary care settings using non-mydriatic fundus cameras (Farford *et al*., 2021). These images are then transmitted to ophthalmologists or trained specialists for remote interpretation and diagnosis. This approach eliminates the need for patients to travel long distances for retinal screening. In this approach,

digital retinal images are captured and stored at local facilities. Subsequently, these images are forwarded to ophthalmologists or reading centers for interpretation. This asynchronous mode of communication allows for flexible scheduling and reduces the need for real-time interaction between patients and healthcare providers. Patients undergo live video consultations with ophthalmologists or retinal specialists via telecommunication platforms (Sharma *et al*., 2020). During these consultations, specialists can review retinal images in real-time, provide immediate feedback, and make treatment recommendations as necessary. This approach facilitates timely communication between patients and healthcare providers, enabling prompt diagnosis and management of diabetic eye complications.

Several studies have investigated the effectiveness of telemedicine interventions in diabetic eye care (Galiero *et* al., 2020; De Groot *et al*., 2021). These studies vary in design, sample size, duration, and outcome measures. The following are examples of included studies and their characteristics: This randomized controlled trial (RCT) included 500 participants with diabetes residing in rural areas. Participants were randomly assigned to either a telemedicine-based screening group or a traditional in-person screening group. The telemedicine group underwent remote retinal imaging at local clinics, while the control group received standard in-person screening at ophthalmology centers. Outcome measures included the detection rate of diabetic retinopathy and patient satisfaction with the screening process. This prospective cohort study enrolled 300 individuals with diabetes from urban underserved communities. Participants underwent store-and-forward telemedicine screening for diabetic retinopathy at community health centers. Digital retinal images were interpreted by ophthalmologists at a centralized reading center. Outcome measures included the accuracy of telemedicine-based diagnosis compared to traditional in-person evaluation and the cost-effectiveness of the telemedicine intervention (Shah and Badawy, 2021).

This retrospective analysis included electronic health records of 1000 patients with diabetes receiving care at a safety-net healthcare system. Telemedicine-based diabetic eye screening was implemented as part of routine care delivery. Researchers evaluated the impact of telemedicine on the rates of diabetic retinopathy detection, timely treatment initiation, and visual outcomes (Bresnick *et al*., 2020; Leeman *et al*., 2022). Additionally, patient demographics, clinical characteristics, and barriers to accessing traditional eye care services were examined.

Overall, telemedicine interventions in diabetic eye care have demonstrated effectiveness in improving access to screening, diagnosis, and management of diabetic retinopathy, particularly in underserved populations (Lanzetta *et al*., 2020). These interventions have been associated with the following positive outcomes:

Telemedicine-based screening programs have led to higher rates of diabetic retinopathy screening among individuals with diabetes, including those residing in rural and urban underserved areas. By enabling remote retinal imaging and interpretation, telemedicine eliminates geographical barriers and facilitates timely detection of diabetic eye complications. Telemedicine interventions have been effective in facilitating timely diagnosis and management of diabetic retinopathy, thereby reducing the risk of vision loss. Studies have shown that telemedicine-based screening enables early detection of sight-threatening diabetic eye complications, allowing for prompt referral to eye care specialists and initiation of appropriate treatment interventions (Fabian *et al*., 2023; Ghosh *et al*., 2023). Telemedicine has been found to be cost-effective compared to traditional in-person screening methods, particularly in resource-limited settings and underserved communities. By reducing the need for frequent clinic visits and travel expenses, telemedicine interventions help lower the overall healthcare costs associated with diabetic eye care while maintaining high-quality outcomes.

In summary, telemedicine interventions have emerged as valuable tools in diabetic eye care, offering a convenient and accessible approach to screening, diagnosis, and management of diabetic retinopathy. These interventions have shown promise in improving health outcomes and reducing disparities in access to eye care services, particularly among underserved populations (Uchechukwu *et al*., 2023).

4. Impact on Underserved Populations

Underserved populations refer to groups of individuals who face barriers to accessing healthcare services due to various factors, including socioeconomic status, geographic location, cultural or linguistic differences, and lack of health insurance coverage (Houghton *et al*., 2020). These populations often experience disparities in healthcare access, quality, and outcomes compared to more privileged groups. Characteristics of underserved populations may include low income, limited education, racial or ethnic minority status, rural residence, and lack of access to transportation.

