Article • The Validity of Ocular Health Testing in Tele-Optometric Eye Examinations in a Young Adult Population

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ABSTRACT

Background: The global COVID-19 pandemic has accelerated the transition from traditional care to telehealth in many facets of healthcare. Access to healthcare in otherwise remote locations, increased accessibility to appointments, and continuity of care are some of the more apparent advantages. This study aimed to compare anterior segment findings, posterior segment findings, and intraocular pressure (IOP) measurements between traditional in-person examination and tele-optometric examination.

Methods: A cohort of 30 optometry students was recruited to complete two comprehensive eye examinations. A tele-optometric comprehensive eye exam was completed by an in-person technician via the DigitalOptometrics platform and video conferencing with an investigator optometrist. This was then followed by the gold standard in-person comprehensive eye exam by one of the investigator optometrists. Both eye examination methods included anterior and posterior segment evaluation, as well as IOP measurements. The tele-optometric examination used a 14-second Reichert slit lamp video recording to evaluate the anterior segment and the Eidon ultra-widefield retinal photographer to evaluate the posterior segment. DFE was completed with 90D biomicroscopy and binocular indirect ophthalmoscopy. Intraocular pressure (IOP) measurements were taken via non-contact tonometry (NCT) by an in-person technician for the telehealth exam, while the gold standard IOP measurement, Goldmann applanation tonometry (GAT) with Fluress, was taken by the investigator optometrist.

Results: In chi-square statistical analysis, there was a statistically significant difference between telehealth and in-person anterior segment findings ($\chi^2=6.8$ and $p=0.009$). Further analysis with Fisher's exact test also showed a significant difference in anterior segment findings between telehealth and in-person ($p=0.031$). We could not perform chi-square statistical analysis on posterior segment findings because the data was not validated for chi-square analysis. In t-test statistical analysis, there was no statistically significant difference between telehealth and in-person IOP OD ($p=0.166$) and OS ($p=0.076$) measurements. The agreement in IOP between telehealth and in-person was also evaluated with Bland-Altman analysis, using the 95% limits of agreement, which corresponds to ±1.96* standard deviation of the differences between telehealth and in-person measurement.

Conclusion: Based on our study design, we cannot conclusively state that telehealth is comparable to in-person exams when comparing anterior and posterior segment findings. When comparing IOP measurements, NCT in telehealth exams and GAT in in-person exams, the findings were comparable in accuracy. We are aware that there are trends in our results, but future studies should be designed specifically to address these gaps in analysis and limitations.

Keywords: remote care, telehealth, tele-medicine, tele-ophthalmology, tele-optometry

Introduction

Healthcare has experienced a recent acceleration towards telehealth. This has been most apparent since the COVID-19 pandemic, which has catapulted many healthcare fields to transition care to telehealth versus the traditional methods of real-time or face-to-face examinations. Eye care has emerged at the forefront of this transition with technological advances that not only further enable the visualization of ocular structures non-invasively but also allow for testing via remote methods.[1-5] The potential to provide increased healthcare in areas with otherwise limited access is the main advantage of telehealth. Other advantages such as elimination of travel time, greater access to appointments, and convenience to both patient and provider have emerged. In recent unprecedented times, telehealth has surfaced to be a safer alternative to traditional exams without the potential for unnecessary coronavirus exposure or loss of care.[2] Undoubtedly, there has been some hesitancy towards adopting this newer method of eye care delivery due to questionable reliability as compared to traditional methods, but recent studies have strongly demonstrated the contrary. The effectiveness of this powerful tool for both screening measures and diagnosis of some of the most common acute and chronic ocular diseases in both adult and pediatric patients is strongly apparent.[4-6] This study in particular aimed to determine whether tele-optometric examination is comparable to the traditional in-person examination when diagnosing anterior and posterior ocular health abnormalities, as well as when measuring intraocular pressures (IOP) in a cohort of optometry students.

Methods

This prospective study was conducted at the Illinois College of Optometry. The study proposal was approved by the institutional review board (IRB) at the Illinois College of Optometry, and it adhered to the tenets of the declaration of Helsinki. A cohort of 30 optometry students was recruited to participate in the study, excluding those with known active ocular disease or recent ocular surgery. There were 9 males and 21 females in the study; the mean age of the participants was 24.7 years old with a range from 22-33 years. All chart documentation of data was reviewed separately for both anterior segment and posterior segment abnormalities by three different reviewers. An agreement was considered such if the same findings were noted in both telehealth and in-person exams.

Written and verbal consent were obtained from all participants. All participants completed two comprehensive eye examinations. A tele-optometric comprehensive eye exam was completed by an in-person technician via the DigitalOptometrics™ platform and video conferencing with an investigator optometrist. This was then followed by the gold standard in-person comprehensive eye exam by one of the investigator optometrists. Both eye examination methods included anterior and posterior segment evaluation, as well as IOP measurement. The tele-optometric examination used a 14-second Reichert slit lamp video recording to evaluate the anterior segment and the Eidon ultra-widefield retinal photographer to evaluate the posterior segment. The in-person examination used traditional slit lamp examination methods, as well as dilation with 2.5% phenylephrine (Paragon BioTeck, Inc., Portland, OR) and 1% tropicamide (Bausch + Lomb, Tampa, FL). Dilated fundus examination was completed with 90D biomicroscopy and binocular indirect ophthalmoscopy (BIO). IOP measurements were taken via NCT by an in-person technician for the telehealth exam, while the gold standard of IOP measurement, GAT with Fluress, was taken by the investigator optometrist. A one-sample Kolmogorov-Smirnov test was performed to test the distribution of IOP OD and OS for in-person and telehealth. This test showed a normal distribution and a $p>0.05$. Thus, independent t-test was performed to compare IOP by telehealth to that by in-person examination. The chi-square test was used for anterior segment statistical analysis, while t-test and Bland-Altman were used for statistical analysis of IOP measurements. We could not perform chi-square statistical analysis on posterior segment findings because the data was not validated for chi-square analysis.

