

Retinoscopes: Past and present

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Abstract

BACKGROUND

Retinoscopy is arguably the most important method in the eye clinic for diagnosing and managing refractive errors. Advantages of retinoscopy include its non-invasive nature, ability to assess patients of all ages, and usefulness in patients with limited cooperation or communication skills.

AIM

To discuss the history of retinoscopes and examine current literature on the subject.

METHODS

A search was conducted on the PubMed and with the reference citation analysis (<https://www.referencecitationanalysis.com>) database using the term "Retinoscopy," with a range restricted to the last 10 years (2013-2023). The search string algorithm was: "Retinoscopy" (MeSH Terms) OR "Retinoscopy" (All Fields) OR "Retinoscopes" (All Fields) AND [(All Fields) AND 2013: 2023 (pdat)].

RESULTS

This systematic review included a total of 286 records. Publications reviewed iterations of the retinoscope into autorefractors, infrared photo retinoscope, television retinoscopy, and the Wifi enabled digital retinoscope.

CONCLUSION

The retinoscope has evolved significantly since its discovery, with a significant improvement in its diagnostic capabilities. While it has advantages such as non-invasiveness and broad applicability, limitations exist, and the need for skilled interpretation remains. With ongoing research, including the integration of artificial intelligence, retinoscopy is expected to continue advancing and playing a vital role in eye care.

Key Words: Retinoscopy; Autorefractor; Refractive errors; Ophthalmology; Optics; Artificial intelligence

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Core Tip: Retinoscopy is an important method used in the eye clinic for identifying and treating refractive problems. It has several benefits, such as being non-invasive, evaluating patients of all ages, and being helpful for individuals with poor cooperation or communication abilities. It is very helpful in the diagnosis of diseases like cataracts and amblyopia. New features have been added to retinoscopes as a result of technological advances. Contemporary retinoscopes come with digital screens, which make it simpler to analyze the findings. Others have combined the advantages of both with integrated autorefractor capabilities. Retinoscopes have evolved in the past decades to meet the current clinic needs.

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INTRODUCTION

Refractive errors are the leading cause of visual impairment worldwide[1]. Estimation of refractive errors can be carried out objectively or subjectively. Objectively, refraction is carried out by retinoscopy and auto-refractometry.

The retinoscope works on the principle of detecting the movement of a light beam reflected from the patient's retina. By analyzing the direction and speed of the reflected light, clinicians can determine the refractive error, such as myopia, hyperopia, or astigmatism. By their optical function, retinoscopes may also be improvised for the detection of multiple unestablished anterior segment pathologies, including aiding differential diagnosis of several subtypes of immature cataracts in low-resource clinical ophthalmic settings by observing differences in motions exhibited by lens opacities against the background red reflex. All illuminated portable devices can be used for this subjective assessment.

The retinoscope, particularly when used in cycloplegic conditions, proves to be a valuable tool for epidemiological purposes, aiding in screening for the distribution and development of refractive errors in infants and young children[2-4]. Furthermore, it acts as the benchmark for creating alternative tests or procedures aimed at enhancing the measurement or identification of clinically relevant refractive errors in the pediatric population[5]. Significant refractive errors contribute to avoidable vision impairment and amblyopia among pediatric age groups[6]. Regarding targeting community health efforts, the results of some studies suggest a greater predilection of amblyopia based on race as an independent factor; however, these inferences may have been influenced by geographical bias[7,8].

The optics of retinoscopy can be explained using Foucault's principle[9]. The retinoscope can also be used to measure leads and lags of accommodation at near using the Monocular Estimated Method of retinoscopy[10]. While it may not be employed frequently, the retinoscope has practical applications in clinical settings for measuring the amplitude of accommodation[11]. There are various tools for subjective refinement of astigmatic correction, including astigmatic fan dial, Jackson cross-cylinder[12], *etc.* Stenopaic slit refraction enables the refinement of moderate astigmatism in lower resource settings[13]. This paper sought to summarize the historical background and importance of this technique while highlighting the evolution of this procedure and the current advancements being made.

MATERIALS AND METHODS

A search was conducted on the PubMed and with the reference citation analysis (<https://www.referencecitationanalysis.com>) database using the term "Retinoscopy," with a range restricted to the last 10 years (2013-2023). The search string algorithm was: "Retinoscopy" (MeSH Terms) OR "Retinoscopy" (All Fields) OR "Retinoscopes" (All Fields) AND [(All Fields) AND 2013: 2023 (pdat)]. Two of the authors scrutinized each publication record for relevance and a PRISMA [14] guideline was used to represent article discovery and is shown in Figure 1.

