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Title:

A new portable digital meniscometer

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Abstract

Purpose: The aim of this study was (i) to develop a new portable, slit-lamp mounted digital meniscometer (PDM), and (ii) to test its accuracy and repeatability compared to the available Yokoi et al video-meniscometer (VM).[1]

Methods: The medians of three consecutive measurements on 5 glass capillaries (internal radii 0.100 to 0.505 mm) were compared between VM and PDM at two different sessions. Also, the central lower tear meniscus radius (TMR) in 20 normal subjects (10M, 10F; mean age 32.3 SD ± 9.3 years) was measured using both techniques. Correlations between the instruments were analyzed using the Pearson coefficient. Differences between sessions and instruments were analyzed using Bland-Altman plots, coefficient of repeatability (CR) and paired t-tests.

Results: The PDM and VM were accurate in vitro (95% CI of difference: PDM -0.0134 mm to + 0.0074; p=0.468; VM -0.0282 to + 0.0226; p=0.775), and reproducible between sessions (95% CR: 0.019 and 0.018, respectively). The mean difference between the PDM and VM in vitro was 0.0002 mm (CI – 0.0252 to + 0.0256; p=0.984). In human subjects, TMR measured with the PDM (0.34 ± 0.10 mm) and VM (0.36 ± 0.11) was significantly correlated (r=0.940; p< 0.001), and there was no statistically significant difference between the measured TMR of the instruments (p=0.124).

Conclusions: This new slit-lamp mounted digital meniscometer produces accurate and reliable measurements, and provides similar values for tear meniscus radius, in human studies, to the existing video-meniscometer. The instrument is suitable for use in both research and clinical practice.

Key words: Portable digital meniscometer, reflective meniscometry, tear meniscus radius, tear film, dry eye diagnosis

Dry eye is a multi-factorial disease resulting in damage to the ocular surface and patient symptoms of discomfort, principally due to an insufficient tear film.[2] This insufficiency is typically caused by an aqueous deficiency or increased evaporation of the tear film.[2] The tear menisci along the superior and inferior lid margins represent 75 to 90% of the tear film volume at the ocular surface.[3] Thus, evaluation of the tear menisci is regarded as an indicator of the tear film volume and is important in the diagnosis of aqueous tear deficiency.[4-7] Measurement of the tear meniscus height is used in many studies for tear volume assessment and, in clinical practice, it is mostly performed with a slit-lamp.[8-13] However, identifying the upper limit of the meniscus at the slit lamp is challenging unless sodium fluorescein is added to the tear film, rendering the test invasive and less informative.

In contrast, the analysis of the radius of curvature of the tear meniscus (TMR), while more difficult to do, is assumed to be better in predicting tear volume in a non-invasive way.[1, 6, 14-16] TMR can be evaluated by the use of an optical coherence tomographer,[5, 15, 17-20] or a meniscometer.[1, 14, 21-24] Although both instruments measure the tear meniscus non-invasively, they have not found wide application among clinicians, either because they are not commercially available in all parts of the world, or they are too expensive.[25] One such meniscometer, developed by Yokoi et al, projects a defined grid of black and white lines onto the tear meniscus.[1, 26] The meniscus acts as a concave mirror and the size of the reflected image is used to calculate TMR. However, to our knowledge, only three such video-meniscometers are in use worldwide. Consequently, the aim of this study was (i) to develop a new portable, slit-lamp mounted meniscometer, and (ii) to test its accuracy and repeatability compared to the available Yokoi et al video-meniscometer.

Methods

Instrument development:

To project a target onto the anterior curvature of the tear meniscus, an illuminated target was needed. A conventional iPod-touch (Apple Inc., Cupertino, CA, USA) with a 3.5” multi-touch-display 7.5 x 5.0 cm (480 x 320 Pixel) was used for this purpose. An application software for the iPod-touch was developed to generate a grid of black and white lines on the display (Figure 1). The width of the lines is shown on the display and can be varied between 0.15 and 7.5 mm via the touch screen. Additionally, the vertical orientation of the iPod is given in degrees on the display. To define the distance from the tear meniscus, the iPod-touch was fixed to a digital photo slit-lamp (BQ900 with IM900 digital imaging module, Haag-Streit, Koeniz, Switzerland). A commercially available iPod-Touch stand (Xtand, Just Mobile e.K., Berlin, Germany) was modified and mounted on a metal axis on the stand so that it could be fixed to the tonometer post of the slit-lamp (Figure 2). This set-up allowed adjustment of the target in several different orientations in relation to the tear meniscus.

Specular reflection with the slit-lamp was achieved by setting the incidence angle of the target grid equal to the observation angle of the microscope, which was set at 40x magnification. The distance between the target (iPod) and the tear meniscus (a=target distance) was controlled with a sliding calliper.

Imaging of the reflection was produced through a digital camera (RM 01 CCD-camera, 1600 x 1200 pixel, Haag-Streit, Koeniz, Switzerland) incorporated into the slit-lamp, and relayed to image-grabbing software (EyeSuite Imaging, Haag-Streit, Koeniz, Switzerland) within a PC. The computer screen had a resolution of 1280 x 1024, producing a total magnification of about 100x, which was the best compromise in terms of resolution and brightness of the image. On the image of the reflected grid obtained, the distance between the outer edges of two white lines (total wide of two white and one black projected line) was measured using the ImageJ 1.46 software (http://rsbweb.nih.gov/ij) (Figure 3). With a known size of the target (y), distance of the target (a) and the size of the image on the screen (y'), the radius of the tear meniscus can be calculated using the given formula for a concave mirror (Figure 4).

In vitro study:

The inner surfaces of 5 glass capillaries were used as a model of the tear meniscus The inner diameters of the glass capillaries (Hilgenberg GmbH, Malsfeld, Germany) were confirmed by use of a hole-gauge before cutting them in half. The medians of three consecutive measurements on the 5 glass capillaries (radii 0.100mm to 0.505mm) were compared between the existing video-meniscometer (VM) (Figure 5) and the new portable digital meniscometer (PDM) at two different sessions and after re-set-up of the PDM.

