· Clinical Research ·

A modified 3D stereophotogrammetry-based distraction test for assessing lower eyelid tension

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Abstract
● **AIM:** To investigate the reliability of a modified three-dimensional distraction test (3D-DT) and three-dimensional pinch test (3D-PT) for assessing lower eyelid tension (LET).
● **METHODS:** A cross-sectional study was conducted among 97 volunteers including 97 eyelids with no history of trauma, tumor, or reconstructive surgeries. Six three-dimensional photographs were acquired for each participant, including two photographs obtained in a neutral position (NP), two using a modified 3D-DT with a 15.9-grammes stainless steel eyelid hook performed, and two using 3D-PT.
● **RESULTS:** The mean absolute differences between NP, 3D-DT, and 3D-PT measurements varied between 0.07 and 7.42, 0.10 and 13.10, and 0.07 and 15.97, respectively; technical error of measurement varied between 0.05 and 7.81, 0.09 and 10.19, and 0.07 and 12.47, respectively; and relative error measurements varied between 0.10% and 11.50%, 0.16% and 30.51%, and 0.11% and 38.75%, respectively. For intra-rater reliability, the intraclass correlation coefficients (ICCs) were more than 0.80 in seven out of eight measurements obtained in the NP and 3D-DT, whereas those obtained in the 3D-PT were as low as less than 0.30 by rater 1; the ICCs of all the measurements obtained in all the positions (NP, 3D-DT, and 3D-PT) were more than 0.80 by rater 2. For inter-rater reliability six out of eight NP and 3D-DT measurements had an ICC greater than 0.80, whereas those of 3D-PT measurements were less than 0.30. For intra-method reliability, the ICCs of all the NP measurements were more than 0.87, whereas those of the six 3D-DT measurements and four 3D-PT measurements were more than 0.80.
● **CONCLUSION:** Our study results prove that the modified 3D-DT, which involves the use of an eyelid hook, can be a highly reliable method for evaluating LET. Furthermore, this novel and simple method may be utilized as the basis for further investigation and routine pre- and postoperative clinical evaluation.
● **KEYWORDS:** three-dimensional distraction test; lower eyelid tension; standard-weighted eyelid hook; three-dimensional stereophotogrammetry; landmark system
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INTRODUCTION

The pressure exerted on the eyes by the eyelids is defined as horizontal eyelid tension[1]. Although several factors can cause eyelid malposition[2], senile involution can significantly weaken horizontal palpebral traction and eventually decrease lower eyelid tension (LET)[3]. Progressive lower eyelid laxity may cause inappropriate ocular exposure and may have unpleasant effects on the aesthetics of the face[4-6]. Eventually, this laxity will need to be corrected surgically[6-8].

Traditionally, LET is assessed using the distraction test (DT) or pinch test (PT), which are performed by grasping the lower eyelid skin using the thumb and index finger and pulling downward until the lower eyelid cannot be stretched any further. The degree of laxity is considered normal if the distracted distance is less than 2 mm from the cornea; values higher than 6 mm are considered to indicate laxity. Over time, numerous studies have been conducted to evaluate the use of various devices for the assessment of LET[1,9-13]. However, most of these instruments, including the clamp and latex sensor, were considered infeasible due to their highly variable displacement distances and the overestimated LET values[1,9].

With the dramatic development of high-resolution three-dimensional (3D) stereophotogrammetry, the digital system has been utilized in the measurement of the normal anthropometric parameters of the cranial, facial, and periocular regions and in the planning of the optimal procedure for reconstructive eyelid surgeries[14-15]. However, only a few studies have investigated the application of 3D imaging systems in functional eyelid tests[16-17]. A digital imaging system was first utilized in a study by Stuchi *et al*[18] to investigate the reliability of using the DT to assess LET. The research demonstrated the potential application of digital systems in "dynamic" functional tests. However, only palpebral changes were investigated in that study; changes in other periocular parameters such as the medial and lateral canthal angles, which could be easily obtained using the digital system, were not included.