Results

Anterior Segment

When comparing anterior segment results between telehealth and in-person examination, 23 participants out of 30 (77%) matched in findings. The specific anterior segment findings that were noted can be found in Figure 1, while the specific anatomical locations can be found in Figure 2. In chi-square statistical analysis, there was a statistically significant difference between telehealth and in-person anterior segment findings ($\chi^2=6.887$ and $p=0.009$). Further analysis with Fisher's exact test also showed a significant difference in anterior segment findings

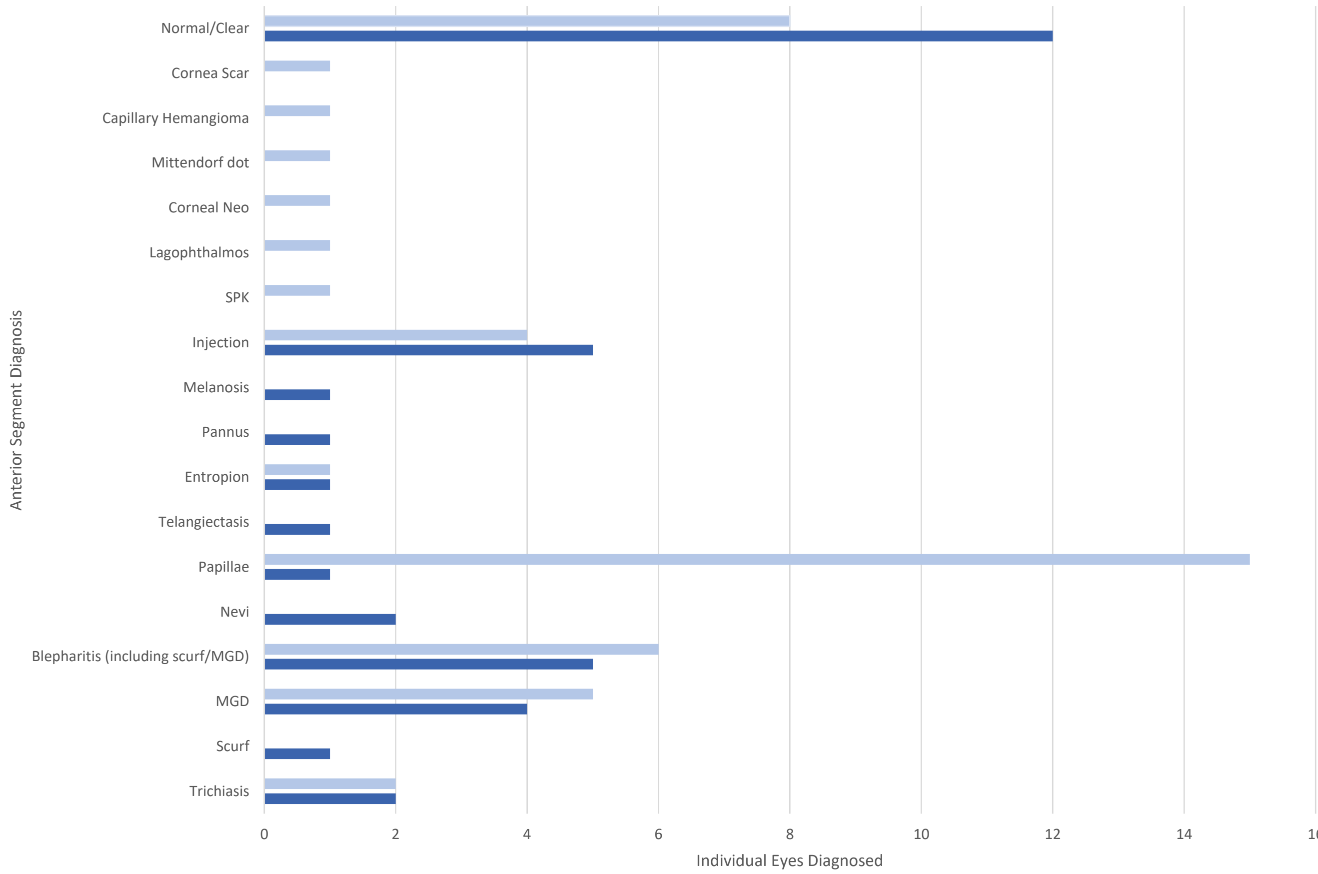

Figure 1. Comparison of telehealth vs. in-person anterior segment findings by diagnosis

