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A Novel Technique for Measuring Ocular Duction Ranges

Jae Yun Sung[1], Kee Sup Park[2], Yunseo Ku[3], Sung Bok Lee[4], Kyoung Nam Kim[4], and Yeon-Hee Lee[4]

[1] Department of Ophthalmology, Chungnam National University Sejong Hospital, Sejong, Korea
[2] Department of Ophthalmology, Konyang University College of Medicine, Daejeon, Korea
[3] Department of Biomedical Engineering, Chungnam National University College of Medicine, Daejeon, Korea
[4] Department of Ophthalmology, Chungnam National University College of Medicine, Chungnam National University Hospital, Daejeon, Korea

Correspondence: Yeon-Hee Lee, Department of Ophthalmology, Chungnam National University College of Medicine, Chungnam National University Hospital, #282 Munhwa-ro, Jung-gu, Daejeon 35015, Korea.
e-mail: yeonheelee72@gmail.com

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Purpose: To report a novel technique for measuring ocular ductions and evaluate its performance in normal participants.

Methods: We developed a laser pointer technique (LPT), a novel technique for quantitative measurement of ocular ductions. The device consists of a screen and headset with a laser pointer. Participants rotate their head while wearing the headset maintaining fixation on an optotype in the center of the screen until the target becomes blurry. Twenty-eight healthy volunteers were enrolled. The ocular ductions were measured with the LPT and compared to those of the Goldmann perimeter technique (GPT).

Results: The mean horizontal and vertical duction ranges were 95.2° ± 10.1° and 84.1° ± 10.8° using the LPT, respectively, and 113.2° ± 14.1° and 105.8° ± 12.5° using the GPT, respectively; both were significantly greater in the GPT than LPT (both $P < 0.05$). The total time required for testing was shorter with the LPT compared to the GPT (56.1 ± 4.5 seconds and 92.3 ± 11.6 seconds, $P = 0.003$). Both the LPT and GPT measurements showed excellent intraobserver repeatability, and LPT showed better interobserver repeatability.

Conclusions: Considering its reproducibility, accuracy, and simplicity, the LPT is expected to be useful for evaluating patients with ocular motility disorders as a first-order evaluation in the absence of sophisticated examination devices.

Translational Relevance: The laser pointer technique, the new method for measuring ocular ductions, could be useful for evaluating patients with ocular motility disorders in clinical practice.

Introduction

Evaluation of ocular duction is important for the diagnosis and management of patients with paralytic and restrictive strabismus. Measuring ocular duction and quantifying its changes are essential for determining disease progression and the response to therapy. In the clinical setting, ocular duction is commonly graded using simple scales ranging from −4 to 0 for underaction and 0 to +4 for overaction.[1] However, due to its subjective nature and high degree of observer variability, this method is not capable for accurate quantification. To obtain reliable and objective measurements, quantitative methods have been proposed. Kestenbaum[2] developed the limbus test. Urist[3] developed the lateral version light-reflex test. However, the accuracy of this test was limited because it relied on the examiner's subjective estimation of corneal center, and the reflexes on the sclera are often difficult to see. The established method for measuring ocular ductions is a technique using a Goldmann perimeter.[4–6] However, this method requires a trained technician, and the equipment is not available in many areas and clinics.

The purpose of this study is to describe a novel technique for measuring ocular ductions and evaluate its performance. We measured range of ocular ductions in healthy participants using the

novel technique and compared the results with those obtained by Goldmann perimetry. In addition, we analyzed intraobsever and interobserver repeatability of the two tests to determine the usefulness of the novel technique.

Methods

Participants

The study protocol was approved by the Institutional Review Board of Chungnam National University Hospital and adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from all participants. Twenty-eight healthy volunteers without any ocular problems were included in this prospective study.

Only patients with visual acuity (VA) better than 20/30 without refractive correction were included. Testing was performed on the right eye, with the left eye occluded. To exclude the possibility of measurement error caused by the prismatic effect of glasses, all tests were performed without glasses. Patients with strabismus, ocular motility disorders, orbital or neurologic diseases, or a history of orbital surgery were excluded.

Novel Device for Measuring Ocular Ductions and Measurement Technique

We developed a novel technique for quantitative measurement of ocular ductions, which we named the laser pointer technique (LPT). The device consists of two parts, a headset and screen. The headset consists of a headband, battery case, and laser pointer (Fig. 1).