In vivo study:

Twenty subjects (male = 10, female = 10, mean age 32.3 years, range = 23-56 years) were randomly selected from the students and staff of the School of Optometry and Vision Sciences at Cardiff University, UK. All procedures obtained the approval of the Cardiff School of Optometry and Vision Sciences Human Ethics Committee and were conducted in accordance with the requirements of the Declaration of Helsinki. All subjects gave written informed consent before participating in the study.

Subjects were excluded if they were pregnant or breastfeeding; had a current or previous condition known to affect the ocular surface or tear film; had a history of previous ocular surgery, including refractive surgery, eyelid tattooing, eyelid surgery, or corneal surgery; had any previous ocular trauma, were diabetic, were taking medication known to affect the ocular surface and/or tear film, and/or had worn contact lenses less than two weeks prior to the study. Exclusion criteria was dry eye, defined by either an item-weighted McMonnies questionnaire score >14.5 or a fluorescein tear break-up time <10 seconds.

The lower TMR was measured by one observer using both techniques (VM and PDM) in a randomized order. The median of three consecutive measurements was recorded for both techniques. All assessments were of the inferior tear meniscus of the right eye directly below the pupil centre with the subject looking straight ahead at a fixation target. The room temperature and relative humidity were controlled to remain within normal limits. To minimize diurnal and inter- blink variation, measurements were taken in the morning between 10 and 12 o'clock and 3 to 4 seconds after a blink.

Statistical analyses:

Normal distribution of data was analysed by Shapiro-Wilk test. Differences between sessions (day 1 and day 2) and instruments were analyzed using Bland- Altman plots, coefficient of repeatability (CR) and paired t-tests. The relationship between PDM and VM measurements was analyzed by Pearson product moment correlation. The data were analyzed by use of SigmaPlot 12 (Systat Software Inc., Chicago, USA) and BiAS 10 (epsilon-Verlag, Darmstadt, Germany).

Results

In vitro study:

The PDM and VM were accurate (95% CI: PDM -0.0134 to +0.0074mm; p=0.468; VM -0.0282 to +0.0226mm; p=0.775), and reproducible between sessions (95% CR: 0.019mm and 0.018mm, respectively) (Fig. 5.6). The mean difference between the PDM and VM was 0.0002mm (CI –0.0252 to +0.0256mm; p=0.984) (Fig.7).

*In vivo study***:**

In human subjects, TMR measured with the PDM (0.34±0.10mm) and VM (0.36±0.11mm) was significantly correlated (r=0.940; p< 0.001). The mean difference between PDM and VM was -0.0151mm (CI -0.0285 to -0.0018mm; p=0.124) in this cohort (Fig.8).

Discussion

Reflective meniscometry is a non-invasive method to measure TMR, useful in dry eye diagnosis. The first photographic meniscometer was introduced by Bron in 1997 and Yokoi et al. in 1999.[1, 26] It consists of a target of 14 black and 13 white lines, each 2 mm wide, attached to a macro-camera.[1] A video system with a CCD camera and target consisting of a central white bar of 3.5 mm wide on a black surround was also described. A modification of the video system called "video-meniscometer" with a target of a series of black metal bars, 4 mm wide and 4 mm apart, set directly in front of the objective lens and illuminated from behind was developed by Oguz et al.[24] and Yokoi et al.[21] in 2000. In a similar manner to this study, calibration for the original meniscometer system was carried out using glass capillaries.[1] Also using glass capillaries Kato et al. found no significant differences between TMR measured with the VM and an anterior segment optical coherence tomographer.[27]

With our new developed ipod-touch based portable, slit-lamp mounted meniscometer we found a good accuracy and reproducibility across the whole range of typical TMR (Figure 6). In contrast the VM seems to have the tendency to under-estimate the TMR for small radii and to over-estimate TMR for larger radii (Figure 7).

This effect also becomes obvious in the comparison between the two methods (Figure 7). So the radii measured by the PDM seem to be more consistent than those measured by the VM. These differences might be caused by the different design of the target lines. While the VM uses metal bars mounted directly in front of the observation system, the target of the PDM consists of digital produced lines which are separated from the observation system. As a result, the PDM target does not interfere with the observation system of the slit-lamp, since the VM target effectively functions as an aperture within the observation system thus influencing the depth of field. A second source of error arises from the working distance of the instrument. While the VM has a working distance of 24 mm, a longer distance of 50 mm is used by the PDM. By looking at the concave mirror formula (Figure 3) it becomes obvious that the smaller the working distance (a) is the greater the error gets if the system is not exactly aligned.

With the PDM we found a TMR of (0.34 ± 0.10 mm) in a group of normal non-dry eye patients. This was not significantly different from the TMR measured with the VM (0.36 ±0.11 mm) and is in accordance to previously reported measurements with reflective meniscometry in normal.[1, 21] The correlation between the two methods indicates the PDM is a valid measure of TMR. For dry eye patients the reported TMR measured with reflective meniscometry varies between 0.22 and 0.25 mm.[6, 21, 24] While meniscometry uses specular reflexion to analyse TMR, in optical coherence tomography a vertical line scan produces a cross-sectional image of the tear meniscus. On the images taken with an OCT, the 3-point method is used to fit a circle to the anterior border of tear meniscus. TMR of the lower tear meniscus reported with this method varies from 0.25 to 0.46 mm for normals and between 0.15 to 0.20 mm in dry eye patients.[15, 17, 18, 20, 28]

For the purpose of calculating meniscus volume, the anterior shape of the meniscus is treated as a part of a circle even it is likely to have a more complex shape.[29] To understand differences in TMR measurements between reflective meniscometry and optical coherence tomography it would be helpful to describe the shape of the meniscus more precisely and to analyse the location on the meniscus were the PDM is measuring the meniscus. While OCT and the existing VM have a fixed vertical orientation of the target, the PDM allows a rotation of the target and therefore a measurement of the meniscus under different angles. Furthermore the line width of the target can be easily varied via the touch screen. This enables the projection of different grids to the meniscus, which may help give a more detailed description of tear meniscus anterior shape.

