Strip Meniscometry: A New and Simple Method of Tear Meniscus Evaluation

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PURPOSE. To investigate the applicability and efficacy of a new and simple method of quantification of the volume of tear meniscus, termed “strip meniscometry,” in the diagnosis of the dry eye syndromes in a prospective controlled study.

METHODS. One hundred eyes of 50 patients with dry eye (19 males; 31 females) aged between 18 and 76 years (mean, 54.3 years), as well as 80 eyes of 40 normal subjects aged from 15 to 70 years (mean, 50.8 years; 12 males, 28 females) were recruited in this study. The patients and the control subjects underwent strip meniscometry for 5 seconds, tear film lipid layer interferometry, tear film breakup-time measurement, and ocular surface vital staining with fluorescein and rose bengal dyes and the Schirmer-1 test.

RESULTS. Strip meniscometry scores correlated with tear quantity and stability, ocular surface staining scores, and lipid layer interferometry grades and improved after 2 weeks of punctal plug occlusion.

CONCLUSIONS. Strip meniscometry is a swift, noninvasive, promising new method that is expected to find application in the diagnosis and evaluation of the outcome of treatment of dry eye syndromes. (Invest Ophthalmol Vis Sci. 2006;47:1895–1901) DOI:10.1167/iovs.05-0802

The estimation of tear volume or secretion is regarded as essential for the diagnosis of dry eye syndromes, in which the Schirmer test traditionally has been reported to be an indispensable tool for such diagnosis.1 The Schirmer test involves a strip of filter paper 35 mm long and 5 mm wide and bent at one end that is placed in the lower conjunctival sac approximately one third of the palpebral width from the temporal canthus. The strip, when inserted, induces some level of irritation and reflex tearing.2 Holly et al.3 demonstrated that the initial insertion of the strip induces a higher rate of tear secretion that decreases in an exponential fashion toward a lower final rate. It is commonly accepted that <5 mm of wetting in 5 minutes is a sign of dry eye. The Schirmer test relies on the presence of a good tear meniscus to act as a reservoir from which fluid can be drawn and absorbed by the paper.

The tear menisci provide a reservoir that contributes to the formation of the precorneal tear film with each blink and accommodates excess tears during reflex tearing or lacrimal obstruction or after topical drop instillation.1 It has been reported that the tear meniscus contains 75% to 90% of the aqueous tear volume, which is positively correlated with the lacrimal secretory rate.2 The meniscus volume is also reported to be reduced in tear-deficient dry eye.3–5 Thus, quantitative assessment of tear meniscus parameters may be useful in the diagnosis of dry eye syndromes. Tear meniscus variables, such as height, width, cross-sectional area, and meniscus curvature, have been reported to be of value in the diagnosis of dry eye.6–8 With limitations of the reported techniques due to their invasive nature causing stimulation of reflex tearing or changes in tear volume by addition of fluorescein dye to the tear film,6,8 Recently, evaluation of the radii of tear meniscus curvature by reflective meniscometry has been reported to be a useful and noninvasive method, with promising applications in the determination of tear kinetics and diagnosis of dry eye.9,10 Tear meniscus curvature measured by reflective meniscometry has been shown to have positive correlations with fluorescein staining scores and the grading of tear film lipid layer interferometry.7,10 A mathematical relationship between tear film thickness and meniscus curvature has been proposed, with the meniscus curvature being reported as a reliable index of total tear volume.7,11,12 We, hereby, report a novel, simple, noninvasive method for measuring tear meniscus volume that we have termed “strip meniscometry” and that we expect to have wide application in the diagnosis, screening, and evaluation of the outcome of treatment of dry eye syndromes.