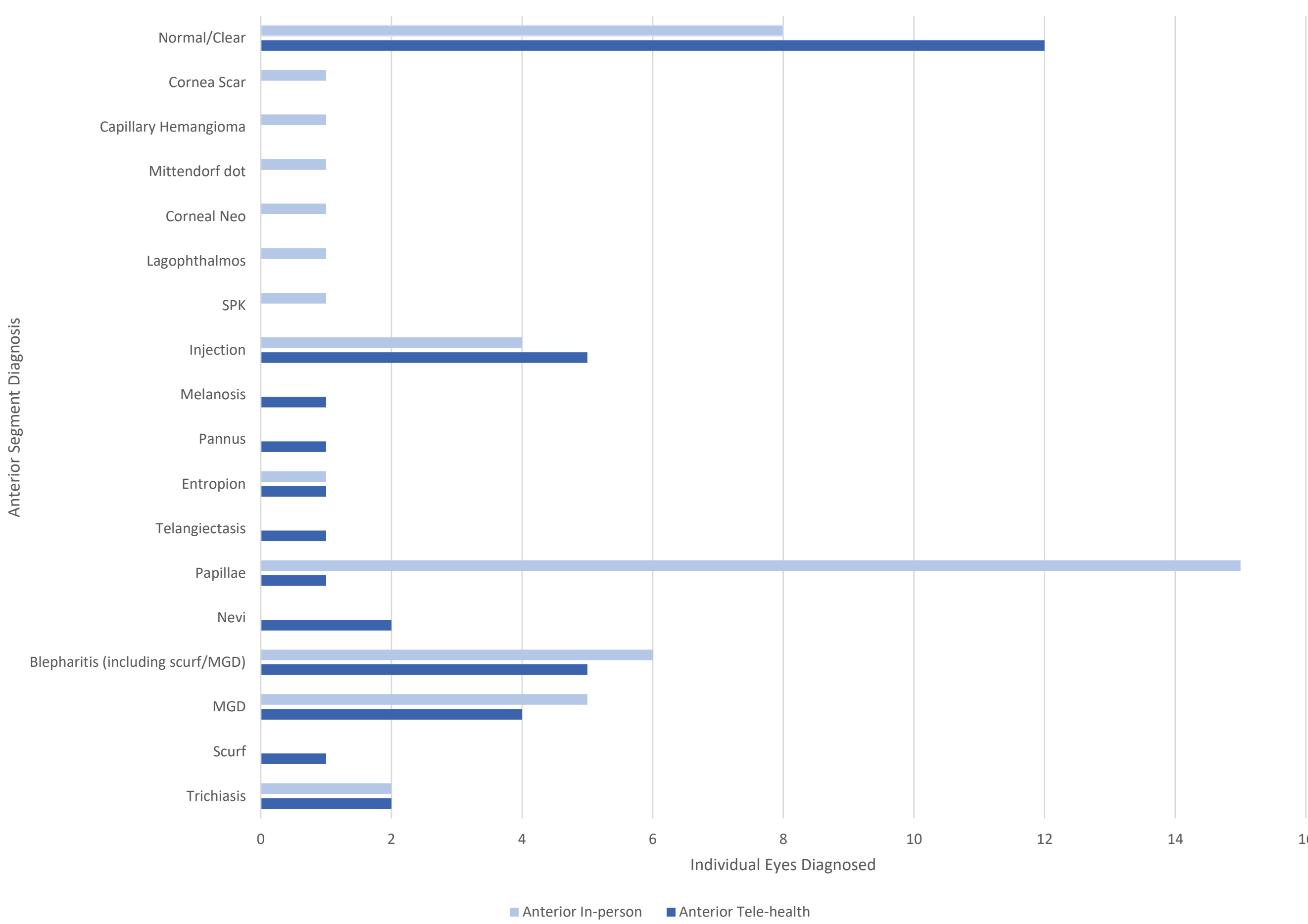

Figure 2. Comparison of telehealth vs. in-person anterior segment findings by anatomical location

Table 1. Cross Tabulation of Anterior Segment Findings

			AnteInPerson		
			No	Yes	Total
Yes = healthy No = abn	Yes	Count	3	1	4
		% within AnteInPerson	42.9%	4.3%	13.3%
	No	Count	4	22	26
		% within AnteInPerson	57.1%	95.7%	86.7%
Total		Count	7	23	30
		% within AnteInPerson	100%	100%	100%

between telehealth and in-person (p=0.031). Please refer to Table 1 for the Anterior Cross Tabulation data.

Posterior Segment

When comparing posterior segment results between telehealth and in-person examination, 28 participants out of 30 (93%) matched in findings. The specific posterior segment findings that were noted can be found in Figure 3, while the specific anatomical locations can be found in Figure 4. Chi-square statistical analysis was not able to be performed on posterior segment findings because the data was not validated for chi-square analysis. Please refer to Table 2 for the Posterior Cross Tabulation data.

Sensitivity and specificity of telehealth in identifying anterior segment abnormalities were 42.9% and 84.6%, respectively. Because telehealth did not identify any abnormalities in posterior segment findings, sensitivity was 0.0% and specificity was 100%. The receiver operating characteristic (ROC) curve for anterior segment findings reveals an area under the curve (AUC) of 0.693 (95% CI: 0.44 to 0.95), while the ROC curve for posterior segment findings reveals an AUC of 0.500 (95% CI: 0.08 to 0.92).

IOP measurements

The IOP measurements ranged from low to normal in both telehealth (9-20 mmHg) and in-person (11-20 mmHg). NCT measurements via telehealth averaged an IOP of 14.30 OD with SD ±3.92 and an IOP of 14.37 OS with SD ±3.69 mmHg, while GAT measurements via in-person exam averaged an IOP of 14.90 OD with SD ± 3.52 and an IOP of 15.07 OS with SD ± 3.42 mmHg, respectively. There was no statistically significant difference between telehealth and in-person IOP OD (p=0.166) and OS (p=0.076) measurements. The agreement in IOP between telehealth and in-person was also evaluated with Bland-Altman analysis, using the 95% limits of agreement, which corresponds to ±1.96* standard deviation of the differences between telehealth and in-person measurement. The agreement was ±4.8 mmHg OD and ± 4.1 mmHg OS, with 83% of results being within ±2.5 mmHg OD and 80% of results being within ±2.5 mmHg OS.

