Review Article

A current status of teleophthalmology in low- and middle-income countries: literature review

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Conflict of Interest

No potential conflict of interest relevant to this article was reported.

ABSTRACT

Background: Teleophthalmology is being actively implemented in developing countries. Using sound information and communication technology (ICT), it has been significantly improving service provision in the field of eye health such as screening for diabetic retinopathy (DR), which can be prevented by early diagnosis and treatment even in resource limited settings. This study is exploring the usability of teleophthalmology in Low- and Middle-Income Countries (LMICs) while systematically reviewing how it is adopted to each domain and eye diseases.

Methods: The study searched for all literature regarding teleophthalmology in LMICs using PubMed, Cochrane Library, and Google Scholar published from January of 2005 and October of 2017. Two independent researchers found 362 literatures, and 67 articles were finally selected through sets of criteria including PRISMA method.

Results: The study identified 26 articles for DR, 10 for retinopathy of prematurity, and 31 for the rest of the eye diseases. LMICs account the most with 36 articles. The most widely used technical domain for teleophthalmology was ‘sensor and point of care diagnostics,’ which depicts the device-dependent-characteristic of teleophthalmology. When the stage of the research is post-pilot, the most widely used technical domain became ‘provider to provider communication.’

Conclusion: A major part of Teleophthalmology is providing services through mobile or portable devices. We also found that application of teleophthalmology is more active where there is firm social infrastructure for ICT.

Keywords: Telemedicine; Developing countries; mHealth; Ophthalmology

INTRODUCTION

eHealth is a concept to provide health services embracing education and health information through computer, telephone, or other mobile communication methods. It also includes the use of mobile communication, referred as mobile health (mHealth). World Health Organization adopted eHealth as a priority for Universal Health Coverage (UHC) at the World Health Assembly in 2005 as it is acknowledged as an effective measure to achieve UHC.¹ It

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is a cost-effective tool to strengthen health system by extending health service coverage, improving accessibility, and enhancing capabilities.^{2,3}

The field of Ophthalmology also recognized eHealth as an innovative approach in Low- and Middle-Income Countries (LMICs). As stated in the study of Bastawrous and Hennig,⁴ an inverse correlation is found between the global burden of eye diseases and the number of ophthalmologists in the area (inverse care law). For last 50 years, despite international efforts to confront the challenges, the level of outcome is still not meeting the needs due to the brain drain and financial shortcomings. However, technology such as a medical device that is basically consisted with portable-sized add on optical parts to the camera of smartphones, is in favor of teleophthalmology, a branch of telemedicine in ophthalmology. It eliminated the barriers of eye health services that previously were limited by heavy weight and high cost of equipment. It maximized the advantage of telemedicine in ophthalmology in which diagnosis and data collection are mostly image based.⁵ As the outcome showed high potential of the image analysis, ophthalmology has become the favored area for the most advanced eHealth platform.⁶

Because of its various advantages regarding health accessibility, numbers of studies suggest that teleophthalmology is useful for LMICs. However, there is insufficient amount of studies that clearly address its practical application on which domains and diseases it is used for. Therefore, the study explores previous studies regarding the application of teleophthalmology in LMICs between 2005 and 2017 through a systematic review.

METHODS

Prevalence of visual impairment and vision loss

Literatures were searched at 3 databases: PubMed, Cochrane Library and Google Scholar. Using the databases, the Brazilian study of 2005 was searched as the first conducted in LMICs. Therefore, the scope of the study is from 2005 to October of 2017.

The study was conducted by Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) which is a reporting guideline for a systematic review. It is beneficial that necessary materials can be obtained via PRISMA official website without any registration.

Furthermore, we also used COSI model (Core, Standard, Ideal) which considers optimal source of information for the study. It is very effective consisting of 3 components; Core search (to search keywords within available sources), Standard search (to utilize various information derived from reference search), and Ideal search (to conduct hand-search related journal or newspaper, including above 2 search strategy). In order not to omit related studies, we strategically divided keywords into the ones reflecting 'technical area of the study' and 'economic status of the target countries.'