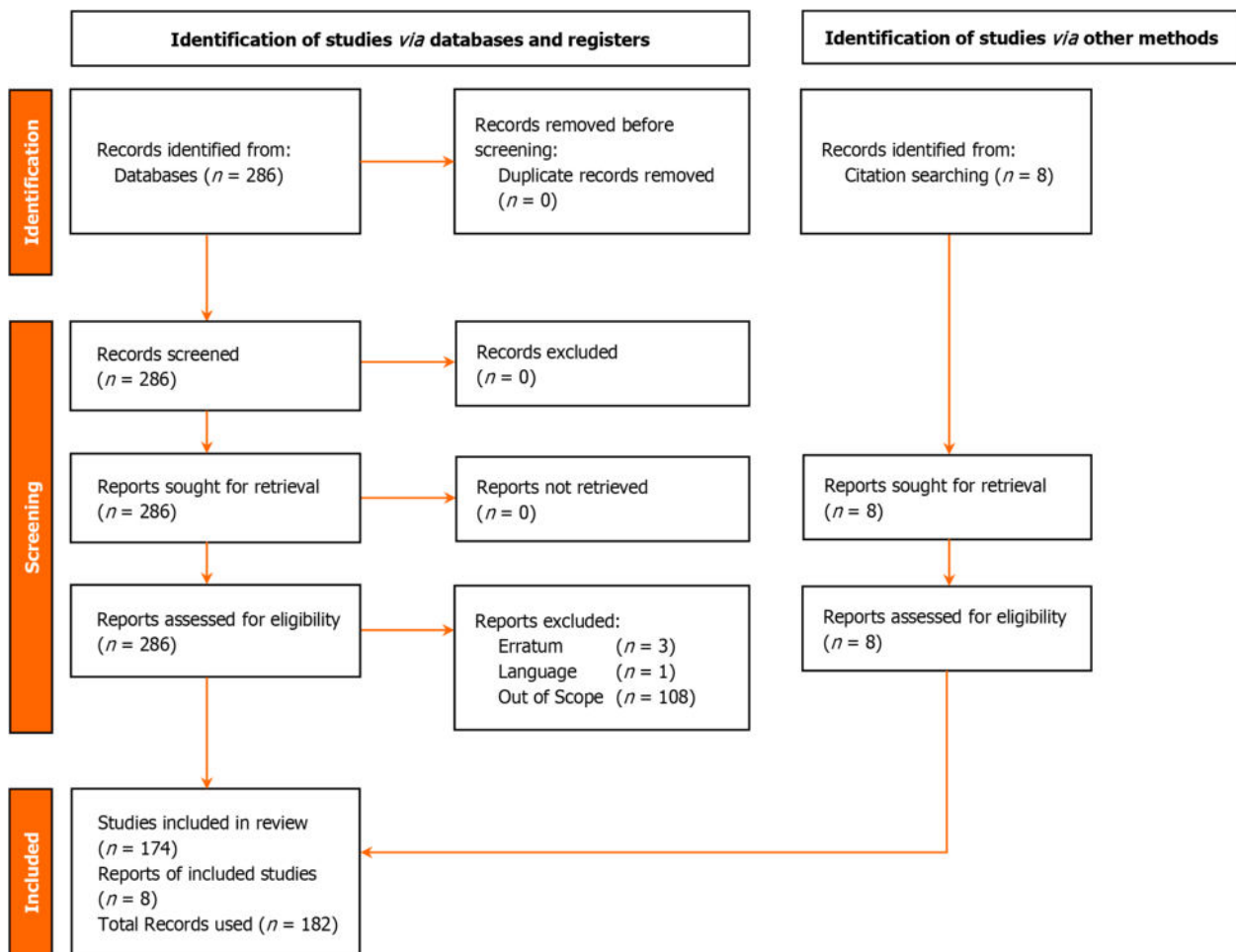


Figure 1 PRISMA guideline.

RESULTS

The search string returned a total of 286 records. Articles not in English language were excluded. Three records were excluded as they were erratum to other publications, and one was excluded as it was not in English. A total of 108 records were classified as out of scope and were therefore not included. The authors then searched the references and citations of the remaining 178 studies, further harvesting an additional eight studies reviewed in this paper.