Table 1. Cross Tabulation of Posterior Segment Findings

			PostInPerson		
			No	Yes	Total
PostTele	Yes	Count	2	28	30
		% within PostInPerson	100%	100%	100%
Total		Count	2	28	30
		% within PostInPerson	100%	100%	100%

Discussion

Anterior Segment

The results showed that although both telehealth and in-person examinations revealed anterior segment abnormalities, in seven participants, the results were not equivalent (Table 3). In one participant, the telehealth exam noted an abnormality while the in-person examination did not. In three participants, the in-person examination noted an abnormality while the telehealth examination did not. In the remaining three participants, both telehealth and in-

Table 3. Comparison of Anterior Segment Findings in 7 Participants in Disagreement Between the 2 Methods of Collection

Subject	Anterior segment pathology observed	Eye	Tele-optometry examination (14s anterior segment video)	In-person examination (slit lamp biomicroscopy)
4	Superficial punctate keratits	OU	Not observed	**Observed**
7	Inferior trichiasis	OU	**Observed**	**Observed**
7	Papillae	OU	Not observed	**Observed**
12	Inferior nevus	OS	**Observed**	Not observed
12	Capillary hemangioma	OD	Not observed	**Observed**
21	Papillae	OU	Not observed	**Observed**
22	Inferior nasal pannus	OS	**Observed**	Not observed
22	Corneal neovascularization	OU	Not observed	**Observed**
24	Blepharitis	OU	Not observed	**Observed**
29	Meibomian gland dysfunction	OU	**Observed**	Not observed

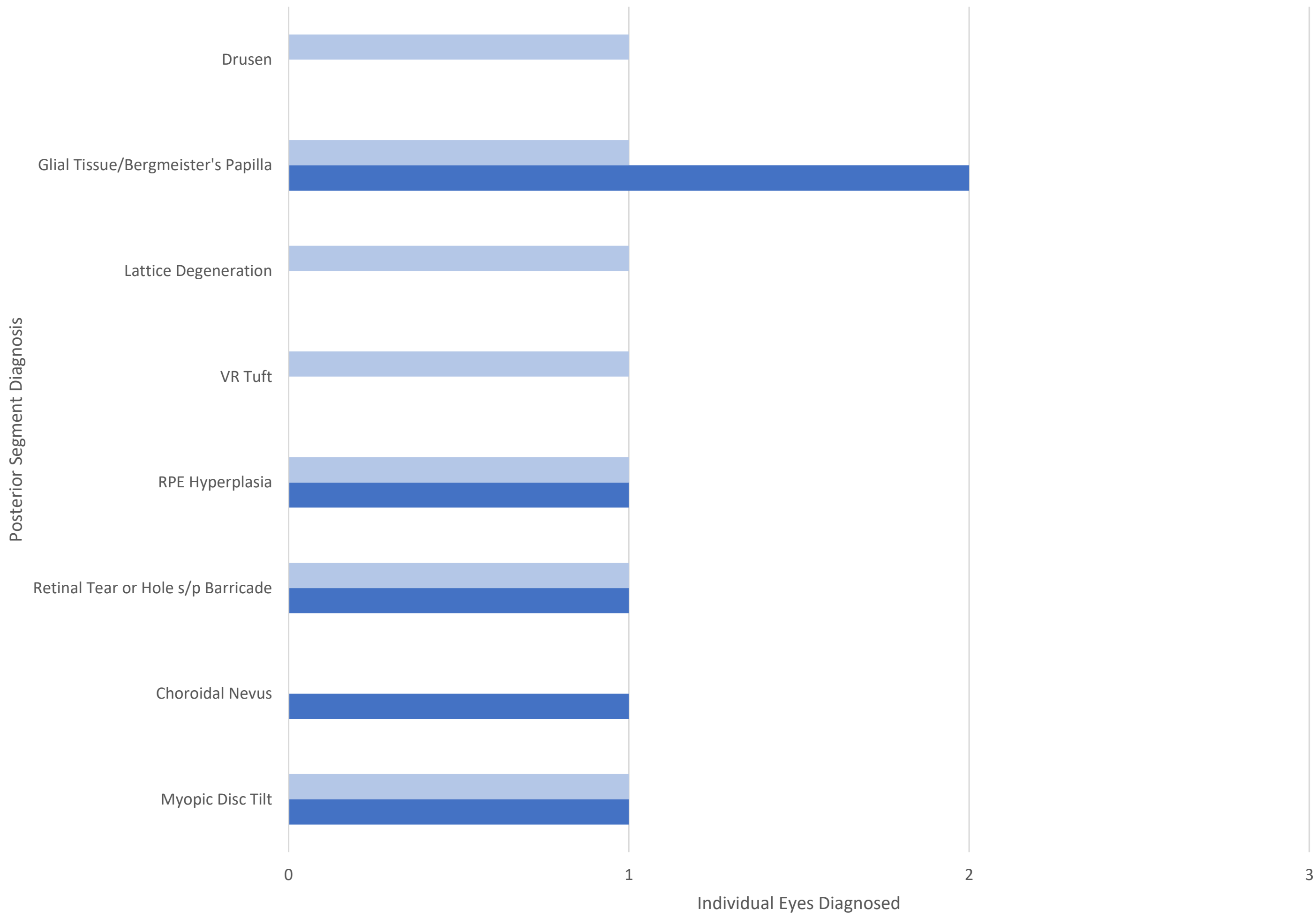

Figure 3. Comparison of telehealth vs. in-person posterior segment findings by diagnosis