In our previous study, we introduced the application of a standard three-dimensional lateral distraction test (3D-LDT) to evaluate the LET[19-22], which demonstrating the potential further utilization of this novel methods in the field of periocular reconstruction. Hence, in the present study, we aim to investigate the reliability of a modified 3D-DT, which involved the use of a stainless eyelid hook, for the evaluation of LET. To the best of our knowledge, this is the first study in which the traditional DT was compared with a modified 3D-DT that involved the use of a stainless-steel eyelid hook to assess LET.

SUBJECTS AND METHODS

Ethical Approval All procedures performed in this study involving human participants were approved by the Institutional Review Board of the University of Cologne (No.17-199). Written Informed consent was obtained from all volunteers included in this study. The study protocol adhered to the principles stated in the Declaration of Helsinki's "Ethical Principles for Medical Research Involving Human Subjects".

Participants For this study, the right eyes of 97 volunteers (52 men and 45 women, 97 eyes) aged 21–85y (59.06±16.06y) were recruited in the Department of Ophthalmology, University of Cologne, Germany. Volunteers with a history of facial paralysis, facial morphological disorders, eyelid trauma, eyelid tumor, reconstructive eyelid surgeries, and any ocular or orbit abnormality influencing the eyelid tension were excluded.

Figure 1 Stainless-steel eyelid hook with 15.9-grammes was utilized in this study A: Its body length was 15.0 mm, and the head width was 10.0 mm; B: Its thickness was 1.0 mm.

3D Image Acquisition All images were acquired using the VECTRA M3 3D Imaging System (Canfield Scientific, Inc., Parsippany, NJ, USA) and processed as 3D models using the Face Sculptor software. Additionally, all 3D models were stored for further measurements and analyses using the VECTRA Analysis Module (VAM) software. A single experienced operator, trained by Prof. Heindl LM, and 3D anthropometry specialist Dr. Guo YW performed all image acquisitions under the same circumstances. Six 3D images were acquired for each participant, including two images acquired in the neutral position (NP), two images acquired in the 3D-DT using a 15.9-grammes stainless steel eyelid hook (Figure 1), and two images obtained in the 3D-PT with the first author Hou XY pulling the lower eyelid downward by her thumb and index finger in the same way for each participant. The hook was placed and stayed on the lower eyelid for a few seconds and was removed after the 3D photos were acquired with the camera. The duration between different photo-taking was about 10min to ensure that the lower eyelid returned to the original position (NP) and relaxed enough for the next photo. Additionally, each volunteer was questioned regarding his/her comfort level (none, mild discomfort, moderate discomfort, and severe discomfort) of the stretching traction on the eyelid during the application of the eyelid hook.

Before daily capture, the VECTRA system was calibrated according to the user guidelines. For images captured in the NP, each participant was asked to maintain a neutral expression while gazing into a mirror straight ahead. After

Table 1 List of inter-landmark distances

Abbreviation	Definition
IPc	Inter pupillary center distance, horizontal distance between Pc(left) and Pc(right)
MRD	Margin-reflect distance, vertical distance between pupil center and the lower eyelid margin
VPF	Vertical palpebral fissure, vertical distance between Ps and Pi
HPF	Horizontal palpebral fissure, horizontal distance between En and Ex
MCA	Medial canthal angle, angle between Ln'-En-Ln'
LCA	Lateral canthal angle, angle between Lt'-Ex-Lt'
ScE	Sclera exposure, vertical distance between Ci and Pi, defined as Ci-Cs when with fornix conjunctiva exposure
ConjE	Conjunctiva exposure, vertical distance between Cs and Pi

another calibration, the second image was captured under the same conditions (Figure 2A). Subsequently, the 3D-DT image was captured when the disinfected eyelid hook was hooked on the volunteer's lower eyelid margin. Another 3D-DT image was taken under the same conditions 10min later (Figure 2B). Finally, the PT image was acquired when the operator pulled the midpoint of the lower eyelid downward until it could not be pulled any further. Another PT image was acquired 10min later (Figure 2C). After acquiring all the images, two sets of measurements on the same image will be conducted by two trained raters to perform the reliability test including intra-rater, inter-rater reliability, and intra-methods reliability (Figure 3).