In the literature the measurement of tear meniscus parameters is mostly performed at the centre of the lower eyelid, directly under the pupil. Some authors report tear meniscus height (TMH) to be greater at the centre of the lid,[30] but others find no thinning of the inferior tear meniscus,[31] or even that the TMH that is smaller at the center.[11] These differences might be explained by the different techniques used and the different locations at which TMH was measured. At the same time, when calculating tear meniscus volume, the meniscus is assumed to be equal along the lower lid,[5, 32] or a correction factor of ¾ is used to account for an unequal distribution.[30, 33, 34] Since the PDM is mounted on a standard slit-lamp it can be used for measurement of TMH and at the same time for measurement of TMR at different location along the lid and therefore to analyse tear film distribution along the lid.

Conclusions:

In summary, measuring TMR is a useful non-invasive test in dry eye diagnosis.[1, 15, 16, 20, 21] The potential techniques to measure TMR are either not commercially available or too expensive for clinical use. We have developed a portable, slit-lamp mounted, digital meniscometer that produces accurate and reliable measurements, and is able to provide similar values for tear meniscus radius, in human studies, to the existing video-meniscometer. This makes the instrument suitable for use in both research and clinical practice.

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Figures:

Figure 1. iPod-touch (Apple Inc., Cupertino, CA, USA) as a target with adjustable grid width. The numbers on the touch screen give the width of the bars in mm and the vertical orientation of the instrument in degrees.

Figure 2. PDM instrument mounted on a digital imaging slit-lamp (BQ900 with IM900 digital imaging module, Haag-Streit, Koeniz, Switzerland).

Figure 3. Measurement of line distance on the PDM-image using ImageJ 1.46 software.

Figure 4. Concave mirror formula for calculation of the tear meniscus radius in reflective meniscometry.

Figure 5. Video-meniscometer.

Figure 6. In vitro radius difference between sessions of the PDM.

Figure 7. In vitro radius difference between sessions of the VM.

Figure 8. In vitro radius difference between PDM and VM.

Figure 9. In vivo radius difference between PDM and VM.

Figure 10a. Example of a steep tear meniscus radius (r=0.19 mm) measured with the PDM**.**

Figure 10b. Example of a flat tear meniscus radius (r=0.42 mm) measured with the PDM.