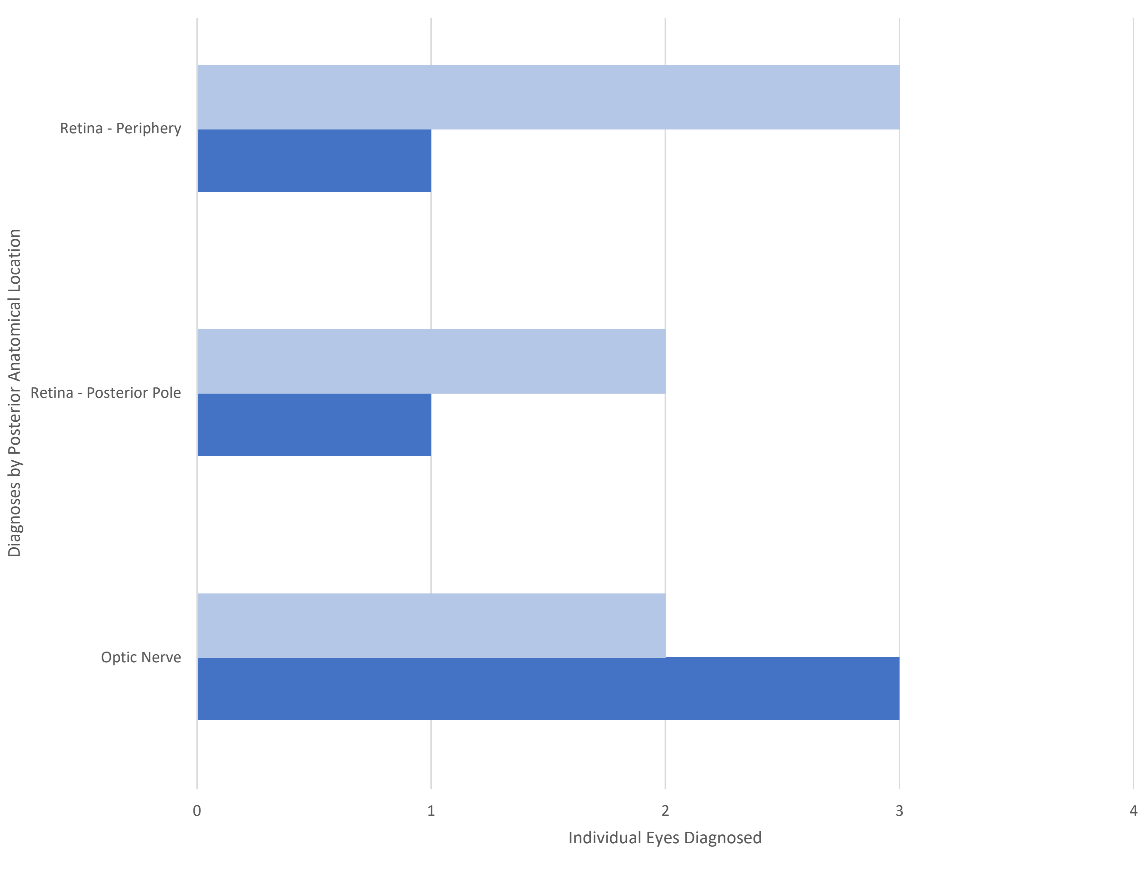

Figure 4. Comparison of telehealth vs. in-person posterior segment findings by anatomical location

person examinations determined abnormalities, but different findings were documented for the same patient. Our chi-square analysis revealed that results were statistically significant; 23% of our participants did not match in findings when comparing the two modalities. This percentage bears clinical relevance, and considerations are given for why this may have been the case. A major limitation in the telehealth examination was the inability to perform a more dynamic slit lamp examination and the lack of ability to focus on small opacities. An example of this is the marked difference in diagnosis of papillae in-person vs. telehealth (Figure 1), which can be explained by the inability to evert the eyelids during the telehealth examination. Although the 14-second prerecorded Reichert slit lamp video was of high image quality, the remote clinician was limited to a view of the patient's eye in primary gaze without the ability to change magnification, vary illumination, or manipulate the instrumentation independent of the technician. This study did not have the remote technician ask the patient to look in varying gazes, evert upper and lower eyelids, change magnification, or focus farther in particular areas of concern. The remote clinician did have the ability to replay, pause, and restart the video. These interactive options, if available, might all have helped to further diagnose anterior segment disease.

At the time of this study, the Reichert Video had not been evaluated for sensitivity or specificity in anterior segment diagnosis, but there have been multiple studies using a variety of equipment that have focused on improving anterior segment diagnosis. The iTouch5G (Apple, Cupertino, CA), the Nidek Versacam (Nidek, Fremont, CA), and PictorPlus (Volk, Cleveland, OH) have all been compared for sensitivity and specificity. The iTouch, a smartphone camera, was first compared to the Nidek Versacam, a diffuse light ophthalmic camera, with lens attachments for both anterior and posterior segment evaluation. Depending on the diagnosis, the sensitivity for the iTouch ranged from 54% to 71%, while the sensitivity for the Nidek Versacam ranged from 66% to 75%. The specificity ranged from 82% to 96% for the iTouch and from 91% to 98% for the Nidek Versacam. The PictorPlus, a nonmydriatic portable camera with anterior and posterior segment attachments, was found to have a sensitivity of 87% to 88% in conjunction with a patient clinical history.[7-9] One of the more intriguing options may be a remote controlled robotic stereo slit lamp developed by Nankivil et al.[10] Their development of a modified commercial slit lamp, the Zeiss 100, allows control of all optical and mechanical components remotely. Adjustments such as "light intensity, slit width, slit height, slit angle, biomicroscope position (front to back, side to side, up and down), and microscope magnification could all be adjusted from a remote location."[10] The slit lamp also allows for real-time stereoscopic imaging, control/position indicators, video, audio, and multiple examiners to view and to control the slit lamp simultaneously. This allows for collaboration between examiners from multiple remote locations to discuss diagnosis and treatment options for the patient further.[10] Diagnosis of anterior segment pathology via remote methods is possible, but as multiple reviews have shown, diagnostic accuracy can vary widely depending on the pathology in question and the modality of imaging used. For the purposes of this study, the ability to assume control or to request real-time changes remotely, such as adjustments to slit lamp illumination, width size, magnification, etc., might have lessened the discrepancy between in-person and tele-optometric findings.

