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Technological Advances in Eye Care/Instrumentation in Clinical Optometry: Computerized Ophthalmic Diagnostic and Imaging Techniques

Afe Victor Dania[1] and Chinedu Uchenna Azubuike[2]*

[1]Department of Optometry, Abia State University, Nigeria

[2]Department of Ophthalmology, Alex Ekwueme Federal University Teaching Hospital, Nigeria

Abstract

Clinical optometry is the bedrock of optometric practice, as proper diagnosis provides room for adequate and timely management of eye and vision disorders for optimal visual health and prevention of avoidable blindness. As a result, patients, practitioners, tech-enthusiasts, and all players in the eye and healthcare industry continually seek safe, relatively fast, objective, reliable, and repeatable ways to make eye care service delivery more efficient. Some of the ever-increasing advances towards achieving these include the use of Artificial Intelligence (AI) in monitoring devices such as the Eyebox (for concussion diagnosis) and the IDx-DR (for fundus assessment), and the Ultra-Wide-Field (UWF) technology, in retinal scanning. Artificial intelligence provides excellent human-like interactions with software and offers decision support for specific tasks while ultra-wide-field technology in retinal scanning increases the expanse of retina that can be captured at a time. This article attempts to highlight the strengths of these cutting-edge contributions from academics, researchers, and clinical practitioners over already established ones, and also provides specific references for additional reading. However, in view of the proliferation of several devices acclaimed by their manufacturers and promoters to aid in the diagnosis and management of several conditions of medical interest, the scope of this work is limited to technological advances in eye care and instrumentation in clinical optometry, with a focus on computerized ophthalmic diagnostic and imaging techniques that have been approved by the US FDA in recent years, with sufficient backup information regarding their successful randomized clinical trials and subsequent approval.

Keywords: Artificial intelligence; Clinical optometry; Diagnosis; Eye care instrumentation; Noninvasive ophthalmic imaging

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Correspondence:
Afe Victor Dania, Department of Optometry, Abia State University, Uturu, Nigeria, Tel: +2348037933933; E-mail: afedania28@gmail.com

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Introduction

Imaging techniques are clinically used to study the anterior and posterior segments of the eye. The anterior segment imaging system includes slit-lamp biomicroscopy, confocal microscopy, Scheimpflug imaging, Anterior Segment Optical Coherence Tomography (AS-OCT), and ultrasound biomicroscopy [1]. There have been three basic types of ophthalmic imaging used in eye care in the past two decades for posterior segment assessment. The three major technologies for diagnostic imaging of the posterior segment of the eye are: Scanning Laser Polarimeter (SLP), Confocal Scanning Laser Ophthalmoscopy (CSLO), and Optical Coherence Tomography (OCT) [2]. Ophthalmic diagnostic imaging, such as Scanning Computerized Ophthalmic Diagnostic Imaging (SCODI), allows for the early detection of glaucomatous damage to the nerve fiber layer or optic nerve of the eye. The goal of these diagnostic imaging tests is to discriminate between patients with normal IOP who may have glaucoma [3]. Highly trained optometrists, ophthalmologists, and imaging technicians are available to document the appearance of basic ocular structures such as the external eye, anterior segment, and retina throughout the life of a study [3].

Optical Coherence Tomography (OCT), a non-invasive imaging test, uses light waves to capture cross-sectional images of the retina. With OCT, your eye doctor (the optometrist) can see each of the retina's distinctive layers. This allows the eye doctor to map and measure the thickness [4]. It is important to note that retinal imaging takes a digital picture of the back of the eye, showing the retina (where light and images hit), optic disc (a spot on the retina that holds the optic nerve, which sends information to the brain), and blood vessels [2].