DISCUSSION

Measurement of refractive errors

Refractive errors like hyperopia and myopia are lower-order aberrations generated *via* properties of the ocular refractive media in relation to globe anatomy[15]. The magnitude of either positive spherical defocus (with myopia)[16] or negative spherical defocus (with hyperopia) accounts for their visual significance[17]. "Astigmatism" is a second-order aberration contributed by differences between the eye's principal meridians[18]. Lower-order aberrations are corrected optically with spherical or spherocylindrical lenses. Clinical refraction is essential for deriving optimal corrections. Retinoscopy and the use of the auto-refractometer are good objective techniques for estimating magnitudes of spherocylindrical corrections. However, retinoscopy permits more procedural variability[19,20]. Novel self-contained darkroom refractive screeners have been shown to measure spherical equivalents similar to values determined from routine cycloplegic retinoscopy[21]; both tests reportedly varied only in magnitudes of spherical and cylindrical components[21]. The spherical-equivalent value represents an algebraic sum of the spherical component and the half of the cylinder in an optical prescription[22].

During retinoscopy and other reliable refraction procedures, the principal meridians are orthogonal in cases of regular astigmatism. The power meridian is steepest, while the axis meridian is flattest. When performing minus-cylinder refraction, neutralizing the power meridian *via* retinoscopy requires a less myopic/more hyperopic spherical component. An adequate cylindrical component then neutralizes the axis meridian[23]. On the other hand, the magnitude of a cylindrical component can be derived from the algebraic difference of both parts on an optical cross. Against-the-rule astigmatism exists with a minus cylinder axis along 90 degrees. Astigmatism is with-the-rule (WTR) when the minus

cylinder axis favors 180 degrees. WTR astigmatism is more tolerable[12] and common among younger demographic groups[24-27].

After retinoscopy, good subjective refraction is needed to account for objective over- or under-correction[28]. Amblyopia is a huge consequence of uncorrected or inadequately corrected refractive error[6]. Accurate determination of the magnitude and orientation of both manifest and cycloplegic astigmatism is essential to assuring good visual outcomes following keratorefractive surgery. When utilizing vector analysis in preparation for keratorefractive and refractive lens implant-based procedures, the preoperative best-correction is factored in determining optimal treatment parameters such as target-induced astigmatism and surgical-induced astigmatism (when retreatment protocols become necessary).

On-the-axis retinoscopy as a refractive technique is important in the examination, as well as the treatment of refractive errors and amblyopia[29]. Higher-degree refractive errors are more amblyogenic[30]. The maximum correction of significant refractive errors is essential in amblyopia prevention measures[31]; data acquired from amblyopia screening among preschoolers suggested that hyperopia > 2 D, astigmatism > 1 D, and anisometropia > 0.5 D were unilateral amblyogenic refractive factors[32]. On the other hand, bilateral amblyopia was most associated with bilateral hyperopia ≥ 3 D[32].

For very young child with significant refractive errors, refraction techniques can be optimized to aid favorable emmetropization[33,34]. In the setting of long-term optometric care, consistently greater-than-expected longitudinal increase in myopic spherical equivalents can aid in early diagnosis of progressive myopia, such that timely myopia control therapies can be instituted[35,36]. Among pediatric populations, myopia is more prevalent post-emmetropization [36], and can be worsened by dim light and near work[37]. Accordingly, hyperopia prevalence is inversely associated with pediatric age[38]. Preterm children may be an exception to this trend[39].

Modern autorefractors yield higher minus-powered spheres and lower plus-powered spheres/spherical equivalents [40]. To avoid over- or under-correction, good fogging techniques are a key step in carrying out subjective refraction. Binocular balancing techniques, although not the subjective refraction endpoint, can help stabilize the relative binocular accommodative stimulus. The Humphriss immediate contrast and prism-dissociated red-green balance methods enable better consistency of results[41].

Conducting refractive screenings for newborns allows for the early detection of refractive conditions' distribution, which could serve as risk factors for amblyopia[42] and other congenital ocular conditions like retinopathy of prematurity [43-45] and retinoblastoma[46]. For young children managed for retinopathy of prematurity, accurate cycloplegic retinoscopy post-treatment enables early detection and good long-term comparison of unwanted refractive consequences [47]. Pathologic changes in adults may also present with a shift in refractive values which may be picked up by retinoscopy[48].