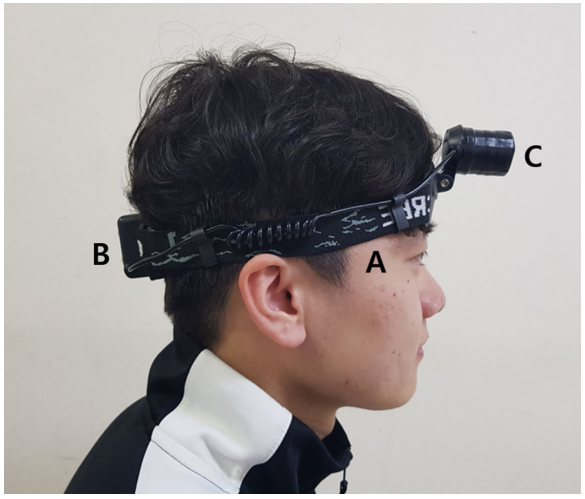

Figure 1. The headset of the LPT device consists of a head band (A), battery case (B), and laser pointer (C).

The screen is made from canvas, which has multiple concentric rings with horizontal, vertical, and 45-degree meridional lines. The multiple concentric rings are lines of gnomonic projection of a hemisphere that reflect the angle of rotation. Participants wearing the headset were positioned 75 cm from the screen. The screen measures horizontally up to 120° and vertically up to 100° (Fig. 2).

At the beginning of the test, the examiner aligned the participant's head to the center of screen and then aligned the laser pointer to the 20/40 optotype in the center of the screen. Then the participants were instructed to rotate their head along the meridians while maintaining fixation on the optotype and to indicate when the target became blurry. The location of the light from the laser pointer at this point was recorded and was regarded as the maximum range of duction. If the light of the laser pointer was positioned out of the meridian, the participant was instructed to correct the head position. For this study, testing was performed on the right eye, with the left eye occluded. We recorded the range of duction on only vertical and horizontal meridians.

Ocular ductions in each participant were assessed using both the LPT and Goldmann perimetry technique (GPT). The time required for each test was recorded.

Adjustment of Geometric Errors in the LPT

In the GPT, the head is fixed while the eyeball rotates. Contrarily, both the head and eyeball rotate together during duction measurements in the LPT. The rotation angle of laser light represents the rotation angle of the head (θ_1), which is not exactly the same as the rotation angle of the eyeball (θ_2) due to different rotation axes of the head and eyeball. In order to obtain the correct eyeball rotation angle, we added a step to adjust the geometrical error in the head rotation angle. Figure 3 shows the geometry of primary position and left eye abduction when the head rotates clockwise. The eyeball rotation angle (θ_2) was calculated using trigonometric functions for abduction, adduction, supraduction, and infraduction as follows, with the angle conversion table provided in Supplementary Table S1.

$$\theta_2 = \theta_1 - \tan^{-1}\frac{7.4^a \times \sin\left(24.8^b - \theta_1\right)}{81.7^c - 7.4 \times \cos(24.8 - \theta_1)} \text{ for abduction } (\theta_1 < 24.8^\circ)$$

$$\theta_2 = \theta_1 + \tan^{-1}\frac{7.4 \times \sin(24.8 - \theta_1)}{81.7 - 7.4 \times \cos(24.8 - \theta_1)} \text{ for abduction } (\theta_1 \geq 24.8^\circ)$$

$$\theta_2 = \theta_1 + \tan^{-1}\frac{7.4 \times \sin(24.8 + \theta_1)}{81.7 - 7.4 \times \cos(24.8 + \theta_1)} \text{ for adduction}$$