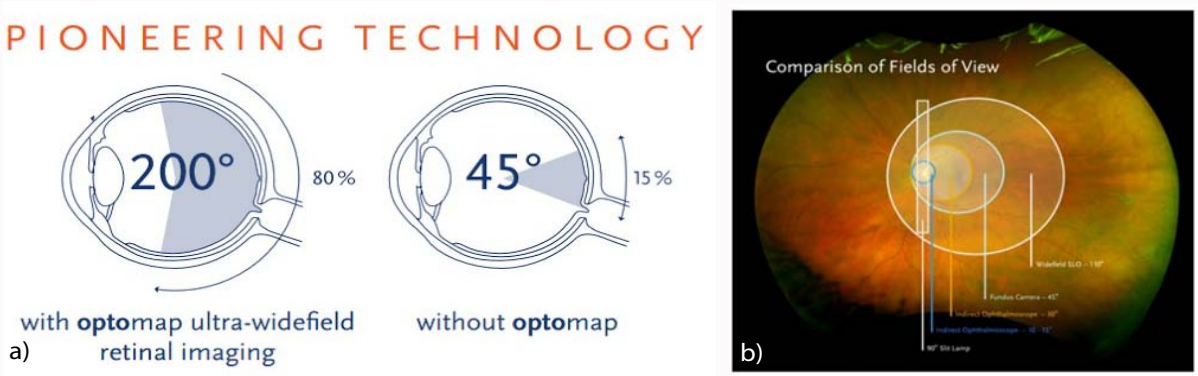

Figure 1: a) Showing schematic representation of the Ultra-Wide-Field (UWF) feature of Optos® [5]. b) Showing fields of view of fundus as acquired using different imaging instruments/techniques in comparison with UWF [6].

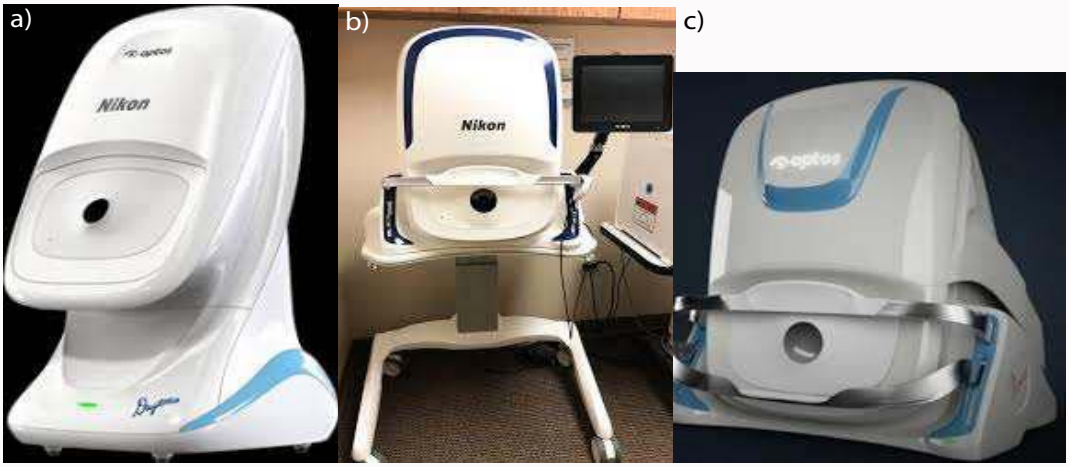

Figure 2: Showing different models of the Optos® retinal Scanner: a) DAYTONA; b) CALIFORNIA; c) MONACO [1].

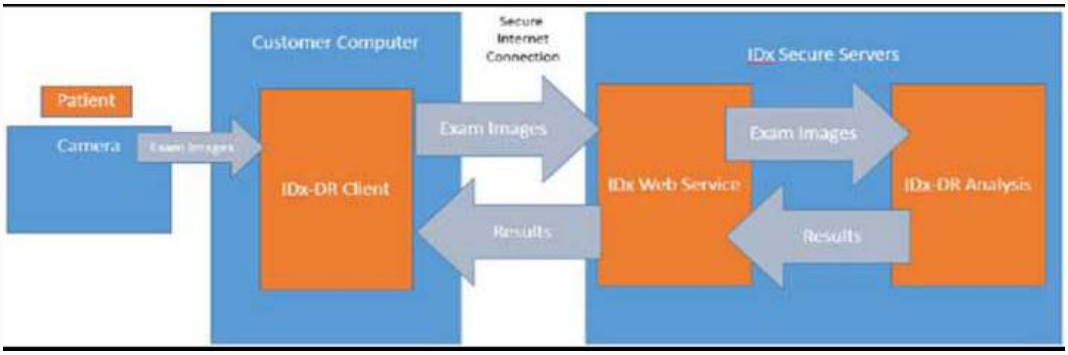

Figure 3: Illustrating the principle of the IDx-DR Technology [8].