Landmarks A total of 13 landmarks were identified in this study. Five primary landmarks were identified in each image using the landmark system of the VECTRA. Subsequently, six landmarks were identified on the upper and lower eyelid margins (Ln', Ln'', Lt', Lt'', Ps and Pi) according to the axis across the primary landmarks. Additionally, Cs represented the mid-inferior point of the corneoscleral limbus, and Ci represented the intersection of the axis passing through the pupil and the upper boundary of the fornix conjunctiva. Afterward, inter-landmark measurements of each image were taken using the VAM software. These measurements included those of two angles [*i.e.*, the medial canthal angle (MCA) and the lateral canthal angle (LCA)] and six linear distances [*i.e.*, inter-pupil distance (IPc), margin reflex distance (MRD), vertical palpebral fissure (VPF), horizontal palpebral fissure (HPF), scleral exposure (ScE), and conjunctival exposure (ConjE); Table 1].

Statistical Analysis Four typical statistical methods were used to evaluate intra-rater, inter-rater, and intra-method reliability. The intraclass correlation coefficient (ICC) indicated high reliability if the result was close to 1 and low reliability if the result was close to 0[23-24]. Mean absolute difference (MAD) was calculated by averaging the absolute difference between the two measurements. Relative error measurement (REM) was calculated by dividing the grand mean of the two measurements by the MAD and multiplying the result by 100[25]. Technical error of measurement (TEM) was computed as ($\sqrt{(\sum D^2)/2N}$),where *D* represents the difference between the two measurements, and *N* represents the subject's count[26]. All the results were classified into five categories according to the initiating scales outlined by Camison *et al*[15] and Andrade *et al*[27]: <1% represents "excellent"; 1%–3.9% indicates "very good"; 4%–6.9% means "good"; 7%–9.9% denotes "moderate"; and ≥10% represents "poor".

The commercial software SPSS version 23 (IBM Corp., Armonk, NY, USA) was used to perform all statistical analyses. For normally distributed data, paired Student's *t*-tests were used to assess the difference between two sets of measurements and paired Wilcoxon tests were applied for non-normally distributed data. *P* values <0.05 were considered statistically significant.

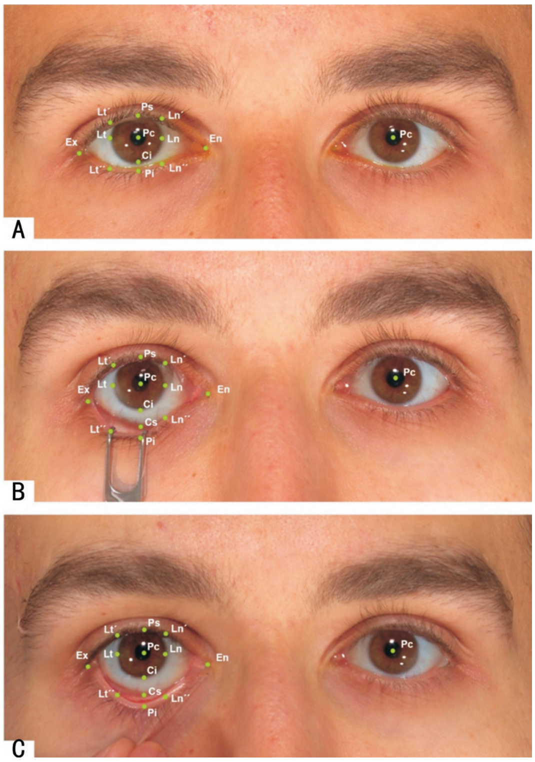

Figure 2 The 3D images for a 22-year-old male volunteer A: The 3D image of neutral position (NP); B: The 3D image of modified distracted position (DP), with the eyelid hook; C: The 3D image of traditional pinch test (PT).