MATERIALS AND METHODS

Strip Meniscometry: Structure and Composition

Meniscometry strips (width, 3 mm; height, 45 mm) are made up of a mixture of rayon, acetate, nylon, nylon 66, nitrocellulose, vinyl, polypropylene, polysulfone, and polyethersulfones. The strip nitrocellulose membranes have a pore size of 8 μm. Natural blue dye 1 is printed at the tip of the strip. A millimeter and a numeric scale of up to 35 mm is printed on the sides. The membrane filter paper strips are coated with a hydrophobic polyether masking membrane on both sides and are press processed to eliminate the polyether masking film centrally, to create a central ditch 0.5 mm in width and 100 μm in depth. When the strip is immersed in tears, the tears go into the ditch, change color to blue when contacting the natural blue dye at the tip of the strip, and are restricted to the ditch without spreading sideways by a hydrophobic masking film. A schematic drawing and a sample of the strips are shown in Figure 1.

In Vitro Tests

One microliter of nonpreserved artificial tear solution (Soft San Tears, Santen, Japan) was instilled with a micropipette on a sterile Petri dish,
and the tip of the meniscometry strip was immersed for 5 seconds, measured by a stop watch. The experiment was repeated for instillations of 5, 10, and 20 μL and 25 times under each setting (Fig. 2). The temperature and humidity of the examination room were maintained at 24°C and 30%, respectively, during the tests. One week later, the experiments were repeated in the same conditions.

Subjects and Examinations

One hundred eyes of 50 patients with dry eye (19 males, 31 females) aged between 18 and 76 years (mean, 54.3 years), and 80 eyes of 40 normal subjects aged from 15 to 70 years (mean, 50.8 years; 12 males, 28 females) were examined in the study. Both groups were similar in age and gender. Patients and control subjects who had a history of atopy; allergic diseases; Stevens-Johnson syndrome; chemical, thermal, or radiation injury; or any other ocular or systemic disorder or had undergone any ocular surgery or contact lens use that would create an ocular surface problem or dry eye were excluded from this study. The ophthalmic examination consisted of a slit lamp examination, DR-1 tear film lipid layer interferometry, determination of tear film break-up time (BUT), fluorescein and rose bengal staining, Schirmer test, and strip meniscometry. All strip meniscometry was performed by six ophthalmologists who were not informed whether they were performing the examination on a patient with dry eye or a control subject. The study was in compliance with the tenets of the Declaration of Helsinki, and informed consent to undergo the procedures was obtained. No subject used topical artificial tear drops within 6 hours before the examinations.

DR-1 Tear Film Lipid Layer Interferometry

DR-1 interferometry observes the specular reflected light from the tear surface. Light from a white light source is reflected by a half mirror, focused by a lens, and used to illuminate the tear surface. The specular reflected light from the tear surface returns through the half mirror to a charge-coupled device camera that produces images on the device monitor. Two polarizers and a quarter-wave plate help eliminate unnecessary reflected light from the lens and detect only the specular reflected light from the tear fluid. The camera is focused on a 2.2 x 3.0-mm area of the central cornea, so that a circular area 2 mm in diameter is observable. Lipid layer interference images were recorded soon after a complete blink and were printed out on a color printer. The classification of tear lipid layer patterns have been described elsewhere.

Strip Meniscometry Examination

The tear meniscus was observed with a biomicroscope illumination system (Carl Zeiss Meditec, Inc., Dublin, CA) set at a 90° angle and tangential to the central inferior meniscus. The beam width was 0.05 mm and the height 5 mm, with the magnification set at 32 x. The tip of the meniscometry strip was briefly (5 seconds, measured by a stop watch chronometer) touched to the edge of the lower tear meniscus without touching the eyelid or the ocular surface. The length of the blue dye column in the central ditch (in millimeters) after the testing was regarded as the strip meniscometry value of that eye. The temper-
ature and humidity of the examination room during strip meniscometry tests were also maintained at 24°C and 30%, respectively. Soon after the test, the patients were asked about experiences of irritation, discomfort, or touch sensation during the application of the strip.

**In Vivo Reproducibility Tests**

The strip meniscometry tests were repeated three times, with 1-week intervals in both eyes of the same 10 patients with dry eye and 10 control subjects who consented to repeat examinations. These subjects were called and examined at appointments at the same times (9–10 AM) on the same day of a particular week.