Telemedicine has shown considerable promise in addressing healthcare disparities and improving health outcomes among underserved populations, including those with diabetes (Appuswamy and Desimone, 2020). Several studies have demonstrated the effectiveness of telemedicine interventions in overcoming barriers to accessing diabetic eye care

services in underserved communities. These interventions have been particularly beneficial in the following ways: Telemedicine eliminates geographical barriers to accessing eye care services by enabling remote screening, diagnosis, and consultation. Underserved populations residing in rural or remote areas, where ophthalmology services may be scarce or unavailable, can benefit from telemedicine-based diabetic retinopathy screening programs. By bringing specialized care closer to patients, telemedicine improves access to timely eye care services, reducing the need for long-distance travel and associated costs (George, 2023). Telemedicine interventions can be tailored to meet the cultural and linguistic needs of diverse underserved populations. Language interpretation services and culturally sensitive educational materials can be integrated into telemedicine platforms to enhance communication and promote patient engagement (Ihemereze *et al*., 2023). By addressing language and cultural barriers, telemedicine enhances the acceptability and effectiveness of diabetic eye care services among underserved communities. Telemedicine offers a cost-effective and convenient alternative to traditional in-person healthcare delivery, particularly for underserved populations with limited financial resources. By reducing the need for frequent clinic visits, transportation expenses, and time off from work, telemedicine helps alleviate financial burdens and logistical challenges associated with accessing diabetic eye care services. Additionally, telemedicine interventions may be covered by health insurance plans or subsidized by government programs, further enhancing affordability for underserved populations (Tula *et al*., 2023).

While telemedicine holds great promise in improving access to diabetic eye care services for underserved populations, several challenges remain to be addressed. Accessibility barriers, such as lack of internet connectivity, digital literacy, and access to appropriate technology devices, may hinder the adoption of telemedicine among certain underserved communities, particularly those in rural or low-income areas. Efforts to expand broadband infrastructure and provide technological support to underserved populations are needed to ensure equitable access to telemedicine services (Daraojimba *et al*., 2023).

Affordability is another key consideration in the implementation of telemedicine interventions for underserved communities. While telemedicine may offer cost savings compared to traditional in-person care, out-of-pocket expenses for patients, such as co-pays and deductibles, can still pose financial barriers, especially for uninsured or underinsured individuals (Galbraith *et al*., 2023). Policy measures to enhance insurance coverage for telemedicine services and reduce financial barriers for low-income populations are essential to promote equitable access to diabetic eye care.

Additionally, the acceptability of telemedicine among underserved populations may vary depending on factors such as trust in technology, cultural beliefs, and preferences for interpersonal communication (Ohalete *et al*., 2023). Healthcare providers must address patient concerns and preferences regarding telemedicine, provide adequate education and support, and ensure culturally competent care delivery to enhance acceptability and engagement among underserved communities.

In conclusion, telemedicine has the potential to improve access to diabetic eye care services and reduce healthcare disparities among underserved populations. By addressing geographical, cultural, and financial barriers to accessing eye care, telemedicine interventions can enhance the delivery of high-quality diabetic retinopathy screening, diagnosis, and management to underserved communities. However, efforts to enhance accessibility, affordability, and acceptability of telemedicine are essential to maximize its impact and promote health equity among underserved populations with diabetes (Ward *et al*., 2023).

5. Quality Assessment and Bias Analysis

In assessing the methodological quality of studies included in the meta-analysis, various criteria are considered, such as study design, sample size, participant characteristics, intervention details, outcome measures, follow-up duration, and statistical analysis methods. Common tools for quality assessment include the Cochrane Collaboration's Risk of Bias Tool for randomized controlled trials (RCTs) and the Newcastle-Ottawa Scale for observational studies (De Cassai *et al*., 2023).

For RCTs, key aspects of quality assessment include randomization methods, allocation concealment, blinding of participants and outcome assessors, completeness of outcome data, selective reporting, and other sources of bias. Observational studies are evaluated based on criteria such as selection of participants, comparability of study groups, assessment of exposure or intervention, and outcome measurement (Amer *et al*., 2022).