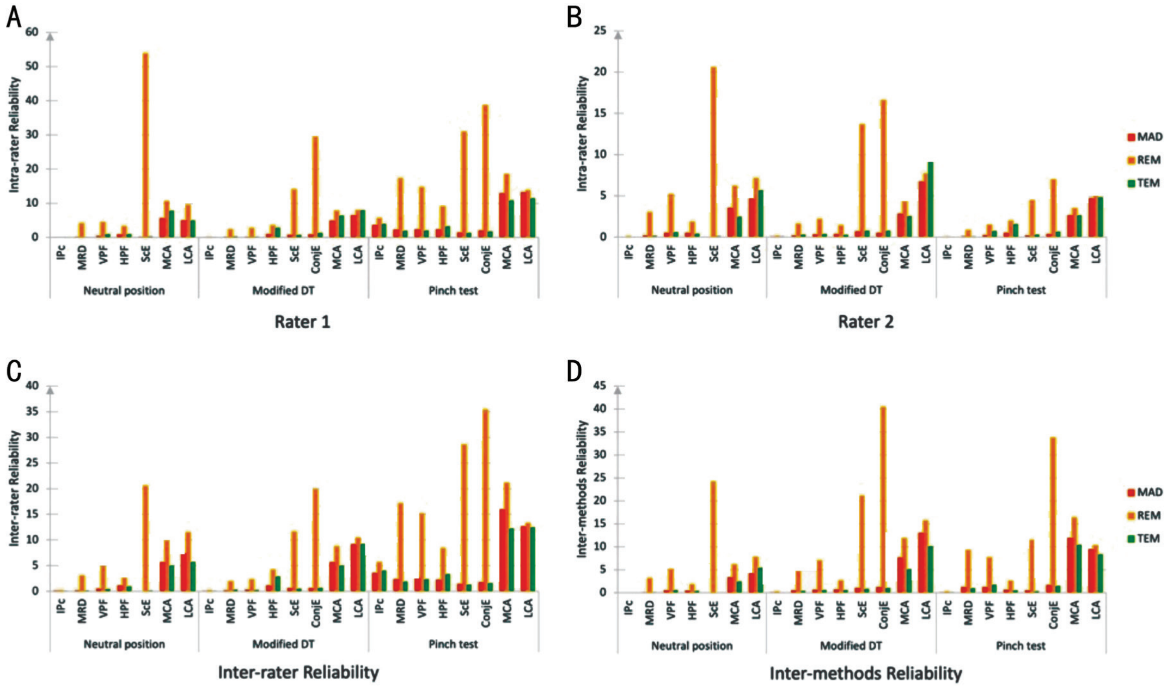

Figure 3 Intra-rater, inter-rater reliability, and intra-methods reliability of all measurements on 3D images A: Intra-rater reliability of rater 1 in the condition of neutral position, modified DT, and pinch test, respectively; B: Intra-rater reliability of rater 2 in the condition of neutral position, modified DT, and pinch test, respectively; C: Inter-rater reliability of rater 1 and rater 2 in the condition of neutral position, modified DT, and pinch test, respectively; D: Intra-methods reliability in the condition of neutral position, modified DT, and pinch test, respectively. DT: Distraction test; IPc: Inter pupillary center distance; MRD: Margin-reflect distance; VPF: Vertical palpebral fissure; HPF: Horizontal palpebral fissure; ScE: Sclera exposure; ConjE: Conjunctiva exposure; MCA: Medial canthal angle; LCA: Lateral canthal angle.

RESULTS

The demographic features of the participants are outlined in Table 2. A total of 97 volunteers (52 men, 53.6%; 45 women, 46.4%) aged from 21 to 85y (59.06±16.06y) were included in this study. Ninety-six (99.0%) participants were Caucasians. Sixty-five (67.0%) participants reported that they experienced no discomfort, 24 (24.7%) experienced mild discomfort, 5 (5.2%) experienced moderate discomfort, and two (2.1%) experienced severe discomfort.

Table 3 shows the mean values and differences between all the measurements acquired in the NP, those obtained using the 3D-DT, and those obtained using the 3D-PT. Except for HPF (P=0.21), significant differences were found for all measurements. Table 4 shows the intra-rater, inter-rater, and intra-method ICCs and mean differences across all measurements obtained from each 3D image.