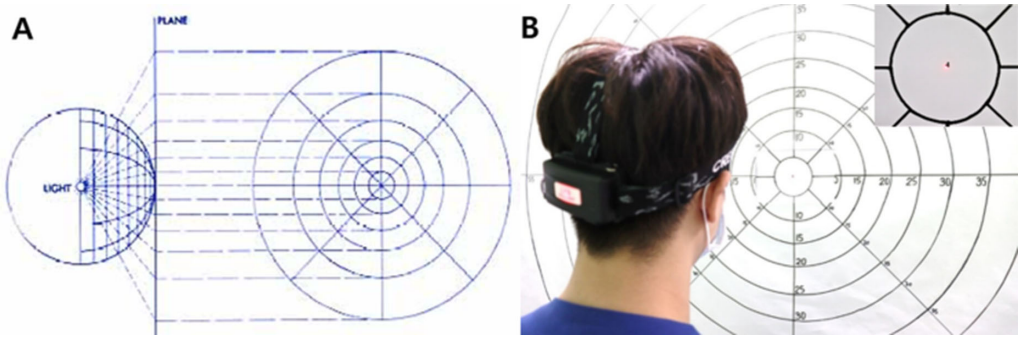

Figure 2. The LPT. (A) The screen is made from canvas, which has multiple concentric rings with horizontal, vertical, and 45-degree meridional lines. The multiple concentric rings are lines of gnomonic projection of a hemisphere that reflect the angle of rotation. (B) Participant wearing the headset was positioned 75 cm from the screen. The 20/40 optotype is displayed in the center of the screen and shown in the *upper right corner* of the photo (B) as a magnified image. The screen measures horizontally up to 120° and vertically up to 100°.

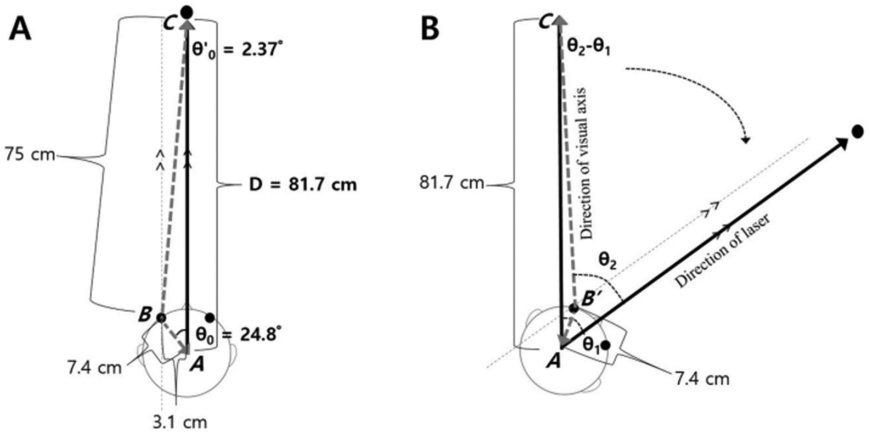

Figure 3. Geometry of primary position (A) and abduction when the head rotates clockwise (B) in the LPT. The distance between the head rotation axis and the target optotype (D) and divergence angle of orbit (θ_0) is calculated to be 81.7 cm and 24.8 degrees, respectively, using trigonometric functions of the triangle *ABC* in the image on the *left* (A). These were calculated using 7.4 cm as the distance between two rotation axes of the eyeball and head and 6.2 cm as the distance between two pupils.[7,20,21] The image on the *right* (B) shows a case when a head rotation angle (θ_1) is greater than 24.8 degrees (θ_0). The error angle between the eyeball rotation angle (θ_2) and the head rotation angle (θ_1) can be calculated using trigonometric functions of the triangle $AB'C$. The error angle in case of adduction, supraduction, and infraduction can be calculated with similar geometry.

$$\theta_2 = \theta_1 + \tan^{-1}\frac{7.4\times\sin(\theta_1)}{81.7-7.4\times\cos(\theta_1)} \text{ for supraduction and infraduction}$$

[a] = distance between head rotation axis and eyeball rotation axis[7]
[b] = divergence angle of orbit
[c] = distance between the head rotation axis and the target optotype

Measuring Ductions with Goldmann Perimetry

The GPT was performed using the established method.[4–6] Participants were seated in front of the Goldmann perimeter with the head aligned using a chinrest and headband. With one eye occluded, the participants were instructed to follow the target as it moved outward along the horizontal and vertical meridians as far as possible, without moving their head. Participants were instructed to report when central fixation was lost (i.e., the target blurred or disappeared); this was set as the endpoint. The difference between central and peripheral fixation was clarified to maximize the accuracy of subjective measurements, and the observer verified the loss of fixation via a central telescope.[6] The endpoint was recorded and regarded as the maximum range of duction.