These older technologies only capture a small area of the retina at a time and therefore often miss detecting serious peripheral retinal conditions [3].

Advances in Eye Care and Instrumentation in Clinical Optometry

Novel ophthalmic diagnostic and imaging techniques

1. Optos Ultra-Wide-Field (UWF) Retinal Scanning;
2. New Monitoring Technology:

- IDx-DR (IDX technologies) –for fundus assessment;
- Eye-Box (Oculogica) –for concussion diagnosis.

Optos Ultra-Wide-Field (UWF) Retinal Scanning

This recent retinal imaging technique captures >80% of the retina at a time as compared to the 15% (posterior pole: Macular and optic disc) provided by older techniques at a time, and affords a higher chance of early detection and diagnosis of serious peripheral retinal conditions such as retinal holes, detachment, and lattice that might be missed using other older techniques [1,2] (Figure 1).

It uses high-resolution ultra-wide field imaging (up to 200

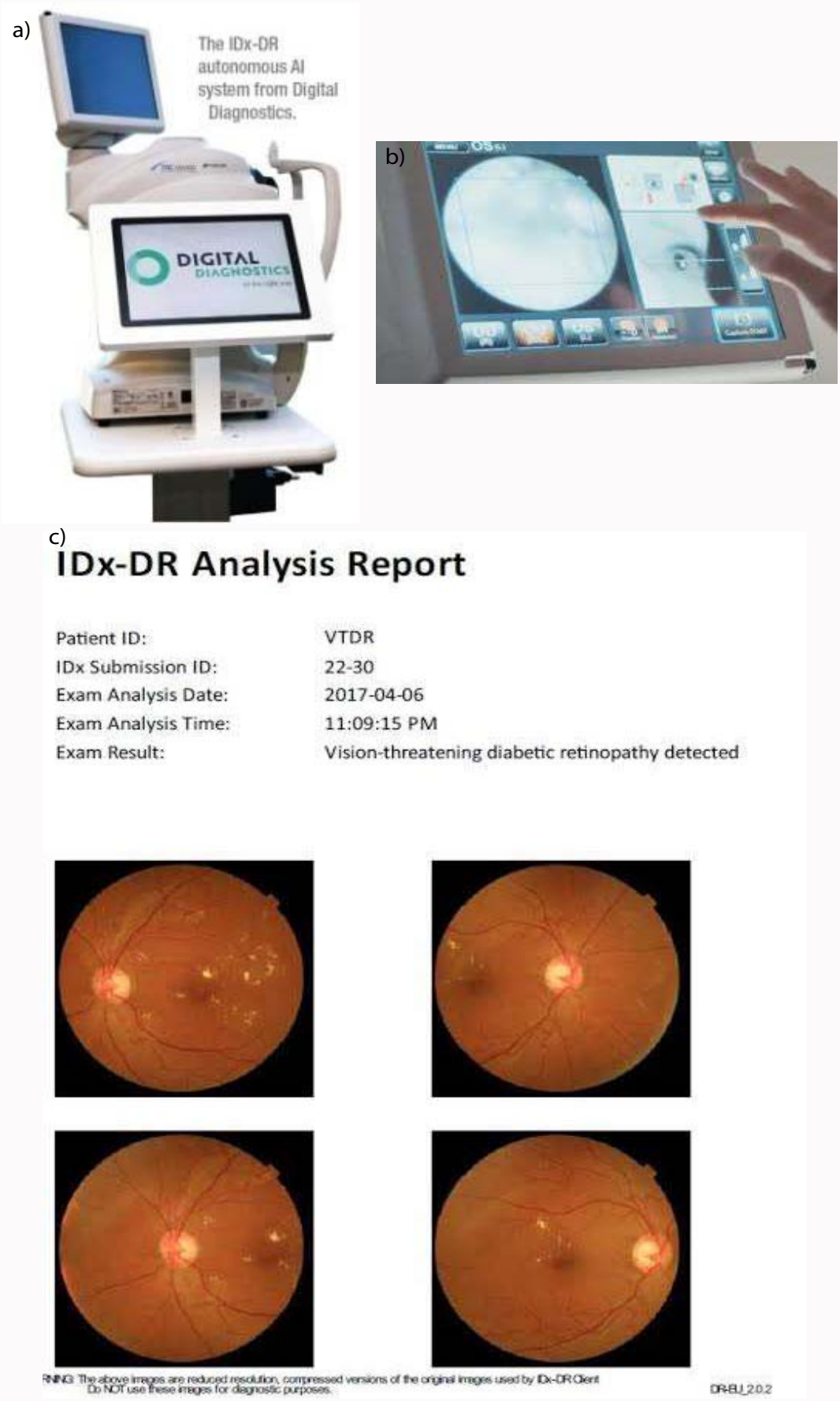

Figure 4: Showing the IDx-DR Machine. (a) 10 its user interface (b), 10 and a typical Printout of IDx-DR Machine Analysis Report (c) [11,12].