Figure 3 illustrates the intra-rater, inter-rater, and intra-method reliability of all measurements obtained from the NP, 3D-DT, and 3D-PT images.

Intra-rater Reliability For rater 1, the ICCs were more than 0.80 in seven out of eight measurements obtained in the NP and 3D-DT, whereas those obtained in the 3D-PT were as low as less than 0.30; for rater 2, the ICCs of all the measurements obtained in all the positions (NP, 3D-DT, and 3D-PT) were more than 0.80. Although significant differences (P<0.05) were noted between the measurements with high ICC scores for both raters, the mean differences for the linear distances were less than 1 mm, and those for the angles were less than 4 degrees.

In NP, the MAD and TEM for all the linear distances were less than or equal to 1 mm for both raters, and both angles, *i.e.*, the MCA and LCA, were less than 6 degrees. The REM of ScE was 54% for rater 1 and 21% for rater 2, whereas those of all the other linear distances were less than or equal to 10% for both raters.

Table 2 Demographic characteristics of study participants

Categories	Count
Age (y)	
Range	21-85
Mean±SD	59.06±16.06
Sex, *n* (%)	
Male	52 (53.6)
Female	45 (46.4)
Race/ethnicity, *n* (%)	
Caucasian	96 (99.0)
Other	1 (1.0)
Comfort level, *n* (%)	
None	65 (67.0)
Mild	24 (24.7)
Moderate	5 (5.2)
Severe	2 (2.1)

Table 3 Mean values and the differences of all the measurements in neutral position, 3D-DT, and 3D-PT

Measurements	Test (mm/degree)			*P*	Differences		
	NP	3D-DT	3D-PT		NP *vs* 3D-DT	NP *vs* 3D-PT	3D-DT *vs* 3D-PT
IPc	63.84	63.87	63.71	0.003	0.33	0.006	0.001
MRD	6.23	11.74	13.71	<0.001	<0.001	<0.001	<0.001
VPF	10.52	12.76	16.82	0.002	0.11	0.001	0.01
HPF	32.30	27.58	26.79	0.21	0.16	0.11	0.80
ScE	0.35	5.18	4.90	<0.001	<0.001	<0.001	<0.001
ConjE	-	3.12	5.23	<0.001	-	-	<0.001
MCA	55.67	64.67	73.56	0.003	0.11	0.001	0.01
LCA	59.53	85.01	94.48	<0.001	<0.001	<0.001	<0.001

3D-DT: Three-dimensional distraction test; 3D-PT: Three-dimensional pinch test; NP: Neutral position; IPc: Inter pupillary center distance; MRD: Margin-reflect distance; VPF: Vertical palpebral fissure; HPF: Horizontal palpebral fissure; ScE: Sclera exposure; ConjE: Conjunctiva exposure; MCA: Medial canthal angle; LCA: Lateral canthal angle.

Table 4 Intraclass correlation coefficient and mean differences of intra-rater, inter-rater, and intra-methods across all measurements on three-dimensional images