Repeated Measurements and Statistical Analysis

Using the LPT and GPT, ductions were measured twice by examiner 1 (KSP) and once by examiner 2

(KNK). Both examiners were experienced in the use of the Goldmann perimeter. Each test was performed at 10-minute intervals, and the order of examination was randomized to minimize the possible bias from order of tests. To analyze intraobserver repeatability, the first and second measurements of examiner 1 were compared. To analyze interobsever repeatability, the first measurements of examiner 1 were compared to those of examiner 2.

Statistical analyses were done using SPSS for Windows (version 22.0; SPSS, Chicago, IL, USA). The paired *t*-test was used to compare ocular duction measurements between the two different techniques taken from the same participants. The intraclass correlation coefficient (ICC) and coefficient of variation (CV) were calculated to determine the intraobserver (test–retest) repeatability and interobserver (examiner 1–examiner 2) repeatability of the LPT and GPT. The ICC was calculated as the ratio of subject variance to total variance, with a high ICC (close to 1) indicating a high degree of similarity between values (<0.40, poor; 0.40–0.59, fair; 0.60–0.74, good; >0.75, excellent).[8] The CV was calculated for each pair of measurements, and the mean of all CVs was calculated; values <10% indicated good repeatability. $P < 0.05$ was considered statistically significant.

Results

A total of 28 volunteers (15 men and 13 women) with a mean age of 30.2 ± 2.8 years (range, 25–35 years) were included in the study. The mean uncorrected VA was 20/22 in the right eye.

Ocular Duction Measurements

Using the LPT, the mean horizontal duction was 95.2° ± 10.1° and the mean vertical duction was 84.1° ± 10.8°. Using the GPT, the mean horizontal duction was 113.2° ± 14.1° and the mean vertical duction was 105.8° ± 12.5°. The mean horizontal and vertical ductions were significantly greater with the GPT than with the LPT (both $P < 0.05$) (Fig. 4). The mean test duration was significantly shorter for the LPT than the GPT (56.1 ± 4.5 seconds and 92.3 ± 11.6 seconds, respectively, $P = 0.003$).

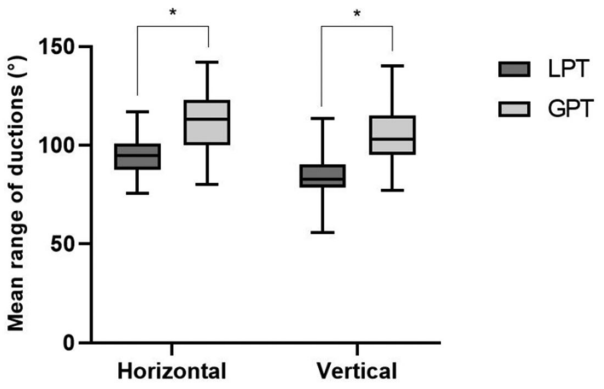

Figure 4. Boxplots showing mean range of ductions. The mean horizontal and vertical ductions were 95.2° ± 10.1° and 84.1° ± 10.8° using the LPT and 113.2° ± 14.1° and 105.8° ± 12.5° using the GPT, respectively; both values were significantly greater for the GPT (both $P < 0.05$).

Intraobserver Repeatability

The first and second LPT and GPT measurements obtained by the same examiner were compared. The ICCs of the mean horizontal and vertical ductions were 0.948 and 0.982, respectively, using the LPT, and 0.926 and 0.829, respectively, using the GPT. The CVs of the mean horizontal and vertical ductions were 1.98% and 2.03%, respectively, using the LPT and 3.50% and 3.10%, respectively, using the GPT (Table 1).

Interobserver Repeatability

The LPT and GPT measurements obtained by two different examiners were compared. The ICCs of the horizontal and vertical ductions were 0.866 and 0.927, respectively, using the LPT and 0.865 and 0.847, respectively, using the GPT. The CVs of the mean horizontal

Table 1. Intraobserver Repeatability of Ocular Duction Measurements of 28 Eyes Using the LPT and GPT

Characteristic	Initial Test (Mean ± SD)	Retest (Mean ± SD)	ICC	CV (%)
LPT, deg				
Horizontal range	95.2 ± 9.7	93.8 ± 9.5	0.948	1.98
Vertical range	84.3 ± 10.2	83.4 ± 10.0	0.982	2.03
GPT, deg				
Horizontal range	115.0 ± 15.4	115.3 ± 15.5	0.926	3.50
Vertical range	108.1 ± 14.5	108.8 ± 15.4	0.829	3.10