Figure 1

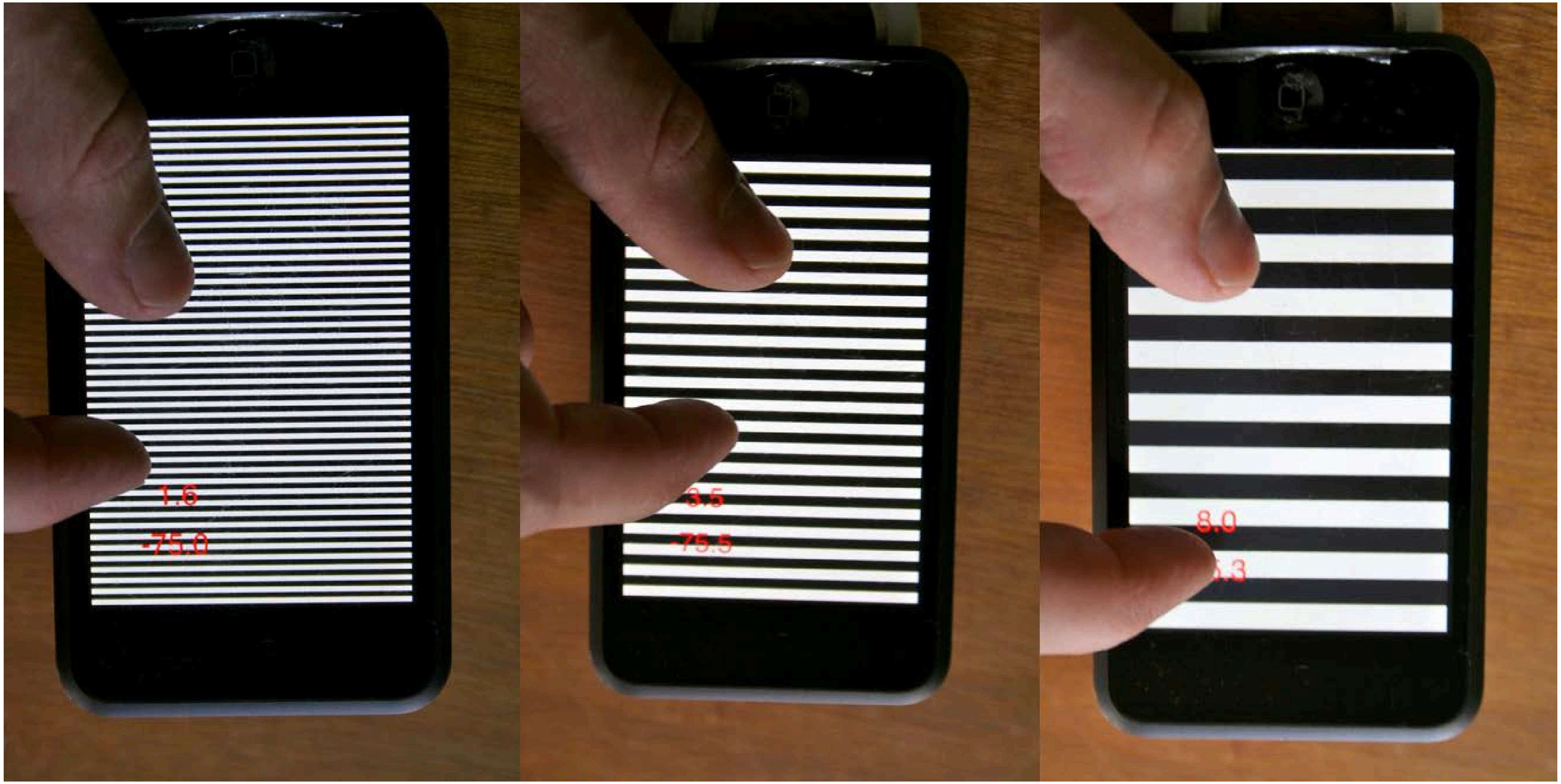


Figure 2

Figure 3

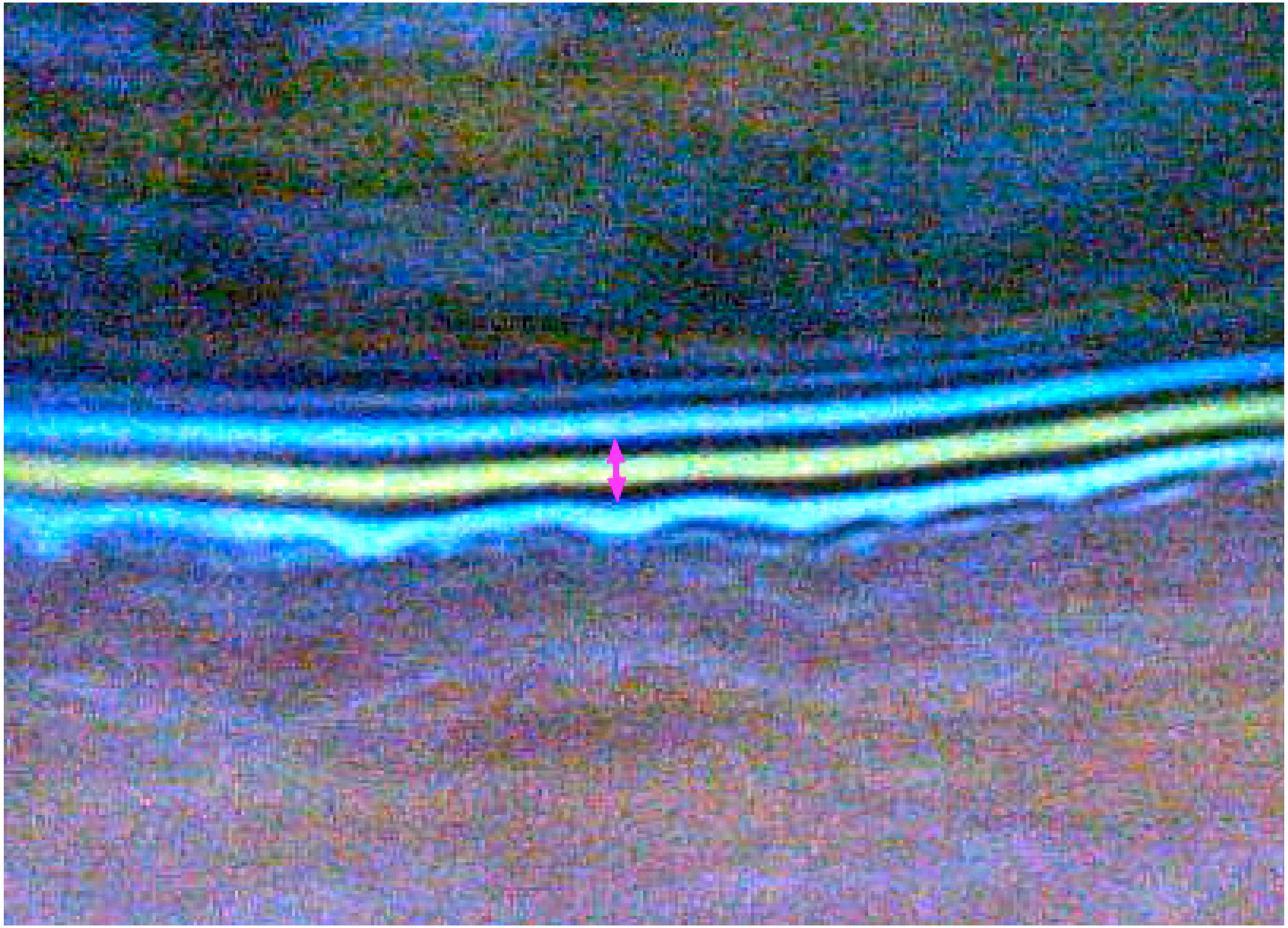


Figure 4

$$r = \frac{2 \cdot a \cdot y'}{y - y'}$$	r = radius of meniscus curvature a = target distance y = target size y' = image size