Landmarks	Intra-rater						Inter-rater			Intra-methods		
	Rater 1			Rater 2								
	ICC (95%CI)	D-mean	*P*	ICC (95%CI)	D-mean	*P*	ICC (95%CI)	D-mean	*P*	ICC (95%CI)	D-mean	*P*
NP												
IPc	0.99 (0.99-1.00)	0.32	0.31	0.99 (0.99-1.00)	-0.01	0.47	0.99 (0.99-1.00)	-0.04	0.01	0.99 (0.99-1.00)	-0.01	0.47
MRD	0.86 (0.79-0.91)	0.03	0.31	0.92 (0.79-0.96)	0.12	0.00	0.94 (0.91-0.96)	0.01	0.83	0.92 (0.79-0.96)	0.02	0.50
VPF	0.97 (0.95-0.98)	-0.05	0.66	0.98 (0.94-0.99)	0.44	0.00	0.98 (0.97-0.99)	-0.01	0.97	0.98 (0.94-0.99)	0.20	0.03
HPF	0.86 (0.78-0.91)	0.45	0.001	0.97 (0.95-0.98)	0.09	0.20	0.84 (0.62-0.91)	-0.80	0.00	0.97 (0.95-0.98)	0.06	0.34
ScE	0.88 (0.80-0.93)	-0.14	0.001	0.98 (0.98-0.99)	0.01	0.74	0.98 (0.96-0.98)	0.02	0.22	0.98 (0.98-0.99)	0.02	0.70
MCA	0.55 (0.28-0.71)	4.2	0.000	0.92 (0.83-0.96)	-2.04	0.000	0.75 (0.63-0.84)	-1.53	0.05	0.92 (0.83-0.96)	-1.04	0.02
LCA	0.79 (0.68-0.86)	1.35	0.07	0.87 (0.80-0.92)	2.4	0.001	0.70 (0.53-0.80)	2.50	0.008	0.87 (0.80-0.92)	2.21	0.01
3D-DT												
IPc	1.00 (0.99-1.00)	0.04	0.15	1.00 (0.99-1.00)	0.02	0.28	1.00 (0.99-1.00)	0.04	0.03	0.95 (0.88-0.98)	-0.14	<0.01
MRD	0.98 (0.97-0.99)	0.05	0.37	0.99 (0.98-0.99)	0.07	0.10	0.99 (0.98-0.99)	0.03	0.53	0.97 (0.93-0.99)	-0.03	0.83
VPF	0.99 (0.99-0.99)	0.04	0.36	0.98 (0.97-0.99)	0.20	0.00	0.99 (0.98-0.99)	0.02	0.66	0.999 (0.99-1.00)	0.02	0.93
HPF	0.52 (0.26-0.69)	0.14	0.66	0.98 (0.97-0.99)	0.07	0.21	0.50 (0.23-0.67)	-0.35	0.29	0.90 (0.76-0.96)	0.02	0.92
ScE	0.86 (0.78-0.91)	-0.31	0.01	0.95 (0.92-0.97)	-0.09	0.20	0.93 (0.84-0.96)	0.39	0.00	0.79 (0.51-0.91)	0.53	0.06
ConjE	0.90 (0.85-0.94)	-0.14	0.45	0.97 (0.95-0.98)	0.15	0.13	0.97 (0.95-0.98)	-0.12	0.24	0.90 (0.78-0.96)	0.30	0.39
MCA	0.80 (0.67-0.87)	2.65	0.002	0.97 (0.95-0.98)	0.37	0.38	0.85 (0.76-0.90)	1.77	0.03	0.80 (0.14-0.94)	7.51	<0.01
LCA	0.87 (0.79-0.91)	-2.53	0.02	0.85 (0.77-0.90)	1.91	0.11	0.78 (0.50-0.88)	6.95	0.00	0.51 (0.20-0.81)	-8.53	0.01
3D-PT												
IPc	0.10 (-0.46-0.44)	-0.37	0.59	1.00 (1.00-1.00)	-0.02	0.06	0.09 (-0.479-0.434)	-0.36	0.60	0.99 (0.99-1.00)	-0.01	0.78
MRD	-0.13 (-0.83-0.31)	0.01	0.97	0.99 (0.99-0.99)	0.02	0.26	-0.07 (-0.73-0.34)	0.10	0.79	0.81 (0.46-0.93)	0.82	0.01
VPF	0.13 (-0.39-0.46)	-0.61	0.14	0.97 (0.95-0.98)	-0.02	0.83	-0.02 (-0.61-0.35)	0.87	0.05	0.69 (0.25-0.87)	0.93	0.04
HPF	-0.19 (-0.86-0.24)	-1.11	0.03	0.79 (0.68-0.86)	-0.08	0.69	-0.34 (-1.14-0.17)	0.68	0.18	0.92 (0.76-0.97)	-0.46	0.02
ScE	-0.28 (-1.06-0.21)	0.21	0.41	0.98 (0.96-0.98)	-0.08	0.05	-0.19 (-0.93-0.27)	<-0.01	0.99	0.93 (0.83-0.97)	0.12	0.43
ConjE	0.09 (-0.46-0.44)	0.24	0.49	0.96 (0.93-0.97)	0.11	0.24	0.30 (-0.14-0.57)	-0.07	0.82	0.58 (0.04-0.83)	0.99	0.05
MCA	0.13 (-0.38-0.46)	-3.55	0.10	0.98 (0.97-0.99)	-1.09	0.01	-0.01 (-0.46-0.33)	9.11	<0.01	0.61 (-0.08-0.85)	10.75	<0.01
LCA	0.26 (-0.18-0.54)	2.74	0.22	0.91 (0.86-0.94)	0.71	0.37	-0.02 (-0.47-0.32)	8.3	<0.01	0.42 (-0.49-0.77)	-0.19	0.95