Keywords reflecting 'technical area of the study' were 'teleophthalmology,' 'mHealth,' 'telemedicine,' 'telecommunication,' 'mobile health,' 'cellular phone/cell phone,' 'mobile device,' 'smart device' and 'tele-eyecare,' which were searched with conjugation 'OR' in between keywords. After completing the search regarding the technical area of the study. The study ruled out the literatures conducted in high income countries or developed countries by keywords related to the 'economic status of the target countries' such as 'Developing Nations,' 'Least Developed Countries,' 'Less-Developed Countries,' 'Less-Developed Nations,'

'Third-World Countries,' 'Third-World Nations,' 'Under-Developed Countries,' and 'Under-Developed Nations,' using conjugation 'OR' in between keywords. Lastly, in order to prevent missing the concerned countries, all countries listed as LMICs on the World Bank Countries List was searched connected by "OR." The search was conducted in October of 2017.

Reviewed literatures were selected by inclusion and exclusion criteria which had been already established in early stage. The inclusion criteria were the studies conducted in LMICs according to the classification system of the World Bank's national income cutoffs. Moreover, the studies had to have contents regarding teleophthalmology defined as 'patient's eye related problems being examined, investigated, monitored, and treated, even though the eye care specialist and patient are located in different geographical areas.' We also included the aspects of the capacity building of eye health for non-eye specialized medical personnel through telemedicine methods. The selection was undertaken by 2 researchers (Kim S, Youn H) independently. Both researchers have master's degree in public health and qualified to conduct the research. After the screening, each study lists were matched. When finding disagreement between the researchers, third person (Yoon S) mediated for agreement after series of discussions.

Duplicated literatures were excluded from the list. Then studies with following criteria were excluded; not written in English, not conducted in LMICs, and pre-clinical studies. At the first stage, literatures were screened by title and abstract. At the second stage, literatures were selected after thorough full-text review.

Total number of literatures searched for this study was 362. By database, 167 were found PubMed, 10 from Cochrane Library and 185 from Google Scholar, respectively (**Fig. 1**). All were searched following strategy. After removing 169 duplications, the researchers screened

Fig. 1. Flowchart of literature selection of the study.

193 studies with inclusion and exclusion criteria. In final, 115 studies were excluded through the screening for the following reasons; not implemented in LMICs (16), grey literatures or not published articles (9), not relevant topic (28), not written in English language (5), and duplication between the 2 independent researchers (68).

RESULTS

An overview of teleophthalmology programs currently deployed in LMICs

In the study, 67 articles were selected through suggested inclusion/exclusion criteria. Majority of studies implemented in the Lower-Middle-Income Countries (n=36), 21 studies were from the Upper-Middle-Income Countries (n=21), and only 10 studies were from Low-Income Countries (Fig. 2A).

India accounts the largest number of articles (n=25) followed by China, South Africa, Kenya, and Thailand. The remaining 1–3 studies were conducted in the rest of the world. Economic status is correlated with telecommunication infrastructure in the countries. Development of teleophthalmology is considerably dependent on telecommunication infrastructure.⁷ In Kenya, many studies were conducted despite the fact that the country had relatively lower income level compared to others. In contrast, Philippine has a National Telehealth Center and telehealth programs on non-communicable diseases that are actively implemented. Only one study was identified suggesting low demand for teleophthalmology.⁸

Types of diseases applied in the teleophthalmology studies are as shown in Table 1. Most studies focus on diabetic retinopathy (DR) of which application pattern is quite consistent with the conventional clinical method. It was followed by retinopathy of prematurity (ROP)

Fig. 2. (A) Number of articles classified by income level. (B) Number of articles classified by diseases.

Table 1. Number of articles classified by domain-disease

Values	Diabetic retinopathy	Retinopathy of prematurity	Glaucoma	Refractive error/vision screening	Age-related macular degeneration	Cytomegalovirus retinitis	Cataract	Primary eye screening
Client education and behavior change communication (1)	1	1	2	1				
Sensor and POC diagnostics (2)	4	8	3	2	1	2	2	11
Restores and vital events tracking (3)		1						
Data collection of reporting (4)	2	5	4	3	1	1	1	5
Electronic health records (5)	1	3	1	1				2
Electronic decision support (6)		4						1
Provider and provider communication (7)	12	4	3	2			3	7
Provider education (8)	1	2	1	1		1	1	1

POC = point-of-care.

for which the importance and the need for the screening is demanding while lacking human resources with adequate expertise. Fifty four out of 67 articles focus on the fundus image-based diagnostics including DR, ROP, age-related macular degeneration (ARMD), cytomegalovirus (CMV) retinopathy, and the optic nerve analysis based diagnostic diseases including glaucoma, accounting for 67% of the total. The result suggests that fundus camera application is responsible for a large portion of the development in teleophthalmology. There also were studies applied teleophthalmology on cataract or refractive error, the 2 most prevalence eye diseases. This infers that conventional diagnostic pattern is still more widely used (**Fig. 2B**).