Figure 5

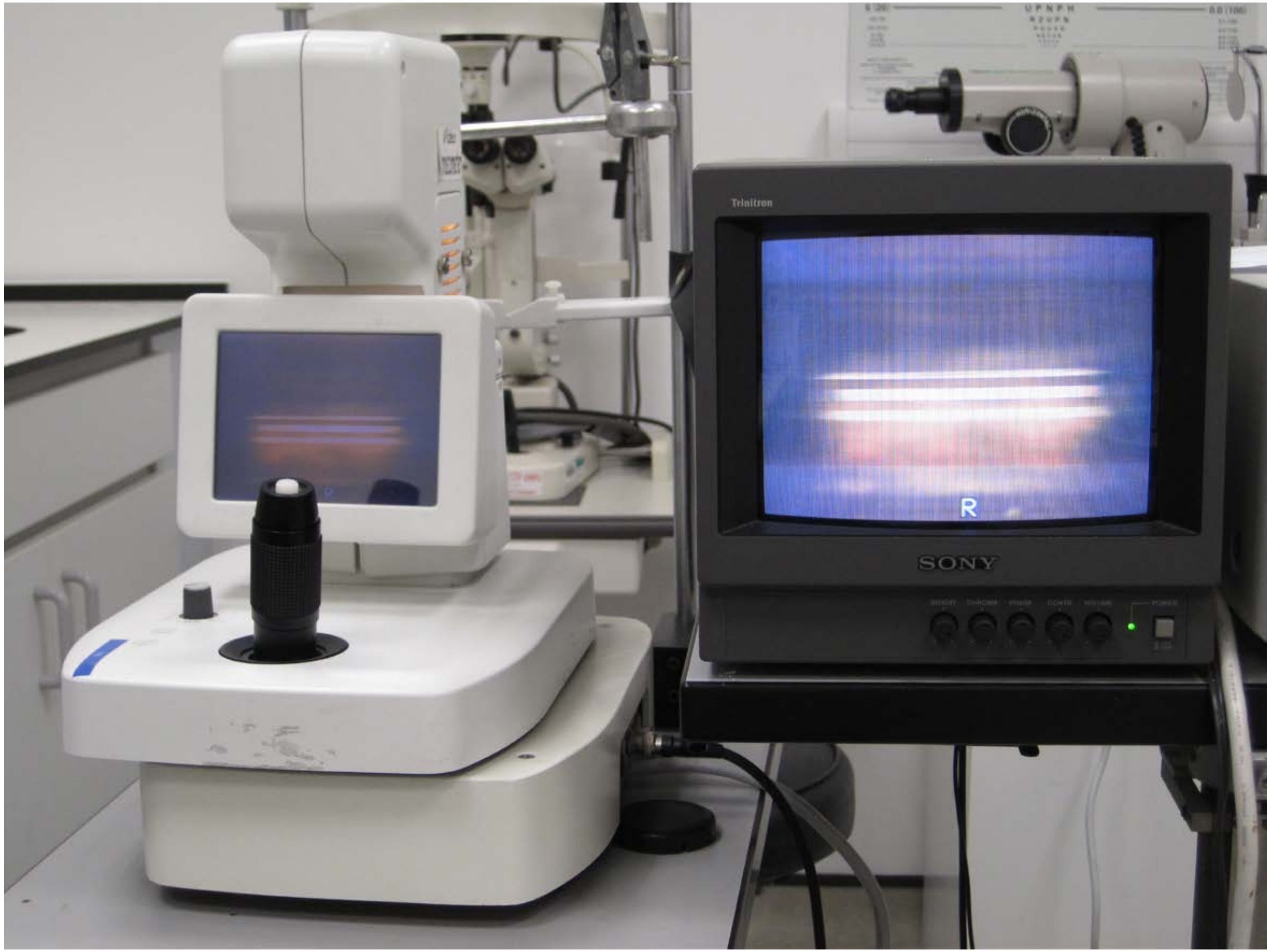