Posterior Segment

The telehealth examination did not note any abnormal posterior segment findings, as compared to in-person examination, which observed two significant peripheral findings in two participants; 7% of our participants did not match in findings when comparing the two modalities (Table 4). From a clinician's point of view, careful consideration must be given as to why the peripheral findings were not noted on the telehealth exam. The Eidon fundus camera, which was the camera used in our study, captured high-quality, 60-degree, two-dimensional fundus images of the posterior pole, nasal, temporal,

Table 4. Comparison of Posterior Segment Findings in 2 Participants in Disagreement Between the 2 Methods of Collection

Subject	Posterior segment pathology observed	Eye	Tele-optometry examination (Eidon ultra widefield retinal camera)	In-person examination (dilated fundus exam with 90D biomicroscopy and BIO)
6	Vitreoretinal tuft	OU	Not observed	**Observed**
22	Lattice degeneration	OU	Not observed	**Observed**

superior, and inferior quadrants. The remaining peripheral fields of view were not captured within its mosaic. The remote clinician was easily able to magnify all images for further evaluation. Quite possibly, a larger mosaic encompassing these absent fields of view would have enhanced the remote clinician's ability to diagnose peripheral retinal disease. This specific limitation can be visualized in Figure 4; when comparing diagnosis between telehealth and in-person examination, the biggest disparity is noted in the peripheral findings. For example, in cases of diabetic retinopathy, Boucher et al. suggested that grading be based on two 45-degree image fields, a single widefield, or an ultra-widefield image that captures all seven standard fields; they also suggsted using the OCT as an adjunct.[5] This standard might have been beneficial in order to note additional abnormal findings in this study. Another limitation is the lack of three-dimensional analysis, which is provided with a standard 20D and 90D fundus evaluation. The Eidon images provided were only two-dimensional.

Diabetes has proven to be at the forefront of this research, with multiple diabetic telehealth programs currently in existence in the United States. Previous studies have shown that tele-ophthalmology is comparable to traditional examination in diagnosing diabetic retinopathy, with a sensitivity of 62.5%-98.2% and a specificity of 76.6%-98.7%.[11,12] One of the most robust tele-diabetic retinopathy screening programs in the country is led by the Department of Veterans Affairs. A health care professional identifies those at risk for diabetic retinopathy or those overdue for screening, then nonmydriatic digital imaging systems are used to obtain fundus photographs by trained technicians or nursing staff. A reading center receives the photographs, which are then further evaluated by eye care professionals, who make recommendations for follow-up care and evaluation.[13] Another study by the Indian Health Service Joslin Vision Network demonstrated that nonmydriatic ultrawide-field imaging compared with nonmydriatic multifield fundus photography improved the detection of diabetic retinopathy by approximately 2-fold and reduced the percentage of ungradable images by 81%. Furthermore, by using ultrawide-field imaging, peripheral lesions were identified in 10% of participants that were suggestive of more severe diabetic retinopathy.[3,14]

In retinopathy of prematurity (ROP), a 6-year retrospective analysis of 1216 premature newborns' eyes at Stanford University compared bedside binocular ophthalmoscopy with remote interpretation of RetCam II/III images. They found a sensitivity of 100% and a specificity of 99.8% in their tele-ROP program, which complements in-person examination in this high-risk population.[15] A joint review of 11 studies by the American Academy of Pediatrics and the American Academy of Ophthalmology noted the largest study in the review to have reported digital photography for detection of referral-warranted ROP to have a sensitivity of 98.2% and specificity of 80.2%.[16] Other studies have shown tele-screening to be an effective modality in diagnosing and managing ROP in infants.[17-19]

A recent study in JAMA Ophthalmology noted that remote diagnosis imaging via a U.S. Food and Drug Administration (FDA) approved noncontact, portable retinal imaging device (iFusion; Optovue) that incorporated color fundus photos and optical coherence topography (OCT) vs. a standard examination by a retinal specialist appeared to be equivalent in identifying referable age-related macular degeneration (AMD).[6] Another device, the ForeseeHome, was approved by the FDA and received Medicare coverage in 2015 to allow for home monitoring of patients with AMD-related choroidal neovascularization. Results are sent to a diagnostic center, and both patient and ophthalmologist are notified of significant changes in testing to allow for proper follow-up. This study found that choroidal neovascularization was detected earlier in high-risk patients using home monitoring.[20,21]

Like anterior segment pathology, the correct instrumentation and methods to obtain imaging are needed for accurate observation and diagnosis of posterior segment disease.