Historical background and evolution of retinoscopy and autorefractors

Early retinoscopy systems were cumbersome, and they consisted of a wall-mounted illumination source: Initially a lamp or lit candle. The handheld unit consisted of a reflecting mirror which was then held perpendicular to the wall-mounted unit and the visual axis of the patient[23].

The irregular reflex seen in the eye when illuminated was first reported in 1859[49]. Cuignet had earlier characterized the changes in this reflex as the illuminating source changed in direction and location[49] but it was not until 1878 that Parent published the objective refraction technique[49]. Since then, retinoscopy has been the most reliable tool for determining objective refraction values. Schaeffel *et al*[50] developed the infrared retinoscope in 1987[50]. These earlier units enabled spot retinoscopy only. Over time, self-illuminated retinoscopes were developed, with the evolution of Copeland's streak retinoscope being a major landmark in the adoption of retinoscopy for broader modern-practice applications[23]. While the early models featured a simple mirror system, modern retinoscopes often employ complex optical designs, such as the streak retinoscope. Over time, retinoscopes have become more refined and user-friendly. These newer instruments offer improved accuracy and ease of use.

The recently introduced "Mirza" tele-lens retinoscopy emerges as a more precise and accurate refractive assessment method for evaluating refractive errors in young, uncooperative children and infants compared to the standard retinoscopy, proving effective in both non-cycloplegic and cycloplegic conditions[51].

Certain portable autorefraction devices are valuable substitutes for retinoscopy when screening and diagnosing refractive errors, particularly in low-income communities with constrained financial resources and a shortage of trained eye care professionals[52]. With tendencies similar to those observed during retinoscopy, non-cycloplegic and cycloplegic autorefraction yields distinct spherical equivalent values when employed for examining children and adolescents: Post-cycloplegic myopic readings often decrease in magnitude while post-cycloplegic hyperopic values increase in magnitude [53].

Retinoscopy-based screening tools have enabled epidemiological studies incorporating larger sample sizes of school-aged children[54]. The availability of more device options also offers variability for examining special-needs children; these advancements have also enabled the acquisition of more epidemiological data regarding vision problems among children with Down syndrome[55]. A streak retinoscope connected to a smartphone-based display system enabled trainer-trainee 'video-refractive retinoscopy' for easy description of retinoscope reflex properties in various refractive states and several other associated optical phenomena[56]. Other developments and the subsequent changes to advancement provided to the retinoscopic technique[50-62] are listed in Table 1.

Autorefractors began to come on the scene within the last 30 years[63]. An "auto-refractometer" denotes a unified device that combines the functionalities of an autorefractor and a keratometer, offering details on refractive error and corneal curvature[64]. Several autorefractometer devices have shown good levels of consistency[65]. Refraction outcomes from autorefractor models produced by reputable stalwart ophthalmic device companies have been comparable to those of dynamic retinoscopy[40].

Table 1 Evolution of retinoscopes presented in the literature

Year	Authors	Instrument	Advancement
1987	Schaeffel <i>et al</i> [50]	Infrared photo retinoscope	Ability to refract off-axis and peripheral areas of the cornea
1987	Miller <i>et al</i> [58]	Television retinoscopy	This setup used a live television camera to gather retinoscope reflex images for the purpose of teaching
2014	Chen <i>et al</i> [57]	Infrared retinoscopy	Extend the detection range of illuminating eccentricity making aberrations easier to detect
2014	Chan <i>et al</i> [60]	Digital retinoscope	Authors developed a digital retinoscope by connecting a smartphone to a streak retinoscope for training and demonstration
2019	Arnold <i>et al</i> [59]	School bus accommodation relaxing skiascopy	School bus accommodation relaxing skiascopy precisely estimates refractive errors including astigmatism in children without the need for cycloplegia
2022	Langue and Ajay[61]	Wifi enabled digital retinoscope	Authors attached a Wifi enabled camera to a retinoscope, allowing reflex to be viewed on other video terminals wirelessly for training
2022	Musch <i>et al</i> [62]	Welch Allyn spot vision screener model VS-100	This novel equipment detects refractive error binocularly. However, false negatives were noted

Autorefractors can be described as closed-field or open-field. The closed-field equipment has a target generated inside the autorefractor while in the open-field versions, the patient is encouraged to look through a clear opening[66]. Specialized camera-based equipment for screening amblyogenic factors such as ametropias, ocular deviations, and opacities like the medical technology and innovations photo screener and Fortune video refractor emerged at the turn of the century[67]. Screening devices such as the Retinomax autorefractor and SureSight Vision Screener showed good sensitivity for detecting significant refractive errors compared to non-cycloplegic retinoscopy[68].