There are more studies regarding the posterior segment of the eye rather than the anterior segment even though it is quite simpler to take the image of anterior segment. It is ironically because procedures to collect and diagnose eye diseases that concern posterior segment are by far more challenging. There have been numbers of approaches to overcome the obstacles in controlling eye diseases regarding anterior segment such as cataract even without the introduction of mHealth. For example, allied health professionals such as mid-level ophthalmic personnel can be trained in short amount of time for the screening of cataract, and such strategy has been adopted in the field for years now. Of course, synergetic effect of the mHealth and utilizing allied health professionals is expected as fifteen studies reported on the effectiveness and efficiency of primary eye care can be maximized when combined with task shifting through mHealth, the most advantageous aspect of teleophthalmology. More concrete example of the case would be the very first and largest real-world application of utilizing non-physicians to grade and refer ROP. The study of Vinekar et al.,⁹ presented that even in the situation shortage of specialists, services for ROP can be delivered through mHealth and that it can be useful for other LMICs with comparable economic and medical settings.

The study examined the successful factors of teleophthalmology in each article. Successful factors in each article was categorized as shown in the **Table 2 (Fig. 3)**.¹⁰ The first important factor in teleophthalmology is strengthening access in terms of health service delivery. Such result may be highlighted because teleophthalmology programs were conducted in remote rural areas where health service accessibility is low. It is not very different for effectiveness and efficiency. It is to measure a program's cost-effectiveness or efficiency compared to existing method, rather than simply providing health services. Effectiveness and efficiency are major factors used for impact evaluation when telehealth or mHealth programs are expanding to community level after pilot stage. The result shows that teleophthalmology is becoming one of the up-rising alternatives in marginalized areas.

Table 2. Categorization of successful factors

Factors	Description
Accuracy	High sensitivity and specificity
Satisfaction	High satisfaction level of beneficiaries or end-users
Effectiveness and efficiency	There is evidence for effectiveness or efficiency in comparison with traditional way of ophthalmology
Useful information	Safety procedure/guideline/recommendation has been yielded from the study
Accessibility	Marginalized people, whom may not have received proper eye health services otherwise, have received appropriate medical attention through teleophthalmology that study utilized
Competency of providers	The service providers are well trained to utilize the teleophthalmology that study utilized, or the service providers are highly confident with the method
Compliance	The compliance of beneficiaries/patients are high
Representativeness	The sample size is big enough to represent the study group
Not applicable	Not applicable for any of the categories above

Fig. 3. Number of articles by successful factors.

Low compliance suggests technology-based innovation may have barriers at early stage due to digital illiteracy.¹¹ Moreover, only 2 studies were identified for representativeness. It reflects on the current limitation of teleophthalmology that scale-up model is not well-established, and evidence is insufficient to guide decision on policy.¹²

In the analysis of successful factors by disease type, achievement of accessibility is important in DR and primary eye screening for which community-based approach is used. There are more studies on the effectiveness and efficiency for DR where application of teleophthalmology approaches are relatively advanced in terms of quantity and quality. Of a few articles on glaucoma, effectiveness and efficiency studies were accounted for a relatively large part. The result shows high percentage of competency for CMV retinitis. This suggests that competency of general physicians in deciding whether to refer to the health institution of higher level is significantly increasing in HIV/AIDS clinics, leading to program's success. It implicates that, similar to ROP, non-ophthalmologists are able to bring expected outcome if they are well trained with teleophthalmologic devices.