IOP measurements

The study focused solely on IOP measurements and found that NCT and GAT were comparable in accuracy. This is supported by other well-established studies, which have compared these two methods of obtaining IOPs. In a study by Chen et. al., the consistency between NCT and GAT measurements in patients with low to normal IOP was similar. However, they established that careful consideration should be given in moderate and higher IOP groups, as NCT showed a greater overestimation of IOP.[22] Another study demonstrated good agreement with GAT and NCT across a wide range of IOPs and could confidently be considered for glaucoma screening programs. Bland-Altman testing within this study revealed the 95% limits of agreement between GAT and NCT as -8.7 to 7.6.[23] Our study findings revealed a narrower 95% limits of agreement. Although GAT remains the standard for IOP measurement in most clinical settings, NCT is also considered a reliable method.

Tele-ophthalmology is not limited to retinal disease; tele-glaucoma has also been a major focus among specialists long before the COVID-19 pandemic. To expand the possibilities, a prospective study by Chandrasekaran et. al. first evaluated 107 participants in clinic then at tele-glaucoma stations. Each station tested NCT, non-mydriatic fundus photography, auto-refraction, and optic nerve-related OCT measurements. Their conclusions indicated that the tele-glaucoma protocol that they developed was comparable to a clinical examination in its ability to detect glaucoma remotely.[24] This is very promising, as it is well known that some of the greatest difficulty with glaucoma is establishing consistent follow-up and continuity of care in this particularly vulnerable population. It is also well known that the COVID-19 pandemic forced many providers quickly to reconsider how they provided such care, since multiple missed appointments could easily lead to irreversible vision loss. The approach of a more hybrid method of delivering glaucoma care was quickly adopted and since has led providers to consider these technologies as a more permanent solution in their own practices following the COVID-19 pandemic.

There are several recent studies focused on tele-glaucoma for screening and monitoring of care. High detection rates of suspicious optic nerves and ocular hypertension were found in the Philadelphia Tele-medicine Glaucoma Detection and Follow-up study.[25] A 2021 article on the use of telemedicine in glaucoma reviewed 14 research projects, all of which found promising outcomes, which ranged from an overall earlier detection and management of suspects, a high rate of detection of ocular hypertensives, and more efficiency with early-stage glaucoma management. It is important to consider that this review also mentioned a "great variation in the reported sensitivity and specificity of tele-glaucoma screening and management and therefore may require further investigation before implementing 100% remote programs."[26] Verma et. al. found that 69% of glaucoma patients seen via tele-ophthalmology could be completely managed without any in-person consultation.[27] A recent study comparing cup-to-disc ratio determined by tele-ophthalmology to in-person examinations by glaucoma specialists showed a positive predictive value of 77.5% and a negative predictive value of 82.2%.[28] Clarke et. al. concluded that patients with low risk of progression and who were followed by consultant-level glaucoma specialists can be reliably monitored by tele-glaucoma methods.[29] In a study by Odden et al. of 200 adult glaucoma patients, tele-medicine was found to be equally effective at identifying disease progression vs. in-person exam.[30]

Technologies that allow for home monitoring of IOP, remote disc photography, and visual field testing have allowed for continuity of care during the COVID-19 pandemic and are promising for the future of glaucoma care. The Sensimed Triggerfish Sensor, an FDA-approved contact lens embedded with a micro sensor, provides continuous, noninvasive monitoring of ocular dimensional changes and has also shown encouraging results in monitoring glaucoma remotely.[31,32] The Icare HOME (Icare Finland Oy, Vantaa, Finland) an FDA-approved tonometer that does not require topical anesthesia, allows for the self-monitoring of IOP from home.[33] Both technologies provide IOP measurements wirelessly to the provider. Peristat online perimetry tests 24 degrees of visual field horizontally and 20 degrees vertically via a web-based program, while Mobile Virtual Perimetry (MVP) is a smartphone-based frequency-doubling technology (FDT) that uses a virtual reality headset. Both have shown high correlation with the Humphrey Visual Field (HVF) and abnormal points.[34-36] The Melbourne Rapid Fields (MRF) is an iPad-based application that tests up to 30 degrees of visual field. When compared to traditional HVF testing, the MRF shows similar test-retest reliability and a high correlation but is more accurate at detecting moderate to severe visual field loss veersus early loss.[37,38] Smartphone disc photography shows promise but has yet to produce equivalent or higher quality undilated images as compared to standard stereoscopic fundus photographs.[39]

Although this study exclusively focused on IOP measurements in both remote and face-to-face examinations, future studies may also include a comparison of cup-to-disc ratios or HVF findings. The potential for tele-glaucoma is tremendous.

Artificial Intelligence

Although artificial intelligence (AI) has been in the picture for well over 50 years, it has come to the forefront of telehealth care due to the COVID-19 pandemic. Machine learning (ML) and deep learning (DL) algorithms, the two most common subfields of

AI, have been widely applied in the past to posterior segment disease but have recently also involved anterior segment disease strategies. AI research has focused on the detection of diabetic retinopathy, visual field testing in glaucoma, screening for AMD, classifying optic disc disease in papilledema, monitoring OCTs for progression and referrals, and predicting early to wet AMD changes. These are just some examples of applications.[40] Much of these algorithms are "self-learned predictive features from input data for labeled outcomes without being explicitly programmed to detect specific morphological features by experts. Therefore, their predictive capabilities are not restricted by the existing knowledge of disease phenotypes and progression."[40] This is a great advantage as compared to other methods of monitoring changes.