**Tear Function Examinations**

Two microliters of a preservative-free combination of 1% rose bengal and 1% fluorescein dye was instilled in the conjunctival sac with a micropipette. The tear film BUT measurement was performed after instillation. The subjects were instructed to blink several times for a few seconds, to ensure adequate mixing of fluorescein. The interval between the last complete blink and the appearance of the first corneal black spot in the stained tear film was measured three times, and the mean value of the measurements was calculated. A BUT of less than 10 seconds was considered abnormal. Fluorescein and rose bengal staining of the cornea was also noted and scored as described elsewhere. Fluorescein staining scores ranged between 0 and 9 points. A score greater than 3 points was regarded as abnormal. The rose bengal staining scores (van Bijsterveld) of the ocular surface ranged between 0 and 9 points. Any score above 3 points was regarded as abnormal.

For further evaluation of tears, the standard Schirmer test-1 without topical anesthesia (0.4% oxybuprocaine chloride) was performed. The standardized strips of filter paper (Alcon Inc., Fort Worth, TX) were placed in the lateral canthus away from the cornea and left in place for 5 minutes with the eyes closed. Readings were reported in millimeters of wet strip after 5 minutes. A reading of less than 5 mm was considered to show dry eye. The diagnosis of dry eye was based on the diagnostic criteria of the Dry Eye Research group in Japan. In brief, dry eye was diagnosed in patients who had (1) dry eye-related symptoms, (2) positive staining with fluorescein or rose bengal, and (3) Schirmer-1 test results of less than 5 mm, or tear film BUT of less than 5 seconds. Dry eye cases were categorized as non–Sjögren’s syndrome (SS) and SS, on the basis of the criteria proposed by Fox et al. Briefly, SS was diagnosed in patients who had dry eyes and dry mouth, serum rheumatoid factor, antinuclear antibody levels ≥1:160, positive serology for anti-SS-A or SS-B antibodies, and a labial salivary gland inflammatory infiltration focus score ≥2. According to the study protocol, DR-1 lipid layer interferometry was performed initially, followed by strip meniscometry, tear film BUT analysis, fluorescein, and rose bengal vital staining of the ocular surface, and, finally, the Schirmer-1 test was performed. Strip meniscometry was performed in all patients and control subjects again 20 minutes after termination of all tests, with instillation of 1 μL of fluorescein dye into the tear film, to observe the change in tear meniscus height with slit lamp observation.

**Punctum Plug Procedure**

Punctum plugs were inserted in 14 eyes of seven patients with dry eye. The size of the puncta were determined with gauges, and flex punctum plugs (Eagle Vision, Memphis, TN) were used. Plugs were inserted in both superior and inferior lacrimal puncta. Tear function and ocular surface examinations, including strip meniscometry, were performed before and 2 weeks after plug insertion.

**Statistical Analysis**

An unpaired t-test with Welch correction was used to test the differences in tear function and ocular surface examination parameters between patients with dry eye and healthy control subjects (GraphPad Software; GraphPad, San Diego, CA). Lower and upper 95% confidence limits were also provided for the strip meniscometry tests. To evaluate the presence of statistically significant differences between the first and second in vitro strip meniscometry tests (“the period effect”) and between different volumes of artificial tear solutions (“the dose effect”), a two-way ANOVA was used. Spearman’s correlation coefficient by rank test was performed to test the correlation of strip meniscometry values with other tear function examination results. Receiver operating characteristic (ROC) curve technique was used to evaluate the sensitivity and specificity of strip meniscometry examination in the diagnosis of dry eye. One-way ANOVA was performed to calculate the coefficient of variation in the patients with dry eye and control subjects at baseline and at the first- and second-week examination points in the in vivo reproducibility strip meniscometry tests (SAS software; SAS Institute, Cary, NC). The coefficients of variation were calculated by dividing the standard deviations by the mean results of a particular test. A probability level of less than 1% was considered statistically significant.