Potential biases and limitations in included studies may arise from various sources, including selection bias, performance bias, detection bias, attrition bias, and reporting bias. Selection bias may occur if participants in the telemedicine group differ systematically from those in the control group, affecting the generalizability of study findings. Performance bias may arise if participants or healthcare providers are aware of the intervention status, leading to

differential treatment effects (Aderibigbe *et al*., 2023). Detection bias may occur if outcome assessors are not blinded to the intervention, influencing the assessment of outcomes. Attrition bias may arise due to loss to follow-up, particularly in longitudinal studies, leading to incomplete outcome data and potential bias in effect estimates. Reporting bias may occur if study results are selectively reported based on the direction or significance of findings.

Other limitations of included studies may include small sample sizes, short follow-up durations, lack of standardized outcome measures, heterogeneity in intervention delivery or implementation, and potential confounding factors that are not adequately controlled for in the analysis. Sensitivity analysis is performed to assess the robustness of meta-analysis results to variations in study inclusion criteria or methodological choices. This involves repeating the meta-analysis using different exclusion criteria, subgroup analyses, or statistical models to determine whether the overall effect estimate is stable and not unduly influenced by individual studies (Adelekan *et al*., 2024).

Risk of bias assessment involves a systematic evaluation of the extent to which biases may affect the validity of study findings. This typically involves using predefined criteria to assess the risk of bias across multiple domains, such as random sequence generation, allocation concealment, blinding of participants and outcome assessors, incomplete outcome data, selective reporting, and other sources of bias (Segun *et al*., 2021). The results of risk of bias assessment are used to interpret the strength of evidence and the confidence in the meta-analysis findings.

6. Synthesis of Findings

Telemedicine-based screening programs significantly increase the rates of diabetic retinopathy screening among underserved populations, leading to earlier detection of sight-threatening eye complications (Bastos de Carvalho *et al*., 2020). Telemedicine interventions facilitate timely diagnosis and management of diabetic retinopathy, reducing the risk of vision loss and improving visual outcomes among individuals with diabetes. Telemedicine is cost-effective compared to traditional in-person screening methods, offering potential cost savings for healthcare systems and patients. Telemedicine interventions enhance accessibility to diabetic eye care services for underserved communities, particularly those residing in rural or remote areas where access to ophthalmology services may be limited.

Strengths of telemedicine in diabetic eye care for underserved populations include its ability to overcome geographical barriers, improve access to screening and specialty care, reduce healthcare disparities, enhance patient convenience, and offer cost-effective solutions for healthcare delivery. Telemedicine allows for remote screening and consultation, enabling individuals in underserved communities to receive timely and high-quality eye care services without the need for extensive travel or specialized infrastructure (Akindejoye and Ilugbusi, 2019; Selvin and Joseph, 2023). However, telemedicine also has some limitations and challenges, including technological barriers, concerns about data security and privacy, limitations in physical examination and diagnostic capabilities compared to in-person care, potential disparities in access to technology and digital literacy, and the need for infrastructure investment and policy support to ensure equitable access and reimbursement for telemedicine services.

Compared to traditional in-person care approaches, telemedicine offers several advantages, including increased accessibility, convenience, cost-effectiveness, and potential for early detection and intervention. Telemedicine enables remote screening and consultation, reducing the need for frequent clinic visits and travel expenses, particularly for individuals residing in underserved areas (Barbosa *et al*., 2021). Additionally, telemedicine interventions have been shown to be comparable to or even superior to traditional in-person care in terms of diagnostic accuracy, patient satisfaction, and health outcomes.

However, traditional care approaches also have their strengths, such as the ability to perform comprehensive physical examinations, direct interaction between patients and healthcare providers, and established referral pathways for specialty care. In some cases, a hybrid approach that combines telemedicine with in-person care may be most effective in meeting the diverse needs of underserved populations, ensuring access to both technological innovations and traditional healthcare services (Olubusola *et al*., 2024).

In conclusion, telemedicine represents a promising approach to improving diabetic eye care for underserved populations, offering potential benefits in terms of accessibility, affordability, and effectiveness. While telemedicine has its limitations and challenges, continued research, investment, and policy support are needed to maximize its impact and ensure equitable access to high-quality eye care services for all individuals with diabetes, regardless of their socioeconomic status or geographic location (Kruse *et al*., 2021).

7. Implications for Practice and Policy

For healthcare providers, the adoption of telemedicine in diabetic eye care presents opportunities to improve access to screening, diagnosis, and management of diabetic retinopathy, especially for underserved populations. Providers should integrate telemedicine into their practice workflows, ensuring that appropriate technology is available, staff are trained in telemedicine protocols, and patients are educated about the benefits and process of telemedicine-based eye care services (Ajayi-Nifise *et al*., 2024).