ICC: Intraclass correlation coefficient; D-mean: Mean differences; NP: Neutral position; 3D-DT: Three-dimensional distraction test; 3D-PT: Three-dimensional pinch test; IPc: Inter pupillary center distance; MRD: Margin-reflect distance; VPF: Vertical palpebral fissure; HPF: Horizontal palpebral fissure; ScE: Sclera exposure; ConjE: Conjunctiva exposure; MCA: Medial canthal angle; LCA: Lateral canthal angle.

In 3D-DT, the MAD of all linear distances was less than 1 mm for both raters. The TEM of all the linear distances except HPF and ConjE of rater 1 was less than 1 mm for both raters. The REM of three linear distances (IPc, MRD, and VPF) was less than 3% for both raters.

In 3D-PT, the MAD and TEM for rater 1 were more than 1 mm in all the linear distances, and more than 10 degrees in both angles (MCA and LCA). The MAD and TEM for rater 2 were less than 1 mm in all the linear distances, and less than 5 degrees in both angles (MCA and LCA).

Inter-rater Reliability Six out of eight NP and 3D-DT measurements had an ICC greater than 0.80, whereas those of 3D-PT measurements were less than 0.30. For NP, except for HPF with a slightly higher MAD (1.15 mm), the other five linear distances were less than 1 mm in MAD and TEM. The MAD and TEM of both angles (MCA and LCA) were less than 6 degrees. The REMs of five out of six linear distances were less than or equal to 5%, whereas the REMs of ScE (21%), MCA (13%), and LCA (14%) were relatively higher.

Regarding the 3D-DT, five linear distances were less than 1 mm, whereas HPF was greater than 1 mm (1.16 and 2.89 mm) in MAD and TEM. The MAD and TEM of the MCA were less than 5 degrees, whereas they were around 9 degrees for LCA. The REMs of the IPc, MRD, and VPF were less than 3%, whereas they were over 10% for the HPF, ScE, and ConjE. In addition, the REM was 9% for the MCA and 10% for the LCA.

Regarding the 3D-PT, all the linear distances were more than 1 mm, whereas both angles (MCA and LCA) ranged from 12.47 to 15.97 degrees in MAD and TEM. All the measurements were more than 10% in REM, except for the IPc (less than 10%).

Intra-method Reliability The ICCs of all the NP measurements were more than 0.87, whereas those of the six 3D-DT measurements and four 3D-PT measurements were more than 0.80.

For the NP, MADs and TEMs of all the linear distances were less than 1 mm, whereas those of both angles (MCA and LCA) were less than 6 degrees. The REMs of all measurements were less than or equal to 7%.

For the 3D-DT, MADs and TEMs of all linear distances were less than or equal to 1 mm, except for ConjE (1.26 and 1.05 mm). REMs of the IPc, MRD, HPF, and VPF were less than 5%, whereas ScE and ConjE were higher (21% and 42%, respectively). In addition, the REM was 12% and 15% for MCA and LCA, respectively.