Table 2. Interobserver Repeatability of Ocular Duction Measurements of 28 Eyes Using the LPT and GPT

Characteristic	Examiner 1 (Mean ± SD)	Examiner 2 (Mean ± SD)	ICC	CV (%)
LPT, deg				
Horizontal range	95.2 ± 9.7	96.5 ± 10.3	0.866	2.94
Vertical range	84.3 ± 10.2	84.7 ± 11.5	0.927	3.83
GPT, deg				
Horizontal range	115.0 ± 15.4	109.3 ± 10.5	0.865	5.66
Vertical range	108.1 ± 14.5	102.2 ± 12.3	0.847	6.55

and vertical ductions were 2.94% and 3.83%, respectively, using the LPT and 5.66% and 6.55%, respectively, using the GPT (Table 2).

Discussion

Various methods have been proposed to measure ocular ductions objectively and quantitatively. Kestenbaum[2] developed the limbus test, which measures ocular ductions in millimeters via a transparent ruler placed in front of the cornea. Urist[3] developed a lateral version light-reflex test, which measures the change in position of the light reflex during extreme lateroversion and converts the measurement using a Hirschberg-type scale. Kushner[9] developed a cervical range-of-motion device to record abnormal head postures, duction limitations, and the range of single binocular vision. The current gold-standard method for measuring ocular ductions uses the Goldmann perimeter.[4–6] In many studies, the GPT showed good reproducibility and accuracy.[4,10,11] However, this method requires an instrument that is no longer in production and also depends on the availability of a trained technician.[11] Lim et al.[12] developed a modified limbus test for measuring the angles of ocular movements using photographs of cardinal positions of gaze. However, the results cannot be obtained immediately because additional image processing and analysis are required. Scleral search coils and video-oculography techniques have been developed to measure eye movement automatically.[13–17] However, these methods were developed for recording eye movements rather than range of ductions. In addition, scleral search coils and contact lenses are complicated, cause excessive discomfort, and are not practical for use in clinical settings. In addition, both scleral search coil and video-oculography techniques require expensive equipment.

In this study, we described a novel method for measuring ocular ductions using a laser pointer technique. The new device has a relatively simple configuration and requires low cost; this facilitates clinical application, especially for underequipped facilities and institutions in developing countries.

The mean horizontal and vertical ductions were 95.2° and 84.1°, respectively, using the LPT in the present study. The mean horizontal duction range was similar to those previously reported using a modified hand perimeter[10] and modified limbus test.[12] The mean vertical duction measured using the LPT was between the above two studies. Mourits et al.[10] adapted a hand perimeter to objectively measure the ocular duction in 40 healthy participants and reported that the mean maximal duction ranges were 94° in horizontal duction and 92° in vertical duction. Lim et al.[12] described a photographic method for measuring ocular movements using a modified limbus test and reported the following mean angles of ocular movements in healthy participants: adduction, 47.4°; abduction, 46.4° (93.8° of horizontal range); elevation, 31.8°; and depression, 47.8° (79.6° of vertical range). Photographs of nine cardinal positions were taken with a digital camera, and the images were then analyzed using Photoshop (Adobe, San Jose, CA, USA) and ImageJ (National Institutes of Health, Bethesda, MD, USA). This method does not depend on the patient's response, so the operator's interpretation is minimally involved, which makes the test more objective.

Gerling et al.[5] used standard GPT to measure ductions in 100 healthy participants and reported horizontal duction of 100.3° and vertical duction of 95.6°. These measurements are slightly larger than the measurements with the LPT. Although the current gold standard for measuring ocular ductions is GPT, we believe the LPT has theoretical advantages over the GPT in some points. The standard GPT uses a white light, while the LPT uses an optotype as a fixation target. When participants can no longer maintain foveal fixation, they notice blurring. These moments of change may be detected rapidly and easily when using an optotype as the fixation target. In contrast, with the GPT, it may be more difficult to identify blurring of the light target when the participant has lost foveal fixation. We suppose that the difference between

two methods may be one of many reasons for the discrepancy in the measurements. Differences in the testing environment may also contribute to the discrepancy. The GPT uses a white light target on the white background of a Goldmann bowl, whereas the LPT uses an optotype in the screen. The LPT has the advantage of using a real-world target.[18]