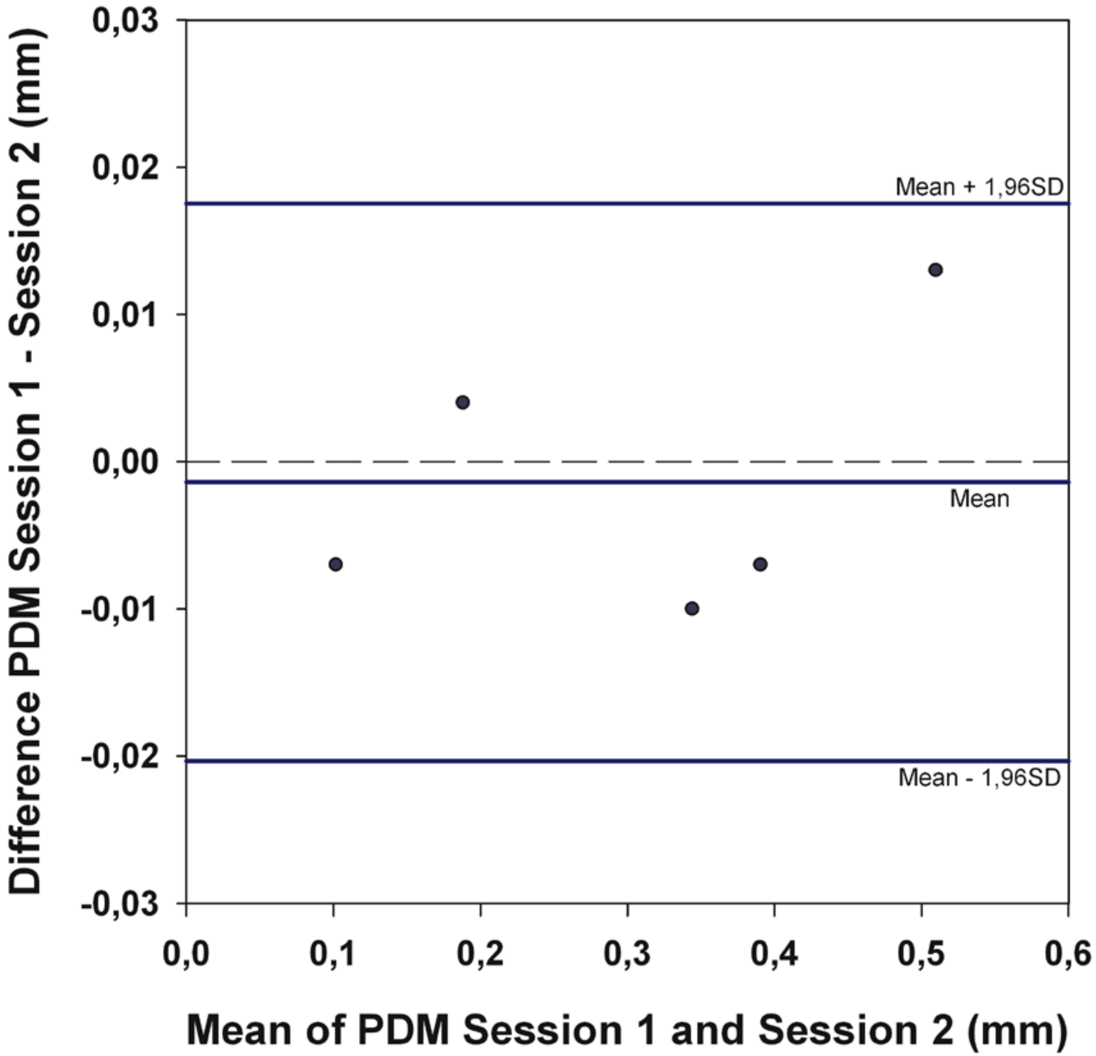
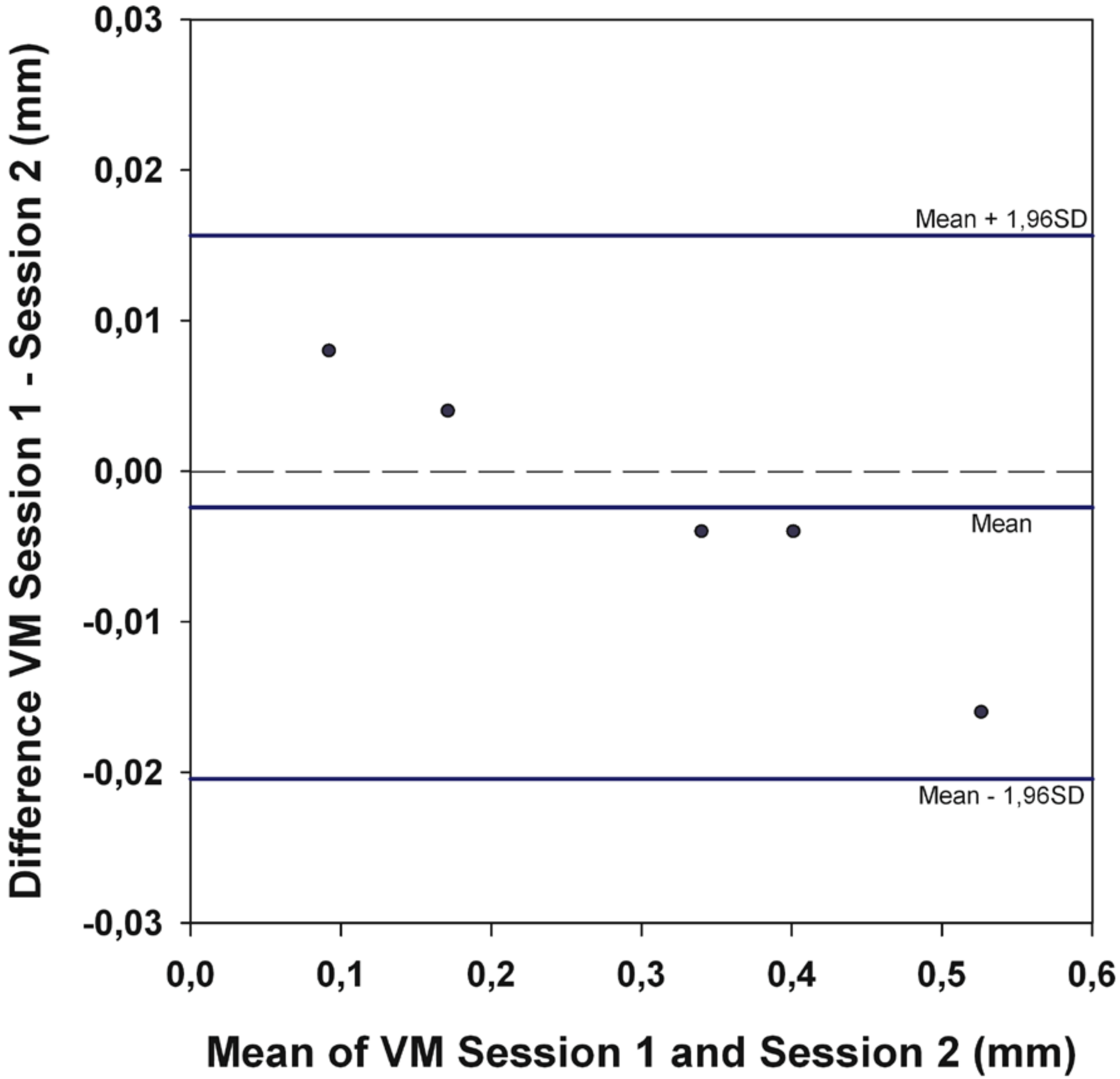