Concerning 3D-PT, MADs and TEMs of Ipc, HPF, and ScE were less than 1 mm, whereas they were more than 1 mm for MRD, VPF, and ConjE. Furthermore, both angles (MCA and LCA) ranged from 8.42 to 11.96 degrees in MAD and TEM. Besides, half of the 3D-PT measurements had a REM of less than 9%, whereas the other four measurements, *i.e.*, ScE, ConjE, MCA, and LCA, were more than 10% in REM.

DISCUSSION

In this study, we investigated the reliability of a 3D-DT based on the VECTRA M3 3D stereophotogrammetry device for the assessment of LET. In addition, we explored the possibility of using the same 3D imaging system in the traditional PT to assess LET, which is usually measured directly using only a caliper or grading scale. Six images were captured for each participant; each image had ten corresponding linear and angular measurements.

Our study demonstrated that compared with the 3D-PT, the modified 3D-DT showed highly reliable results in the assessment of LET. Additionally, our results were highly consistent with those of previous studies[25,28] that investigated the reliability of this 3D system in periocular anthropometry. To the best of our knowledge, this is the first study in which a standard-weighted eyelid hook was utilized for the assessment of LET instead of the conventional, manual method of performing 3D-PT.

In general, the measurements taken in the NP had the best intra-rater, inter-rater, and intra-method reliability. These findings are also consistent with those of previous studies[28-31], in which the 3D imaging system was demonstrated to be highly reliable and accurate for periocular anthropometric measurements. More specifically, the present study was also the first to investigate the reliability of inferior ScE measurements in a healthy population; the measurements were shown to have good reliability. The results could be used as a reference for further study of exophthalmos or thyroid-related ocular diseases.

Furthermore, the results of the modified 3D-DT proved to be more reliable than those of the traditional PT performed using a 3D imaging system. Regarding the intra-rater reliability of the 3D-DT, the MADs and TEMs of all the linear measurements were less than 1 mm, whereas those of angular measurements were less than 7 degrees. In contrast, the MADs and TEMs of all the linear measurements were more than 1 mm, whereas those of the angular measurements were more than 7 degrees for both raters. For the inter-rater reliability of the 3D-DT, the MADs and TEMs of all measurements except for those of the HPF and LCA were shown to be highly reliable. This difference may be due to the influence of position changes caused by the examiner's inability to accurately localize the landmarks on the lower eyelid margin, as well as the interference of the upper and lower eyelashes. Regarding the inter-rater reliability of the 3D-PT, all measurements except for those of inter-mid-pupil distance demonstrated relatively lower reliability, which may be due to the uniformity in the pulling strength used even when the procedure is performed by the same operator. Hence, it was challenging to maintain the stability of the reliability of the measurements, specifically in the 3D imaging system, which records just one image for the functional test.

To date, different methods used to evaluate LET have been investigated[1,9-10,32]. However, most of these methods are complex and the patient may experience obvious discomfort during the procedure. This may lead to unreliable and inaccurate results. The high reliability of the results of the present study may be due to the easy application of the stainless-steel eyelid hook during the 3D-DT, which possibly highlights the instability of the manual pulling (PT) that follows the law of energy conservation in physics.

Furthermore, most of the volunteers (67%) in this study had no discomfort, except for a few sensitive individuals who experienced severe discomfort during the stretching by the eyelid hook. Hence, in our study, topical anesthetic eyedrops were not administrated during the application of the eyelid hook to record the actual discomfort level. In further research, a comparison study between the anesthetic and non-anesthetic groups could be investigated based on the present study.

A potential limitation of this study is that individuals who have pathological changes in the lower eyelid were not included. A patient group should be included as a comparative group in future studies. Additionally, on tighter eyelids, the used weight may not be enough to cause the maximum distraction and fail to detect distraction differences between eyelids, especially in average to high tension situations. The ideal stretching weight should be designed more accurately for different ranges of eyelid status.

Our study results proved that the modified 3D-DT, which involves the use of an eyelid hook, could be a highly reliable method for evaluating LET. More specifically, this modified 3D-DT could provide accurate measurements of the linear changes in MRD, VPF, and HPF during the functional test. Furthermore, this novel and simple method may be utilized as the basis for further investigation and routine pre- and postoperative clinical evaluation.

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