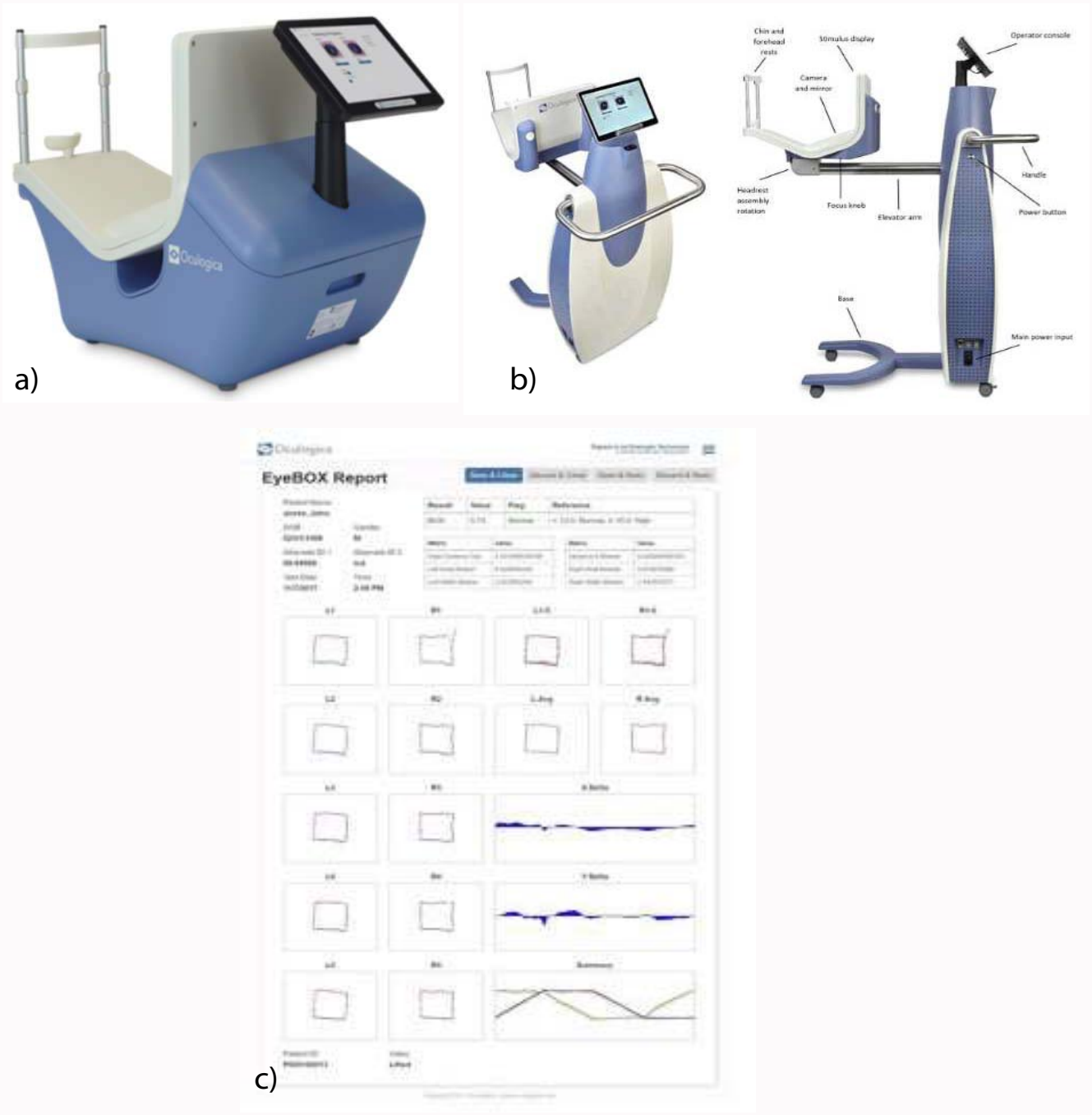

Figure 5: Showing a Typical EyeBox (a) and (b), and its clinical report printout (c) [25].

degrees), passing through many cataracts and pupils as small as 2 mm, and offers wide-field indocyanine green angiography in addition to the previously available composite color, red free, autofluorescence, and fluorescein angiography modes, allowing parallel capture of fluorescein angiography and ICG images without having to switch between modes [2].

It is fast, easy, comfortable, safe, and requires no dilation (except in peculiar cases where it may be necessary) [1]. It also views gas-filled eyes following vitrectomy and a limited view of the fundus, as in permanent keratoprosthesis. Its short acquisition time is beneficial for eyes with nystagmus, and its limitations include eyelash artifacts [7].

This technology is available on three product platforms, Monaco, Daytona and California. Monaco includes the Optos auto-montage feature, which increases the portion of the retina that can be captured to 220° (97%) [2] (Figure 2).

IDX-DR (IDX Technologies) for Fundus Assessment

This software uses artificial intelligence to analyze fundus images, and involves training deep learning algorithms using retinal images of varying disease severities to automatically identify early diabetic retinopathy. It was used in conjunction with a Topcon TRC-NW400 retinal camera (Figure 3).

Topcon TRC-NW400 is a fully automated fundus camera that captures high-resolution images of the retina and anterior segment of the eye without requiring Mydriasis [9].

The IDx-DR technology was approved by the US FDA not for screening for diabetic retinopathy in general, but to screen for and automatically detect more-than-mild Diabetic Retinopathy (mtmDR) only in individual's aged 22 years and older with diabetes mellitus and no history of diabetic retinopathy [12] (Figure 4).