**RESULTS**

**In Vitro Reproducibility Testing**

The strip meniscometry scores were significantly higher, with increased volumes of artificial tear solution in the initial and the second in vitro tests, as assessed by two-way ANOVA (the dose effect; P < 0.01; Fig. 3). There were no statistically significant differences between the strip meniscometry scores between the first and second tests for each volume (the period effect; P = 0.1). The coefficients of variation of the strip meniscometry tests for a 1-μL volume of artificial tear solution were 0.46 and 0.36 for the first and second tests, respectively. The coefficients of variation of the strip meniscometry readings were 0.37 and 0.26 for the 5-μL volume; 0.42 and 0.45 for the 10-μL volume, and 0.16 and 0.16 for the 20-μL volume of tear solutions in the first and second tests, respectively.

**Patient and Control Group Characteristics**

Twenty-seven patients had SS and 23 patients had non-SS dry eye in this study. There were no statistically significant differences between the mean examination parameters between right and left eyes at any examination point in all patients and control subjects (P = 0.61). The mean tear film lipid layer interferometry grade, BUT, vital staining scores, and Schirmer test values were significantly lower in patients with dry eye than in control subjects, as summarized in Table 1 (P < 0.01). The mean strip meniscometry score was...
also significantly lower in the patients than in the control subjects (Table 1; $P < 0.01$). The lower and upper 95% confidence limits for strip meniscometry tests in the patients with dry eye and control subjects were 0.73, 0.91 and 5.21, 5.78, respectively. None of the patients reported irritation, discomfort, or a touch sensation during the strip meniscometry procedure. The strip meniscometry scores showed a positive linear correlation with the Schirmer test scores and BUT values, whereas a negative linear correlation was observed with the tear film lipid layer interferometry grades, fluorescein staining, and rose bengal staining scores, as shown in Figure 4. The AUC (area under the curve) calculated by the ROC technique was 0.93, suggesting an acceptable sensitivity and specificity of the strip meniscometry tests performed in all subjects (Fig. 5). When the cutoff value of the strip meniscometry test was set at less than 4 mm, the sensitivity and specificity of the strip meniscometry procedure were found to be 0.86 and 0.96, respectively (Fig. 5).

Strip meniscometry performed with fluorescein dye instillation revealed a relative decrease in tear meniscus height in all subjects. Representative tear meniscus photographs before, during, and after strip meniscometry in a dry eye patient are shown in Figure 6.

### Table 1. Comparison of Tear Functions between Patients with Dry Eye and Control Subjects

<table>
<thead>
<tr>
<th>Tear Film Examination</th>
<th>Dry Eye ($n = 100$ eyes)</th>
<th>Control ($n = 80$ eyes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR-1 grade</td>
<td>3.25 ± 0.5*</td>
<td>1.5 ± 0.5</td>
</tr>
<tr>
<td>Strip meniscometry (mm)</td>
<td>0.82 ± 0.43*</td>
<td>5.5 ± 1.3</td>
</tr>
<tr>
<td>TBUT (s)</td>
<td>1.02 ± 1.28*</td>
<td>10.87 ± 0.28</td>
</tr>
<tr>
<td>Fluorescein score</td>
<td>3.95 ± 1.44*</td>
<td>0.14 ± 0.42</td>
</tr>
<tr>
<td>Rose-bengal score</td>
<td>3.86 ± 1.26*</td>
<td>0.19 ± 0.6</td>
</tr>
<tr>
<td>Schirmer-1 score (mm)</td>
<td>3.15 ± 1.8*</td>
<td>16.2 ± 9.0</td>
</tr>
</tbody>
</table>

Unpaired *t*-test with Welch correction *$P < 0.01$.

In Vivo Reproducibility Testing

The strip meniscometry scores were significantly lower in patients than in the controls at each examination, as shown in Figure 7 ($P < 0.01$). The coefficient of variation of SM testing within the patients with dry eye was 0.1, and the control group was 0.01, as calculated by one-way ANOVA.
The Effect of Punctum Plug Insertion on Tear Function and Ocular Surface Examination Parameters

PP insertion was associated with significant improvements in the mean tear film lipid layer interferometry grade, BUT, vital staining scores, strip meniscometry score, and mean Schirmer test score, as shown in Table 2 (P < 0.01).