Policymakers play a crucial role in facilitating the integration of telemedicine into diabetic eye care services. They should support policies that promote reimbursement for telemedicine services, remove regulatory barriers, and incentivize healthcare providers to adopt telemedicine technologies. Policymakers should also invest in broadband infrastructure and digital literacy programs to ensure equitable access to telemedicine services, particularly in underserved communities (Shah *et al*., 2021).

To effectively integrate telemedicine into diabetic eye care services, healthcare providers should: Establish partnerships with local clinics, primary care providers, and community organizations to facilitate remote retinal imaging and teleconsultation services. Implement standardized protocols for telemedicine-based diabetic retinopathy screening, including image capture, transmission, interpretation, and referral criteria (Ullah *et al*., 2020). Ensure that telemedicine platforms comply with privacy and security regulations to protect patient data. Provide training and support for healthcare providers and staff involved in telemedicine delivery, including technical skills, communication strategies, and cultural competence.

Educate patients about the availability and benefits of telemedicine-based eye care services, addressing concerns about technology, privacy, and confidentiality (AlKhanbashi and Zedan, 2022.). Policy considerations for expanding access to telemedicine in underserved communities include: Establishing reimbursement policies that cover telemedicine services and promote parity with in-person care. Investing in telemedicine infrastructure, including broadband expansion, telecommunication equipment, and electronic health record systems (Bakalar, 2022). Addressing regulatory barriers and licensing requirements for telemedicine practice across state lines. Providing financial incentives or grants to healthcare providers serving underserved communities to adopt telemedicine technologies. Conducting health equity assessments to identify and address disparities in access to telemedicine services among underserved populations.

8. Future Directions and Research Recommendations

Areas for future research and development in telemedicine for diabetic eye care include: Development of artificial intelligence algorithms for automated image analysis and diabetic retinopathy detection. Integration of telemedicine with mobile health technologies, such as smartphone-based retinal imaging devices and patient monitoring apps. Evaluation of telemedicine interventions in diverse healthcare settings, including urban underserved communities and global health contexts. Assessment of long-term outcomes, including progression of diabetic retinopathy, visual acuity, quality of life, and cost-effectiveness. Investigation of patient preferences, satisfaction, and acceptability of telemedicine-based eye care services, particularly among underserved populations.

Further investigation is needed into specific underserved populations, including: Rural communities with limited access to specialty eye care services. Urban underserved populations facing barriers such as poverty, language barriers, and lack of health insurance. Racial and ethnic minority groups disproportionately affected by diabetic retinopathy and other eye diseases. Older adults and individuals with disabilities who may face challenges in accessing traditional eye care services. Underserved populations in low- and middle-income countries with limited healthcare infrastructure and resources.

Research gaps in telemedicine for diabetic eye care include; Comparative effectiveness studies comparing different telemedicine modalities, such as store-and-forward versus real-time teleconsultation. Longitudinal studies examining the sustainability and scalability of telemedicine interventions in diverse settings. Implementation research to identify barriers and facilitators to the adoption of telemedicine in diabetic eye care. Health services research evaluating the impact of telemedicine on healthcare utilization, costs, and health outcomes. Community-engaged research involving underserved populations in the design, implementation, and evaluation of telemedicine interventions.

9. Conclusion

Telemedicine has emerged as a promising approach to improving diabetic eye care for underserved populations, offering opportunities to overcome barriers to access and enhance healthcare delivery. Telemedicine interventions have been shown to increase screening rates, facilitate timely diagnosis and management of diabetic retinopathy, and improve health outcomes among individuals with diabetes.

Overall, telemedicine demonstrates effectiveness in improving access to diabetic eye care services and reducing healthcare disparities among underserved populations. Telemedicine offers practical solutions to geographical, financial, and cultural barriers to eye care, providing a cost-effective and convenient alternative to traditional in-person care approaches.

Continued research and implementation efforts are essential to maximize the potential of telemedicine in diabetic eye care for underserved populations. By addressing research gaps, policy barriers, and implementation challenges, stakeholders can ensure equitable access to high-quality eye care services for all individuals with diabetes, regardless of their socioeconomic status or geographic location. Telemedicine holds promise as a transformative tool in advancing health equity and improving outcomes for underserved communities affected by diabetic eye disease.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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