The Plusoptix autorefractor emerged in 2004 and has been researched to show good agreement with cycloplegic retinoscopy[69,70]. Yet, additional research conducted by Saini *et al* reveals that in comparison to cycloplegic retinoscopy, the utilization of Plusoptix proves to be a more dependable method for determining the axis of the cylindrical component of refractive error in children[71]. The Plusoptix photo screener has shown greater suitability for the detection of myopia [72]. However, both Pedia Vision and Plusoptix photo-screeners were found to overestimate the magnitude of myopia and astigmatism while also yielding underestimates of hyperopia[73].

Advantages and limitations of the retinoscope

The retinoscope is the most reliable tool for obtaining refractive values in children and individuals who cannot communicate optimally[74-83], and even newborns[84-90]. Retinoscopy is reported to be the most sensitive (78.6%) with a negative predictive value of 96.6%[91].

For assessing the spherical equivalent of subjective refraction in children, cycloplegic retinoscopy proves to be a superior method compared to autorefraction[92]. However, Akil *et al*[93] concluded that there is a strong correlation between cycloplegic retinoscopy and autorefraction values[93]. In situations where it is deemed necessary, non-cycloplegic retinoscopy proves beneficial for evaluating subjective refraction, particularly within school eye health programs[94-97]. In the pediatric ophthalmic examination, retinoscopy after cycloplegia is also more suitable for attaining optimal correction of hyperopia compared to other methods of objective refraction[98]. Among adults, retinoscopy also reduces the probability of hyperopic spherical equivalent under-correction compared to objective results from autorefractors[99]. Dynamic retinoscopy has also been used to determine near addition power in presbyopes[100].

Patients are required to fulfill less strict postural demands during retinoscopy compared to using common table-top autorefractors. Hence, retinoscopy is adaptable to the examination of those afflicted with significant musculoskeletal disorders, as well as children and adolescents presenting with signs of attention-deficit hyperactivity disorder and autism spectrum disorder (ASD), all of whom may have acquired abnormal head posture[101,102]. Special-needs children and young adolescents may also be hyper-reactive to closed-field autorefraction[102]. Young patients with less manifest ASD may also have suboptimal vergence/pseudo-vergence facility findings that may be missed when closed-field autorefraction is relied upon[103]. Evidence suggests that retinoscopes are useful tools for complementing several aspects of clinical research, or knowledge generation in the fields of vision science and translation to optometric practice[104,105].

In animal experiments aimed at studying refractive errors, retinoscopy is an accurate and rapid method of achieving this[106-119]. For this purpose, retinoscopy has been used to study spherical equivalent changes in guinea pigs to understand cellular mechanisms of axial length elongation, choroidal dynamics, and several specific exogenous associations[120-122]. In murine models, continuous retinoscopy under ametropic conditions has also been theorized with the construction of a skull-secured trial frame[123]. Retinoscopic values are also useful in intraocular lens calculations during equine cataract surgery[124].

Challenges of retinoscopy

The outbreak of coronavirus disease 2019 (COVID-19) and its resultant pandemic changed the practice policy of many clinics worldwide. Valuable in-person training hours were lost during the COVID-19 pandemic[125-127]. Thakur *et al* [128] also published a case series showing changes in the retinoscopy-based objective refraction endpoint after recovering from COVID-19[128]. Because the retinoscopic procedure requires that the clinician sit directly in front of patients and

make multiple contacts with lenses and equipment used by patients, several authors recommended discontinuing the procedure in favor of automated objective refractometry[129]. Photophobic patients may also become uncomfortable from the bright light of the retinoscope. Coulter *et al*[102], however, described using the Luneau Retinoscopy Rack and a video target at 10 feet to capture the attention of kids[102].