Approached to teleophthalmology in domains of mHealth

The study also identified mHealth domains that teleophthalmology was applied. The reference was originally developed for Reproductive, Maternal, Newborn Child Health (RMNCH) mHealth interventions which adequately encompasses telehealth applications.¹³ Using this RMNCH framework as a reference has a profound advantage because it specifically deals with health systems rather than technologies. It was developed through the consultation from the stakeholders, which include academia and policy makers, and it exemplifies where opportunities and constraints exist in the health system for mHealth strategies. It is practical in

determining the beneficiaries of particular mHealth strategies and demonstrating the particular barriers of targeted health system. Therefore, the same 12 domains in the framework were used for the analysis of telehealth systemic literature review in non-communicable diseases.¹⁴

Of the domains, the largest number of studies focused on ‘sensor and point of care diagnostics’ followed by ‘provider to provider communication’ (Fig. 4). It reflects the characteristics of ophthalmology that has relatively high dependency on equipment, suggesting imaging device is essential for the diagnosis of eye diseases. Given the result that many studies focus on the development of device, teleophthalmology is now at pilot stage where newly developed devices are being implemented for validation before it becomes an adequate program and fully adopted to the field.

Of the programs that completed the initial pilot study, ‘provider and provider communication’ was the main domain. For community based teleophthalmology through task shifting, communication between high-level health service providers and with low cadre providers were the core domains.

‘Registries/vital tracking’ was widely applied in RMNCH. However, in this study, only one related article was found. It is mainly because teleophthalmology programs are designed to deliver continuous care like non-communicable diseases once a patient is registered unlike RMNCH, which records vital events after registration. A relatively high rate of data collection of reporting domain shows differences in characteristics between ophthalmology and RMNCH. There are many R&Ds on electronic decision supporting in developed countries. It appears that it has not reached the level where it can be applied to developing countries.¹⁵ However, like a case in Kenya, there have been pilot programs implemented in developing countries in association with research institutions from developed countries. Lastly, unlike education and behavior change using SMS messaging found effective in HIV/AIDS or tuberculosis mHealth projects, the result shows that it was not applied as much.¹⁶

Table 3 shows a cross-analysis of domains and diseases. Teleophthalmology with high dependency on equipment are DR and primary eye screening. In DR, which is relatively well programmed and adopted in the communities, ‘provide and provider communication’ takes a large part for task shifting.

Fig. 4. Number of articles classified by domains.

Table 3. Number of successful factors by disease

Successful factors	Diabetic retinopathy	Retinopathy of prematurity	Glaucoma	Refractive error	Age-related macular degeneration	Cytomegalovirus retinitis	Cataract	Primary eye screening
Accessibility	12	4	4	3	2	1	3	10
Effectiveness and efficiency	8	3	3	2		2	1	3
Useful information	3	1	1				1	2
High satisfaction	1	1		1				
Competency of participants	1		1	1		2		1
High sensitivity & specificity	2	1						
Representativeness		1						1
Compliance			1					

In case of ‘electronic decision support,’ while majority of studies focus on DR and ARMD in developed countries, ROP shows the highest utilization. It may reflect on insufficient number of sub-specialists in the department of ophthalmology in developing countries whereas ROP requires pediatric ophthalmologist or retinal specialist to confirm the diagnosis. In case of glaucoma, one of chronic eye diseases, data collection of reporting was higher than the other diseases. It is because glaucoma requires series of exams on intraocular pressure and optic nerve.

DISCUSSION

The purpose of this literature review was to identify current status of teleophthalmology in LMICs while exploring its future direction. Through this literature review, we were able to confirm that there are differences of utilization of the technology depend on the economic status of nation, types of diseases, and domain of the usage.

First, telecommunication infrastructure is a profound foundation of the development of teleophthalmology. According to the results of the study, there are scarce of cases in the least developed countries while there is vivid utilization of the technology in the middle-income countries. This result demonstrates its correlation with telecommunication infrastructure, which is highly dependent on the country's economic status.^{17,18} Moreover, studies in Kenya clearly suggested that teleophthalmology programs can be executed in the suitable information and communication technology environment supported by foreign research funding. Therefore, the fact infrastructure as social capital is the basic foundation of teleophthalmology is confirmed. There is high correlation between the characteristic of the diseases and domain and successful factor.