Figure 6



0,03
0,02
0,01
0,00
-0,01
-0,02
-0,03
Difference PDM Session 1 - Session 2 (mm)
Mean + 1,96SD
Mean
Mean - 1,96SD
0,0
0,1
0,2
0,3
0,4
0,5
0,6
Mean of PDM Session 1 and Session 2 (mm)

Figure 7



0,03
0,02
0,01
0,00
-0,01
-0,02
-0,03
Mean + 1,96SD
Mean
Mean - 1,96SD
Difference VM Session 1 - Session 2 (mm)
0,0
0,1
0,2
0,3
0,4
0,5
0,6
Mean of VM Session 1 and Session 2 (mm)

Figure 8

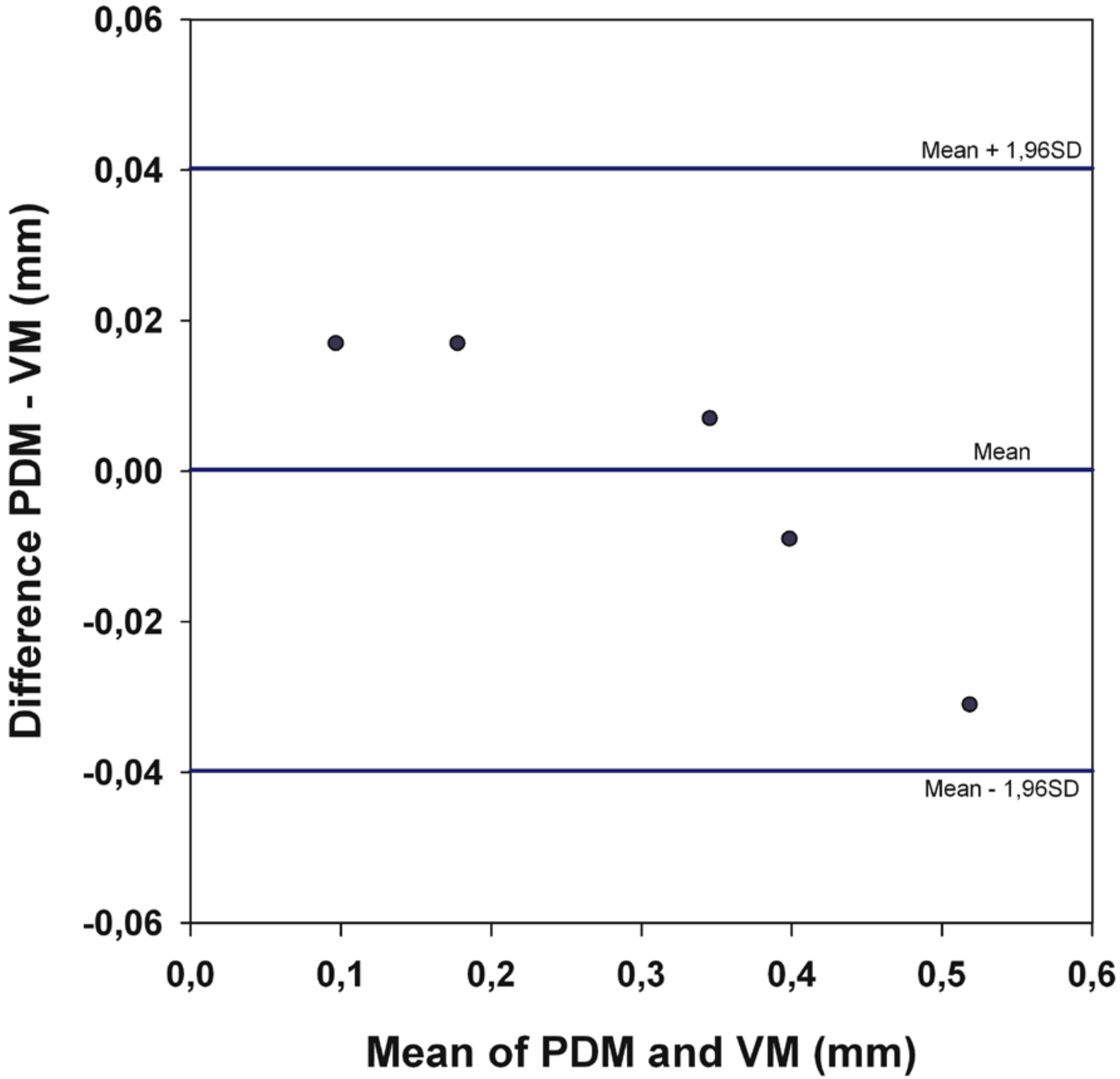

0,06
0,04
0,02
0,00
-0,02
-0,04
-0,06
Difference PDM - VM (mm)
Mean + 1,96SD
Mean
Mean - 1,96SD
0,0
0,1
0,2
0,3
0,4
0,5
0,6
Mean of PDM and VM (mm)