Gaining proficiency in performing retinoscopy portends slow learning curves, requiring a high volume of procedural repetitions[130]. Good clinical guidance and supervision of novice technicians by more experienced personnel serve to overcome challenges associated with the quality of patient care[131]. Also, the cooperation level of patients and the experience of the clinician can influence variations in retinoscopy findings[132]. Failure to attain optimal retinoscopic correction predisposes hyperopic school-aged children to accommodative and vergence anomalies[133].

Potential sources of error and factors affecting accuracy

Examiners' proficiency and experience are important factors influencing the accuracy of retinoscopy[134]. Bharadwaj *et al* [134] described a psychometric technique for predicting individual retinoscopists' accuracy of results[134]. Very high refractive errors can result in an atypically blurred 'starting-point' reflex, thus confusing the inexperienced examiner[23].

The choice of topical agents used for cycloplegic retinoscopy in young children and early adolescents can also result in variability, particularly for young hyperopic children[135]. Mydriatic agents such as tropicamide are listed in several works of literature as cycloplegics for pediatric ocular assessment; however, they exert weaker cycloplegic effects for young children (< 5 years) presenting with accommodative esotropia and high hyperopia[135]. To avert severe adverse events, it remains prudent to select concentrations of topical cycloplegic drops following due consideration of age, body weight, and pre-existing hypersensitivities for individual pediatric patients[136]. Marked pupil miosis associated with senescence, can make the retinoscopy reflex appear obscured, hence limiting accuracy[137,138].

It is, however, noted that retinoscopy is not the endpoint of the refractive process for the majority of patients and there are subjective steps to fine-tune the refractive prescription[139-141].

Diagnostic capabilities of retinoscopy

Generally, refraction is the mainstay for detecting the presence and magnitude of ametropias[142,143]. Refractive errors include hyperopia, myopia, and astigmatism. Retinoscopy is also especially useful in determining the presence and magnitude of astigmatism. Astigmatism may also be regular or irregular[144]. Pre- and cycloplegic retinoscopy findings are crucial in the differential diagnosis of near reflex spasm[145]. Objective refraction with cycloplegics is the standard of care among pediatric patients with significant visual anomalies[146]. Comparing non-cycloplegic and cycloplegic retinoscopy findings can help detect and diagnose accommodative dysfunctions[147]. Cycloplegia is attained by instilling drugs such as cyclopentolate, homatropine, and atropine to eliminate accommodation in the eye before refraction. Cycloplegia usually sets in about 30-40 min after the eyedrop has been instilled[148].

Cycloplegic/wet retinoscopy allows objective assessment of the eye's absolute refractive state[149]. Cyclopentolate, with its faster effect and shorter duration of recovery, is a better option for high-volume outpatient practices[150]. Research conducted by Groth *et al*[151] has suggested (albeit in a canine model) that cycloplegia may not produce statistically different results in retinoscopy[151]. Vasudevan *et al*[152] researched into differences in spherical endpoint between static retinoscopy in the dark as compared to cycloplegic retinoscopy. Their results show that there was no statistical difference between the two methods[152].

Mohindra near retinoscopy proves to be a beneficial technique for consistently screening the refractive status of children under 12 years old, providing reliable results comparable to those achieved with cycloplegic refraction[153].

Retinoscopy *via* the monocular estimation method is a subjective measure of the accommodative response (lead: With over-responsiveness, or lag: With under-responsiveness)[154]. The presence of a lead on accommodation seems to be a factor in myopic progression[155] and the development of amblyopia[156]. Another retinoscopic method applied in clinical settings is dynamic Nott retinoscopy, which assesses the precision of accommodation and proves beneficial for examining accommodative and binocular vision disorders at a point in time[157] or longitudinally[158]. The reduced accommodative facility at near and higher lag of accommodation was believed to predict myopia progression in adults [159]. In Nott's method, the patient wears his distance prescription and is asked to fixate on a target mounted on a calibrated ruler. The examiner observes the retinoscopic light reflex in the eye and adjusts his position forward and close to the patient or away from the eye until the refractive error is neutralized[160]. Notts retinoscopy is especially useful in screening for refractive errors in children with Down's syndrome[161]. Off-axis retinoscopy has gained some credence as a potential hypothetical measure of peripheral refraction[162].