DISCUSSION

The need for a swift, noninvasive, easy-to-use method for quantitative assessment of meniscus volume motivated us to devise a simple, novel methodology which we termed “strip meniscometry.” The special composition of the nitrocellulose membrane, the small pore size, and the presence of masking films on the front and back of both sides of the strip allow very quick absorption of tears into the press-cut central ditch by a capillary tube effect without spread and absorption of tears laterally in the strip. Our initial in vitro experimentation with the meniscometry strips revealed that the strip meniscometry scores were consistently higher, with increased volumes of the artificial tear solution suggesting the possibility that meniscometry strips might reflect the changes in the meniscus and tear volume in in vivo trials as well. The absence of statistically significant wide range changes in strip meniscometry scores between the two tests in in vitro trials suggested that the testing might be useful in in vivo settings and encouraged us to proceed with a prospective trial, testing the efficacy and application of this new methodology in the diagnosis of dry eye.

The mean Schirmer test value, tear film BUT, vital staining, interferometry, and strip meniscometry scores were significantly worse in patients with dry eye than in the control subjects in this prospective clinical study. In vivo reproducibility tests of strip meniscometry performed on the same patient and control subjects on three different occasions separated by 1-week intervals showed constantly and significantly lower strip meniscometry scores in patients with dry eye compared with the control subjects. Moreover, absence of statistically significant differences in the strip meniscometry scores within the patient and control groups at different examinations suggests that strip meniscometry may be useful in clinical settings as well. In addition, the lack of a wide range in strip meniscometry scores, despite performance of the tests by six different doctors, also suggests reproducibility and applicability of the tests in clinical practice.

Although we could not perform tear meniscus height measurements concomitantly with strip meniscometry due to lack of a graticule slit lamp eye piece at the time of the conduct of the prospective clinical trial, we confirmed in all subjects by instilling 1 mL of fluorescein dye into the tear film in repeat tests that strip meniscometry results in a relative decrease in tear meniscus height, suggesting that strip meniscometry...

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**FIGURE 5.** The ROC graph showing the sensitivity and specificity of strip meniscometry test.

**FIGURE 6.** The change in tear meniscus height with strip meniscometry. (A) Tear meniscus appearance before strip meniscometry. (B) Application of strip (5 seconds). (C) Note the decrease in tear meniscus height after strip meniscometry.

<table>
<thead>
<tr>
<th>Cut-off value (mm):</th>
<th>&lt;1</th>
<th>&lt;2</th>
<th>&lt;3</th>
<th>&lt;4</th>
<th>&lt;5</th>
<th>&lt;6</th>
<th>&lt;7</th>
<th>&lt;8</th>
<th>&lt;10</th>
<th>&gt;10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity:</td>
<td>0.46</td>
<td>0.69</td>
<td>0.82</td>
<td>0.86</td>
<td>0.89</td>
<td>0.94</td>
<td>0.95</td>
<td>0.97</td>
<td>0.99</td>
<td>1.00</td>
</tr>
<tr>
<td>Specificity:</td>
<td>1.00</td>
<td>1.00</td>
<td>0.99</td>
<td>0.96</td>
<td>0.95</td>
<td>0.86</td>
<td>0.80</td>
<td>0.04</td>
<td>0.01</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**Estimated Area**