Teleophthalmology is most frequently used for DR and ROP, and these 2 diseases depict following 2 advantages of teleophthalmology. The most vigorously advancing area of teleophthalmology regards devices, which reflects the fact that it is the most challenging barrier of eye health services in conventional method of provision. Conventional fundus camera is expensive and heavy while lacking mobility, which makes it only installed in tertiary hospitals out of reach of patients from rural communities. When teleophthalmology that solves problems of conventional devices is introduced DR and ROP is most rapid and proliferated are of the usage of the technology. Therefore, attaining accessibility is the most successful factor of teleophthalmology and there are pre-requisite domain technologies. In addition, there is ‘provider to provider communication’ factor in case of ROP since it is a solution for extremely low number of pediatric ophthalmologists and neonatal intensive units by eye clinics far from them through teleophthalmology.

The study anticipated the future trend of teleophthalmology being more proliferate in LMICs through the literature review. The rate of increasing prevalence of blindness-causing eye diseases is faster than the expansion of health services in LMICs, and, Teleophthalmology can be a solution for these problems.¹⁹⁻²² Like other non-communicable diseases, eye diseases are now considered to cause a 'double burden' in the developing countries. It refers to the situation that health institutions, health personnel, and health care infrastructures cannot properly function. With still existing burden of infectious diseases and mother and child health, the burden increases with the growing prevalence of chronic disease. Moreover, eye disease is a risk factor of diabetes, high-blood pressure. Other chronic diseases are resulting the burden of eye diseases in developing countries. If the problem of geographical and time barriers along with the lack of human resources can be solved with a relatively low cost, accessibility can substantially be increased. Due to these advantages, considerable number of developing countries are recently introducing the concept of teleophthalmology to their health systems.²³

Another reason would be that it is becoming fairly easy to introduce teleophthalmology and to enhance its capabilities. Mobile devices are becoming cheaper and lighter even though their functions are more advanced.^{24,25} Smartphone is becoming a profound mediator to save and transfer images, and advanced user-interface let even people without proper education may use it.²⁶⁻²⁸ Faster speed and wider coverage telecommunication environment is very much friendly for teleophthalmology.

For the further development of teleophthalmology, following limitations need to be improved. First of all, there is uneven distribution of the countries subject to this study because there are limited number of countries that have both capacity, such as infrastructure, and needs for teleophthalmology. For instance, Thailand became one of the leading countries regarding teleophthalmology researches after establishing teleophthalmology system between Bangkok and health centers in remote rural areas. The disparity of teleophthalmology amongst countries is expected to be increasing, and this clearly demonstrates that it has strong correlation with socio-economic infrastructure.²⁹⁻³³ Second, there are certain eye diseases that more focused in teleophthalmology than others. It can be explained as following. It is a refraction of that disease burden caused by cataract and other cornea diseases is decreasing while there is increasing disease burden of posterior eye diseases. Moreover, it is already possible to provide proper diagnosis for anterior of eye diseases with simple devices such as flash torch. Lastly, results of the studies referred in this paper still do not provide the validity of teleophthalmology. Even aspects regarding devices, which takes the largest portion of the domains, there are scarce number of cases that has been scaled up with market power. There are more studies that have concerns for exaggerations regarding the functions and effectiveness of the devices.²⁴ There is a weakness of portable devices that image quality cannot be assured when optical axis is well-aligned. Moreover, there is no standard for the light sources, and some devices are using the Flash LED that does not assure safety. Therefore, international standard and accreditation should be supplemented regarding the devices.³⁴⁻³⁶

The study explored literatures concerning the status of teleophthalmology in LMICs from 2005, and there are limitations as followings. First of all, even though the search was conducted using the World Bank Countries Lists, the fact that India and Kenya take more than half of the implementing sites distinctly demonstrates that there is biased selection of the countries. Moreover, there is a possibility of opting out valuable studies from Lusophone

countries like Brazil or Francophone countries like Senegal since only literatures written in English were considered. Lastly, the study only included articles published prior to October of 2017. Since the number of researches regarding artificial intelligence based teleophthalmology skyrocketed after the indicated year, it clearly is one of the limitations of the study.

Taken together, teleophthalmology is in the process of proliferating in LMICs because it is a promising solution to overcome constraints in eye health system like accessibility and low health resources. There are still hurdles in terms of Infrastructure, scalability and validation for new technologies, but it is anticipated that teleophthalmology will be applied to the areas in need of health service provision. The study found its implication on exploring the current status of teleophthalmology and scoping the direction of the field.

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