The presence of a scissor-like reflex on the cornea during retinoscopy is one of the classical signs of keratoconus[163-165], a condition seen frequently among patients with long-standing vernal keratoconjunctivitis[166]. Yet, authors have suggested that this simple tool is not regularly used in the diagnosis of keratoconus[167]. In advanced keratoconus cases, a paracentral corneal oil-droplet sign and marked scissor reflex are confirmatory correlations with other non-retinoscopic clinical signs which include: Fleischer's ring, Munson and Rizzuti signs, Vogt's striae, and subepithelial apical scarring [168]. On the other hand, for earlier diagnosis of subclinical or 'Forme Fruste' keratoconus, patient groups with scissor retinoscopy reflexes, normal intraocular findings, and moderate-to-high astigmatism with corrected distance visual acuity < 6/9 require further assessment of central/apical corneal thickness, as well as biometry of the anterior and posterior corneal curvatures[168]. When available, Placido disc topography (for the air-tear-epithelial interface), scanning slit topography, and Scheimpflug imaging (capable of assessing posterior corneal elevation) are adjunctive to retinoscopy screening cues for true confirmation of preclinical/subclinical keratoconus[169]. This scissor-like retinoscopic reflex may serve as a useful lower-resource marker of irregular astigmatism[170].

In patients with unintended thicker flaps post-laser-assisted keratomileusis, a scissor motion seen on retinoscopy may be the first postoperative indication of wrong preoperative corneal biometry values[171]. In patients suspected of having a spasm of near reflex, a finding of > 2 diopters difference between standard and cycloplegic retinoscopy confirms the condition[172].

Current technology in objective refraction

Although cycloplegic retinoscopy is still considered the primary method for diagnosing refractive errors, challenges such as difficulty in obtaining cooperation from pediatric patients and the clinician's level of expertise have led to the emergence of modern technological alternatives, such as auto-refractometers[173]. Regarding autorefractors, while they are faster and demand less cooperation when used without cycloplegia, they produce more myopic outcomes that lack repeatability, especially within the pediatric population[174,175]. Likewise, photo-refractors, by accurately assessing refractive errors and amblyopic risk factors while overestimating myopia in children and hyperopia in adults, serve as a valuable and reliable alternative technology, particularly in communities with limited or no access to eye care services [176]. SureSight photo-refractors/Vision Screeners are advantageous for detecting hyperopia[177]. Photo-refractor technicians should, however, take individual and ethnic differences when calibrating for a refractive error measurement [178].

There is a possibility that automated devices, like the Plusoptix Power Refractor II, utilizing the eccentric photorefraction principle for detecting significant hyperopia in children, may lack the required level of accuracy in vision screening programs[179]. While the Plusoptix A09 photo screener serves as a beneficial tool for screening refractive errors in 5-to-15-year-old children, its effectiveness, particularly for myopic and astigmatic conditions, could be enhanced by combining it with retinoscopy[180]. Similar to other photorefraction technologies such as the Retinomax, Plusoptix, iScreen Vision Screener, and Adaptica 2WIN, the Spot Vision Screener captures and assesses images of the red reflex in the eyes to detect ametropia (primarily leaning towards myopia) in children starting from 6 mo old[181,182].

Compared to cycloplegic retinoscopy, the 2WIN-S photo-refractometer stands out as a highly dependable, swift, and portable device for evaluating refractive status in pediatric screening[183]. However, total reliance on the refraction measurements of screening tools can be unideal for making precise spectacle prescriptions[184]. The instaref R20, a portable/handheld auto refractometer manufactured based on the principles of Hartmann-Shack wavefront aberrometry, a wavefront sensor-based technology with high clinical usability over the years, showed good reliability and agreement with standard retinoscopy for use in pediatric evaluation[185]. A United States-based company created the Near Eye Tool for Refractive Assessment, a portable device attachable to smartphones, rapidly estimating refractive errors by displaying red-green line patterns through a pinhole optic aligned by the user[186,187]. Open-field autorefractors, such as the Shin-Nippon NVision-K 5001, provide a more dependable and precise assessment of refractive errors, specifically in children with hyperopia and oblique astigmatism, when compared to closed-field autorefractors like the Topcon KR-800[187].

Future technologies

The emerging Binocular Wavefront Optometer employs wavefront aberration principles and adaptive optics technology to efficiently and accurately assess children's refractive status, surpassing traditional autorefraction and retinoscopy under cycloplegic conditions with a superior 0.05 D-interval resolution compared to the standard 0.25 D-interval in optometry[188]. When compared to retinoscopy and autorefraction, the SVOne, a portable Hartmann-Shack wavefront aberrometer utilizing wavefront sensors and capable of connecting to a smartphone, objectively assesses the eye's refractive error[189].