$C = 0.9308$
seems to reflect the amount of fluid level in the meniscus and ocular surface. We intend to determine the relation of meniscometry scores with tear meniscus height and radius of tear meniscus curvature as well as age- and sex-specific cutoff values and the specificity and sensitivity of the strip meniscometry methodology in a larger number of patients in multicenter trials in future studies. Strip meniscometry has shown a statistically significant linear correlation with the Schirmer test, tear film BUT, and ocular surface vital staining scores. It has been shown in a previous study that the meniscus radius has an excellent correlation with vital fluorescein staining of the ocular surface.\(^\text{4,7}\) Tear osmolarity is believed to initiate ocular surface epithelial damage in dry eye.\(^\text{18}\) In aqueous-deficient dry eye, such hyperosmolarity may be due to evaporation from a diminished preocular tear pool, whereas in evaporative dry eye, it may be due to increased evaporation from a normal preocular pool. It remains the further goal of these studies to determine the relation of strip meniscometry testing to tear osmolarity in both types of dry eye. Devising newer strips with a composition and texture that would “collect” but not “ab- sorb” tears would help, not only in the quantification of tear composition and texture that would “collect” but not “ab-sorb” tears would help, not only in the quantification of tear osmolarity in both types of dry eye. Devising newer strips with a composition and texture that would “collect” but not “ab-sorb” tears would help, not only in the quantification of tear osmolarity but also in the assessment of tear osmolarity in the future (Ogawa Y et al. \(^\text{19}\) Strip meniscometry and lipid layer interferometry grades showed a linear correlation as well in the current study. We believe that the lower aqueous tear volume in aqueous-deficient patients with dry eye and consequent reduction in the forward displacement of lid oil as the tear film is compressed during blinking may leave a greater amount of oil on the lid margin for redistribution in the tear film which may explain the correlation we observed.\(^\text{20,21}\) Our overall findings with the strip meniscometry tests suggest that the current methodology may be a favorable candidate for the diagnosis of dry eye.

Statistically significant improvement of the mean strip meniscometry score 2 weeks after punctum plug occlusion in patients with dry eye also suggest that strip meniscometry may find applications in evaluating the outcome of dry eye treatments, which at present mainly consist of the use of artificial tear solutions and punctum plug insertion.\(^\text{22}\) Yokoi et al.\(^\text{25}\) reported with Schirmer strips that as meniscus volume decreases in dry eye, the suction effect of the tear meniscus opposes entry of tear fluid into the strip and the opposite may be true with increased meniscus volume resulting from punctum plug occlusion. These observations may also explain the lower meniscometry values in dry eye and the improvement observed in patients who undergo punctum plug occlusion.

Strip meniscometry is not expected to be useful in tear meniscus volume determination in eyes with conjunctivochalasis, disorders of lid margin congruity, and ocular surface–lid apposition. It could find additional applications, however, in the study of tear kinetics, such as retention of eye drops and assessment of the success of tear drainage surgical procedures or confirmation of lacrimal drainage occlusion after punctum plug treatment, which should be studied in future trials.

In summary, strip meniscometry is performed without fluorescein dye instillation into the tear film and without touching the eyelids and the ocular surface, eliminating the limitations existing in invasive methodologies. The test can be completed within 5 seconds, because of the special composition and design of the strips, making it suitable for busy clinical settings. Strip meniscometry is expected to provide useful tear meniscus parameters for use in diagnosis and to be of value in the analyses of ocular surface diseases.

Table 2. Comparison of Tear Functions before and after Punctum Plug Occlusion (PPO) in Patients with Dry Eye

<table>
<thead>
<tr>
<th>Tear Film Examination</th>
<th>Before PPO ((n = 17) eyes)</th>
<th>After PPO ((n = 17) eyes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR-1 grade</td>
<td>3.5 ± 0.5*</td>
<td>1.0 ± 0.5</td>
</tr>
<tr>
<td>Strip meniscometry (mm)</td>
<td>0.65 ± 0.25*</td>
<td>7.0 ± 1.7</td>
</tr>
<tr>
<td>TBUT (s)</td>
<td>1.0 ± 0.65*</td>
<td>4.87 ± 1.72</td>
</tr>
<tr>
<td>Fluorescein score</td>
<td>6.5 ± 1.8*</td>
<td>1.0 ± 1.9</td>
</tr>
<tr>
<td>Rose-bengal score</td>
<td>4.2 ± 1.0*</td>
<td>2.1 ± 1.62</td>
</tr>
<tr>
<td>Schirmer-1 score (mm)</td>
<td>2.0 ± 1.5*</td>
<td>10 ± 3.1</td>
</tr>
</tbody>
</table>

Paired \(t\) test \(*P < 0.01\)

![Figure 7](image-url)  
**Figure 7.** The mean strip meniscometry values in patients and control subjects in in vivo reproducibility tests.

References