The machine requires approximately two images per patient: one optic disc-centered image and one macular-centered image. Images acquired by the IDx-DR client (software) are sent/transmitted over a secure Internet connection to the IDx-DR web service within the device, which then processes the request and forwards it to the IDx-DR analysis (also within the device). This in turn provides feedback on image quality and the presence or absence of more-than-mild Diabetic Retinopathy (mtmDR) back to the IDx-DR client through the IDx-DR service. If the image quality is insufficient, the machine also signals immediate recapture [13].

Several studies and clinical trials have shown that this technology has approximately 87% sensitivity, 90% specificity, 96% imageability, 73% positive predictive value and 96% negative predictive value [8,14-17].

It is useful in the early detection of mtmDR, helps prevent significant vision loss due to early treatment of DR, has high accuracy, which makes it less likely to show false negatives often, reduces screening workload and improves efficiency [3,18-21]. It is safe, fast, and effective and can be used even without the assistance of a physician [4,22]. The frequency of screening is annual for people with type 1 diabetes and every 1 to 2 years for those with type 2 diabetes [22].

This technology does not include algorithms to detect other diseases such as glaucoma, age-related macular degeneration, and even diabetes mellitus, and is only used with high-quality high-resolution images of at least 1000 × 1000 pixels per image from a digital fundus camera. It is still being improved to enable compatibility with other digital retinal cameras. It requires approximately four hours of training on how to acquire quality images (and also comes with a user-friendly manual) and is not for use in pediatric patients [8].