The mean horizontal and vertical ductions measured using the GPT were 113.2° and 105.8° in the present study, which were larger than those reported in previous studies. A possible explanation for the discrepant finding is the different assessment methods used in the study. With the GPT, ductions can be assessed subjectively (i.e., participants indicate when central fixation has been lost) or objectively (i.e., the examiner observes the endpoint of the pursuit movements by telescope). Both Gerling et al.[5] and Mourits et al.[10] used objective endpoints, whereas we used subjective endpoints in this study. In a study comparing clinical techniques for measuring ocular ductions in thyroid orbitopathy, Dolman et al.[11] reported that the subjective measurements were 5° to 10° larger than the objective measurements using the GPT, probably because the fixation light was visible within 5° of the fixation point.

The time required for testing is important, which represents ease of use. The total time required for testing with the LPT was found to be shorter compared to that with the GPT. One reason for this is the difference in the visual target. As described above, loss of central fixation could be detected more easily when using an optotype target compared to a light target. When measuring duction with GPT, repeated measurements were frequently required because volunteers failed to detect the exact moment of blurring of the light target, which resulted in prolongation of testing time. Another possible reason for the shorter test duration with the LPT is the mechanism of eye movement involved in the tests. Whereas the eye movement for the LPT relies mainly on the vestibular ocular reflex (VOR), that for the GPT relies mainly on smooth pursuit. The VOR is one of the fastest reflexes in the human body and can stabilize the eyes accurately at angular velocities of >300°/s and frequencies >20 Hz. This is because the VOR pathway is relatively short and activates motor neurons using only vestibular sensory information.[19] Therefore, the VOR is intrinsically rapid, accurate, and easy to elicit. In contrast, smooth pursuit is a much slower tracking eye movement, which has a considerably more complex pathway. Smooth pursuit is intrinsically slow and difficult to elicit compared to the VOR.

Our study compared repeatability of the measurements obtained using the LPT and GPT. Using both the LPT and GPT, intraobserver and interobserver ICCs of both horizontal and vertical ductions showed excellent repeatability. All ICC values measured by the LPT showed greater numbers than those measured by the GPT. The CVs of the mean horizontal and vertical ductions were less than 10% with both the LPT and GPT, which indicates good repeatability for both techniques. All CV values measured by the LPT showed greater numbers than those measured by the GPT. Our results were consistent with previous studies that reported good reproducibility of the GPT.[5,6,10,11] Consequentially, we believe that the LPT has acceptable reproducibility.

Despite many advantages, the LPT has several disadvantages. First, slight back-and-forth, lateral, vertical, and tilting movements of the head could occur during the examination, which may cause errors in the measurement. However, the examiner monitors the participant and corrects for undesired head movements. This is not a difficult task for both examiner and participant, and monitoring the head position is also needed in the standard GPT. Second, because the patients cannot see the meridians during the examination, the laser light may fail to track the meridians when they rotate their heads. In this study, if the laser light derailed the meridians, the patient was instructed to correct the head position, and most of the participants followed the instruction well. We evaluated ductions only along horizontal and vertical meridians, and there was no particular difficulty in this process. Examining the diagonal meridians could be difficult for some patients. In this situation, the examiner could help the patient by gently holding and slowly turning the patient's head, thereby tracking the laser light on the diagonal meridians. Third, geometric errors still exist in the LPT even after adding a step to correct the errors, because we used fixed anthropometric data in the process of calculating the error angle. However, we believe that the errors resulting from individual variation would not be that significant, and the LPT still has acceptable accuracy. Last, the LPT requires a large space for the screen. We are developing a new device that uses a gyro sensor instead of the laser pointer and screen, which will not require a large space.

In conclusion, the LPT, a new method for measuring ocular ductions described herein, showed excellent reproducibility and minimal interobserver variability. The LPT requires a shorter test time than the GPT and is easy to perform. Considering its reproducibility, accuracy, and simplicity, the LPT is expected to be useful for evaluating patients with ocular motility disorders as a first-order evaluation in the absence of sophisticated examination devices (i.e., GPT) in clinical settings.

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