Research on posterior segment AI applications includes the IDX-DR software, which analyzes retinal images and determines whether the patient has "more than mild diabetic retinopathy," thereby prompting a referral to ophthalmology. In a recent FDA approved study, 900 patients at 10 primary care sites were able to be correctly identified with referable diabetic retinopathy 87.4% of the time.[21,41] In another study, the evaluation of retinal fundus photographs from adults with diabetes, using an algorithm based on DL, had a sensitivity of 97.5% and specificity of 98.5% for detecting referable diabetic retinopathy.[42] A dedicated AI approach for AMD achieved equivalent diagnostic accuracy as that of a retinal specialist examination. In this study, researchers used a dataset of 35,900 labeled optical coherence tomography (OCT) images obtained from age-related macular degeneration (AMD) patients and used them to train three types of convolutional neural networks (CNN) to perform AMD diagnosis. The same group then developed a website for realistic cloud computing based on this AI platform, available at https://www.ym.edu.tw/~AI-OCT/. Patients can upload their OCT images to the website to verify whether they have AMD and whether or not they may require treatment.[43] Although the greatest focus has been on posterior disease, anterior segment applications have emerged as well. Like posterior segment disease, wherein much of the focus is on AI-based OCT and fundus photography to develop rich datasets, the same can be said for the anterior segment. Much of the AI research is focused on image-based analysis involving slit-lamp photography, corneal topography, anterior-segment OCT, and specular microscopy.[44] A study by Lavrik and Valentin[45] reported a CNN called KeratoDetect that gave an accuracy of 99.3% in detecting keratoconus. In refractive surgery, AI has been used to detect eyes with high risk of iatrogenic ectasia. When compared to the Belin-Ambrosio display (BAD), the Pentacam Random Forest Index (PRFI) ML technique correctly classified post-laser ectasia (PLE) in 80% of eyes vs. the BAD, which classified only 55.3%.[46] The reliable automated detection of Descemet's Membrane Endothelial Keratoplasty (DMEK) graft dislocation was assessed with 609 attached grafts and 563 detached grafts via AS-OCT images. The sensitivity of the DL-based classifier was 98%, with a specificity of 94% and an accuracy of 96%.[47] AI technology has also been used in the diagnosis and grading of cataracts, angle-closure assessment, pterygium evaluation, and anterior angle change assessment.

AI will only improve care in the future, from early detection, assessing progression, and noting appropriate management of care when used in conjunction with tele-medicine. The long-term benefits are clear: AI has the potential to meet significantly unmet needs and clinical gaps in screening, risk stratification, and improving clinical outcomes when used in conjunction with tele-medicine.

Limitations

A cohort of optometry students is a selectively biased and homogenous sample from which to draw a conclusion for comparison. We intentionally only included participants who were older than 18, as this was a pilot study on graduate students. We hope that future studies will also evaluate this same modality in children and its role in vision screenings to allow for greater eye care accessibility. We are aware that this targeted, low-risk population is of a demographic that has a lower prevalence of ocular disease given the age range of 22-33 years old. They are also less likely to present with undiagnosed ocular disease given the inherent culture of optometry students, who are often dilated multiple times during their training by peers and other optometric providers. Optometry students are acutely aware of their own ocular health. Given that this study excluded those individuals with both known active ocular disease and ocular surgery within the last 90 days, we easily omitted these individuals and therefore were less likely to encounter an abundance of unknown conditions for further comparison via telehealth or in-person methods. In future studies, it will be imperative to include a larger and more diverse adult and pediatric study population, which more accurately reflects the patient population. Another limitation of note is that the calculated power was 0.57, which is lower than the traditional 0.8 value.

Based on the studies reviewed in this article, accurate telehealth diagnosis relies heavily on the dynamic visualization of high-quality stereo disc and retinal images, as well as live anterior segment video resolution. It is also well validated that three-dimensional fundus photographs are superior to two-dimensional photographs specific for optic nerve evaluation and show a strong correlation with ophthalmologist disc assessment.[48,49] The lack of three-dimensional stereo disc photos, the exclusion of auto-fluorescence, and the exclusion of some peripheral quadrants may have resulted in inferior disc and peripheral retinal assessment. The inability to perform further real-time manipulation of the anterior segment video, for example requesting the remote technician to increase magnification or to lower the lids, may have helped to limit anterior segment diagnosis further.

This study compared IOP via remote and in-person methods, but it is also worthwhile to explore the assessment of optic nerve cup-to-disc ratios via both methods in the future as well.

As is common in all clinical practice, there is the innate chance of inter- and intra-observer variability. This is also undoubtedly present within this study given the obvious differences between telehealth and in-person exams. Our study design does not allow for us to perform interobserver and intra-observer variability testing. The expertise of the imager or technician is key. The quality of the data obtained is dependent on who is obtaining the data and performing the testing; adequate training of staff is always necessary.

Conclusions

Based on our study design, we cannot conclusively state that telehealth is comparable to in-person exams when comparing anterior and posterior segment findings. When comparing IOP measurements (NCT in telehealth exams and GAT in in-person exams), the findings were comparable in accuracy. We are aware that there are trends in our results, but future studies should be designed specifically to address these limitations and gaps in analysis. Tele-ophthalmology has the capability to address many of the most common ocular conditions as well as to provide an option to monitor patients reliably and continuously without loss of care. Patients have the advantage of continuity of care, earlier detection of disease through telehealth screenings, improved convenience of healthcare, reduced travel time, easier access to appointments, and cost effectiveness. Undoubtedly, this paper did not touch upon the ever-changing legalities that may involve telehealth. Requirements between states can vary significantly. Some states require the optometrist to be on site at all times, while others may only require the initial examination to be performed in-person by the optometrist. Considerations should be given for your individual state and the most current legislation. For the time being, studies have shown that telehealth can be used as an alternative to in-person comprehensive eye examinations in low-risk patients. With the right technology and tools, it is very plausible that telehealth examinations may confidently screen, diagnose, and monitor for many concurrent eye conditions in the foreseeable future.

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