As with all automated diagnostic devices, including those involving AI and electronic transmission of data, there are concerns of cyber security of patient information, false positives t hat may constitute false alarms, leading to further unnecessary medical procedures, false negatives that may delay further evaluation and early treatment, and operator failure in providing images according to machine quality specifications [12,23,24].

EyeBox® (By Oculogica Inc.) for Concussion Diagnosis

The EyeBox® is an FDA-approved electronic eye-tracking device that uses a unique algorithm to assess and diagnose patients suspected o f having concussion non-invasively without baseline data [26]. It was manufactured and marketed by Oculogica, Inc. It is also referred to as the first noninvasive baseline-free test to help diagnose concussion [26] (Figure 5).

It is fabricated for use in individuals aged 5 to 67 years and is very useful in objectively assessing and diagnosing patients with suspected mild traumatic brain injury. It also saves time and labor and is wonderful for use in sports medicine and the military. Study reports from clinical trials have shown that the EyeBox® has 80.4% sensitivity, 66.1% specificity, 31.6% positive predictive value and 94.5% negative predictive value [25].

The EyeBox® consists of a tracking camera that uses infrared illumination to track binocular eye movements (using the pupil as a reference point) and blinks, capturing for each eye, about 500 of gaze data per second for over 220 sec as a video stimulus goes around the stimulus screen perimeter for five cycles at 500 Hz frequency [25].

The EyeBox® tracks eye movements in patients while they watch a short video [27] and it provides a 'Box score' upon completion of the test using the ocular motility and other domains of brain function which helps clinicians determine the presence of concussion [7]. Box scores ranged from 0 t o 20, where values <10 were classified as normal (negative EyeBox classification, hence no concussion) and values ≥ 10 were graded as abnormal (positive EyeBox classification; hence concussion may or may not be present) [25,28].

It should be used in conjunction with other diagnostic tests, such as Computed Tomography (CT) scans, to make a definite diagnosis. It is also useful in identifying those at risk of a Second Impact Syndrome (SIS), where rapid and severe brain swelling due to a second concussion occurs before the first concussion is completely healed [25].

In regular eye care practice, concussion may be ruled out in patients who present with symptoms such as nausea, dizziness, and headache, which are also common in concussion [27].

According to Zahid et al., convergence and accommodative abnormalities associated with concussion were detected using this eye-tracking system in the pediatric population [28]. The procedure was also described as rapid, non-invasive, and objective. In addition, 51% of concussion patients with convergence insufficiency and accommodative disorders also show saccadic dysfunction [29].

Conclusion

It is rare to realize 100% specificity and sensitivity in the use of any device. This implies that not every image can be identified precisely or not be missed, and that several factors such as the computer technique, quality of input images, software failure, and patient cooperation may also affect the results. Although artificial intelligence and automated machines can really and efficiently conduct a task and achieve promising accuracy comparable with that of clinical experts, a certain degree of human intervention is often essential during the process and in the final diagnosis. Therefore, it may never be a replacement for humans. However, these novel diagnostic devices promise better patient management outcome.

Recommendations

1. We hereby recommend that optometric practitioners continue to undergo Continuous Professional Development (CPD) programs and attend seminars in order to keep abreast of trending technologies in eye care for optimum eye care service delivery.

2. Practitioners in clinical optometry should strive to venture into research about or using these latest instruments to obtain more data for comparative assessment of the efficiency of diagnosis using these instruments.

3. The government at all levels, private individuals, Non-Governmental Organizations (NGOs), and other corporate bodies should pull resources together to procure these new instruments, which are already gaining widespread adoption for better healthcare service delivery in our public and private health institutions and training institutions (university optometry clinics).

4. Policies encouraging import duty waivers, grants, and subsidies should be enacted/reviewed by the government, as it will encourage and create environment for investors in the eye and healthcare industry.

Authors Contribution

Both authors contributed equally to the compilation and review of related literature, drafting of the article, critical revision of the article, and final approval of the version to be published.

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