Figure 9

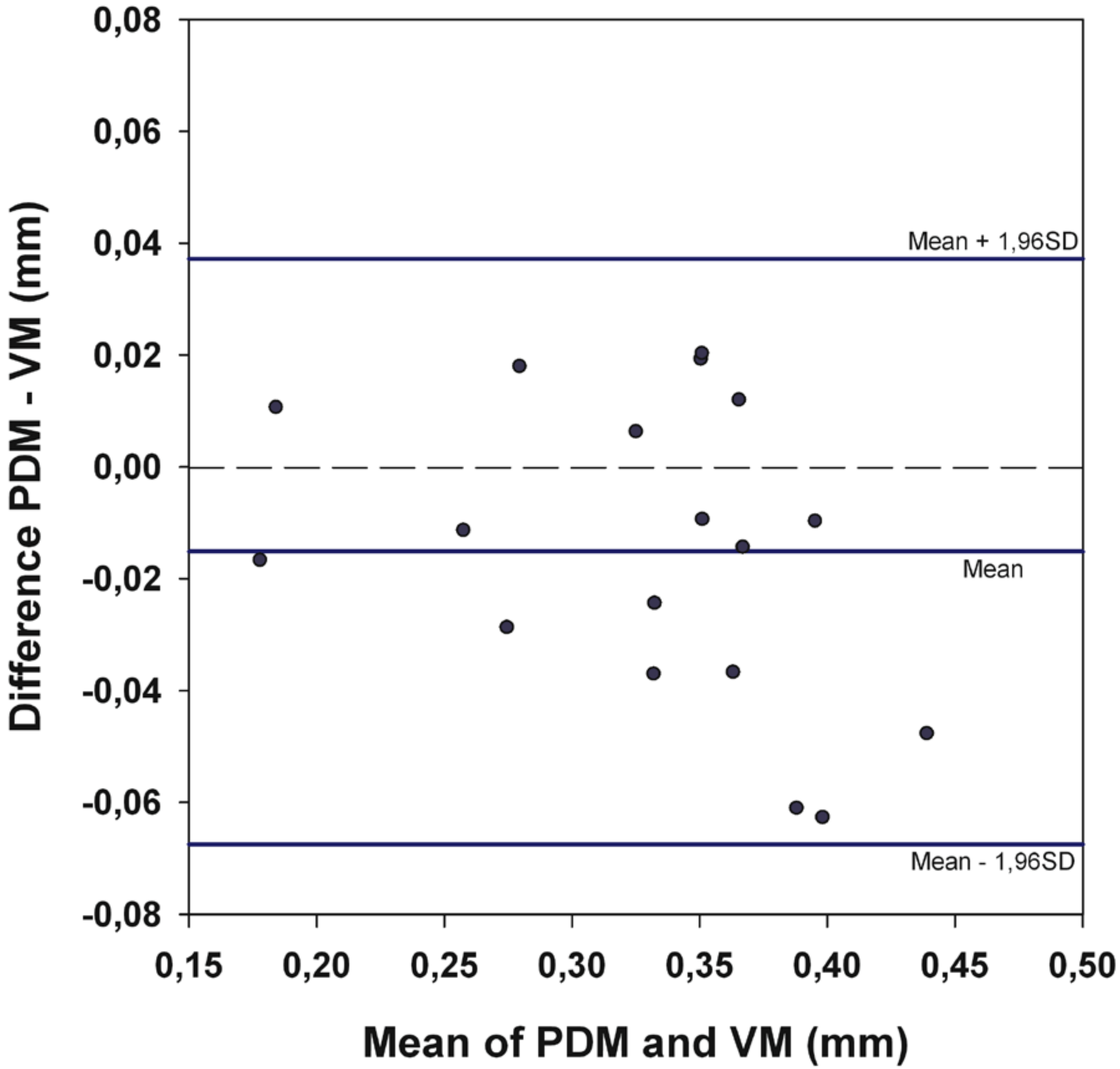

0,08
0,06
0,04
0,02
0,00
-0,02
-0,04
-0,06
-0,08
Difference PDM - VM (mm)
Mean + 1,96SD
Mean
Mean - 1,96SD
0,15
0,20
0,25
0,30
0,35
0,40
0,45
0,50
Mean of PDM and VM (mm)

Figure 10a

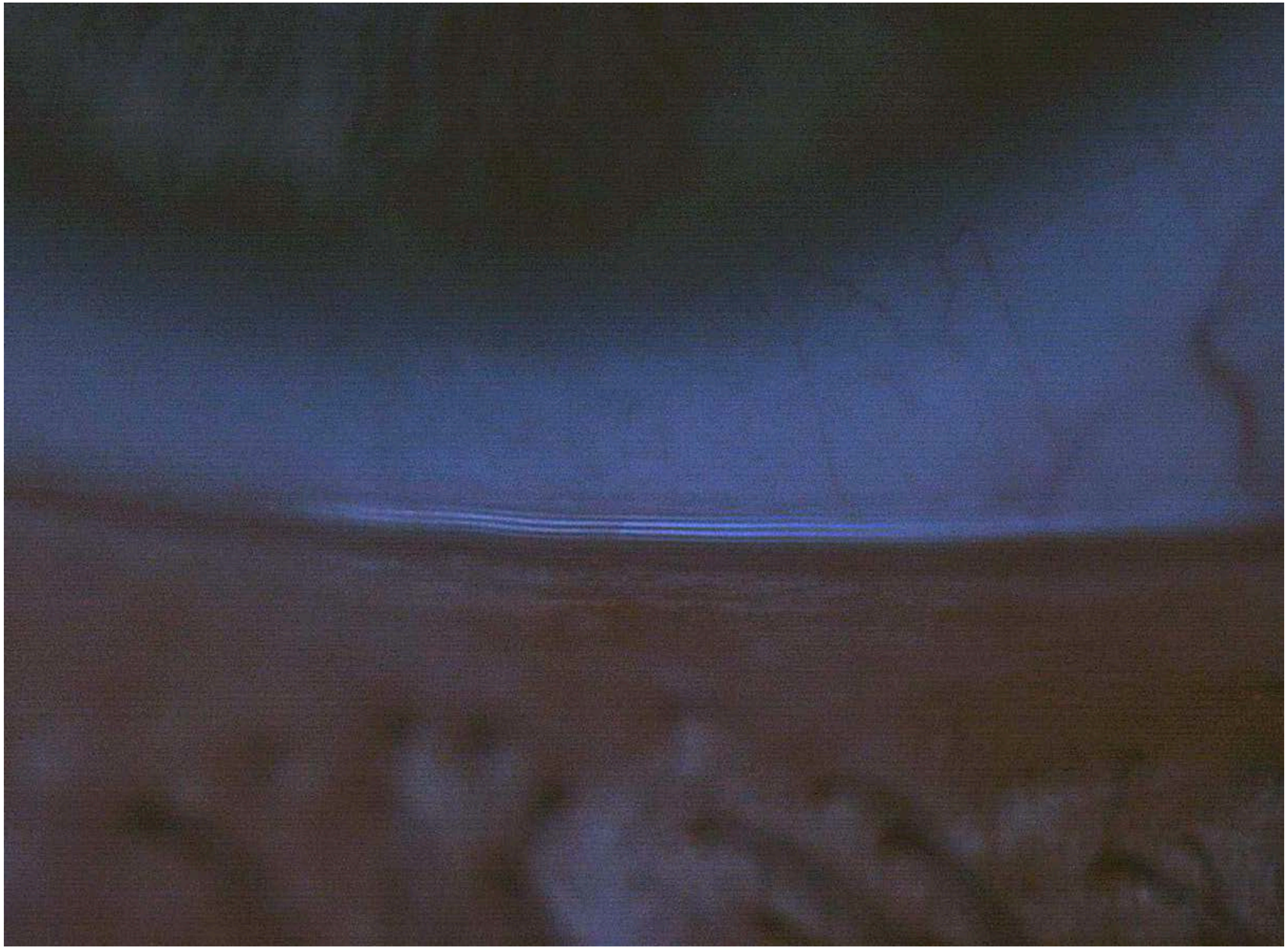


Figure 10b