QuickSee is an affordable and portable autorefractor utilizing wavefront aberrometry, capable of providing a satisfactory assessment of the eye's refractive status[190].

Utilizing wavefront aberrometry technology, the E-see autorefractor delivers a refractive error estimation that is more precise and consistent with retinoscopy compared to alternative autorefraction methods[191]. The SureSight Vision Screener, utilizing wavefront analytic technology, shows promise in evaluating the refractive status of children under three years old comparable to cycloplegic retinoscopy, albeit needing additional validation[192].

While the wavefront-based autorefraction measurements of children's refractive status in both non-cycloplegic and cycloplegic conditions show consistent astigmatic data, there exists a 0.5 D disparity in the spherical equivalent of the non-cycloplegic measurement, which can be mitigated through repeated measurements[193].

Geremias *et al*'s study revealed the Spot Vision Screener as an advanced and effective automated photo screening tool, proving superior in accurately measuring the refractive status of children below 3 years old (a risk factor of amblyopia) under cycloplegia conditions compared to retinoscopy, particularly beneficial in low-resource settings[194]. Likewise, additional research has affirmed the high reliability of the Spot Vision Screener in evaluating amblyopic risk factors among children with neurodevelopmental disabilities[195].

The Plusoptix S12-C photo screener proves to be a valuable and efficient tool for screening amblyogenic risk factors in children as young as 6 mo old, particularly in low-income communities[196]. Similarly, the Plusoptix A12-C photo screener is effective in detecting refractive amblyopia risk factors but not strabismic risk factors in children aged 3 to 4 years[197,198].

Artificial intelligence in retinoscopy

Integrating artificial intelligence (AI) into modern objective refraction techniques can be outlined to serve the following functions: Optimizing technical/operator training, and reducing patient/subject waiting time and discomfort[199-201].

The challenges with in-person examination created by the COVID-19 pandemic necessitated objective refraction simulations[126]. Chandrakanth *et al*[199] proposed a smartphone-based application for documenting retinoscopy called the Gimbscope[199]. This device combines a smartphone with a traditional retinoscope and can be used as a teaching

tool for clinicians wanting to understand the reflex patterns seen during the procedure.

Researchers have experimented with integrating AI modalities with portable vision screeners. Handheld infrared eccentric automated refractors have also been implemented with advanced AI/deep learning algorithms which help minimize environmental and motion artifacts influencing their utility[200]. Similarly, pediatric vision screeners that measure perifoveal retinal birefringence have been optimized with artificial neural networks which detect central fixation and thus, obtain more accurate refraction measures in the setting of amblyopia and strabismus[201]. The development of predictive analytics for ocular refraction is an evolving research area in medical AI. The clinical significance of the Fusion Model-Based Deep Learning System (FMDLS), utilizing Retina Fundus Photographs, has been established in detecting spherical, cylindrical, and axis components of refractive errors, mirroring the effectiveness of cycloplegic refraction[202] while reducing human error. This particular retinal fundus photograph of the FMDLS correlated common features of the optic nerve head, fovea, and subretinal vascular reflectivity among myopes as predictors of the refractive error. As an improvement upon previous AI systems which yield output in spherical equivalent values, the FMDLS algorithm further highlighted optic disc orientation and macular area morphology as regions of interest in differentiating “WTR” from oblique forms of astigmatism; interracial variation was unaccounted for[202]. Training future advanced AI models of ocular refraction with datasets obtainable from wavefront sensor devices may help equate, or even surpass standard refractive measures acquirable with non-machine learning approaches.

CONCLUSION

In conclusion, the retinoscope has evolved significantly since its inception, adapting to changing technology and improving diagnostic capabilities. While it has advantages such as non-invasiveness and broad applicability, limitations exist and the need for skilled interpretation remains. Amblyopia is a main consequence of inappropriate refractive error correction during early childhood. Retinoscopy still represents a useful tool for ameliorating inadequate pediatric refractive error screening coverage in remote and underserved areas.

This study search was limited to retinoscopy. While this is a very common procedure, there is a paucity of related published data and a good number of studies returned by the search only mentioned it in passing while discussing entirely different topics. Widening the search criteria to include refraction could potentially have yielded more studies to review.

FOOTNOTES

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