Dry Eye Symptoms in Patients after Eyelid Reconstruction with Full-Thickness Eyelid Defects: Using the Tomey TG-1000 Thermographer

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Key Words
Thermography · Ocular surface temperature · Tomey TG-1000 · Dry eye · Tarsococonjunctival graft · Full-thickness eyelid defects

Abstract

Background: Large full-thickness eyelid defects are conventionally reconstructed by either a Hughes flap or Cutler-Beard bridge flap. Since the structure of the eyelid and its components are necessary for the tear film production and stability, we investigated the outcome after eyelid reconstruction focusing on dry eye symptoms using a new thermographic device, the TG-1000.

Methods: Seventeen eyes of patients formerly treated with Hughes flaps (n = 16) and a Cutler-Beard bridge flap (n = 1) were compared to untreated healthy eyes (n = 17) regarding the functional and aesthetic outcome. The follow-up ranged from 3 to 63 months (mean 24.88 ± 17.86).

Results: There was no significant difference in Schirmer’s test, break-up time and ocular surface temperature (p > 0.05) between patients after full-thickness eyelid reconstruction and a control group. Eleven patients had minor postoperative complications such as notching of the lid margin (11/17), epiphora (1/17), superficial punctate keratitis (6/17), trichiasis (2/17) and a mild tendency to eversion of the lid margin (6/17). More than 75% of the patients rated their postoperative aesthetic outcome as good or even excellent.

Conclusion: The new TG-1000 device is a simple and quick tool for screening of dry eye. This study shows that tarsococonjunctival grafts offer good aesthetic and functional outcome with sufficient tear film composition and stability.

Introduction

The chief function of the upper and lower eyelids is to protect the cornea. Therefore in all cases, the primary objective of the reconstruction of full-thickness eyelid defects is an adequate corneal protection and preservation of vision, with good aesthetic outcome and symmetry as a secondary consideration [1]. Full-thickness defects greater than 50% of the horizontal length of the upper or lower eyelid are often reconstructed by either Hughes or Cutler-Beard bridge flaps [2, 3]. This can induce either major complications, including marked upper lid retraction after upper lid reconstruction, wound dehiscence, entropion, ektopion and excessive lower lid...
laxity, or minor complications, such as trichiasis, notching or mild eversion and inversion of the lid margin, symblepharon and corneal irritation with dry eye symptoms including punctate keratitis, epiphora, pain, redness, burning and foreign body sensation [4].

In diagnosing dry eye symptoms, tear dynamics are currently evaluated clinically by Schirmer’s test, break-up time (BUT), inspection of lids and conjunctiva (lid-parallel conjunctival folds), measurement of the tear meniscus, osmolarity testing and the rose Bengal test [5–8]. First reports demonstrated that the measurement of the corneal surface temperature may complement the diagnostic tools [9–13]. Ocular surface thermography is a well-known technique for temperature measurement of the anterior eye. Modern thermography, pioneered by Mapstone [12], is a non-invasive technique used to measure the surface temperature of an object by detecting the intensity of infrared light that is emitted from the object. Recently, Tomey presented a new non-contact thermographic infrared light device (Tomey TG-1000, Tomey Germany, Erlangen, Germany). The current instrumentation offers the potential to measure the ocular surface temperature with more accuracy, resolution and speed than previously possible. Kamao et al. [9] showed that the non-invasive measurement with Tomey TG-1000 is a simple and quick tool for screening of dry eye enabling data to be collected quickly, objectively and non-invasively with high intra-observer reproducibility.

Within this article we focus on the aesthetic and functional outcome and especially on dry eye symptoms after eyelid reconstruction of full-thickness eyelid defects using Hughes or Cutler-Beard bridge flaps.

**Patients and Methods**

**Study Protocol**

All 64 cases of full-thickness eyelid reconstruction after tumour excision over a 5-year period (March 2005 to March 2010) at Charité University Hospital Berlin were identified from the operating theatre logbook and reviewed. The Hughes and Cutler-Beard bridge flaps were only performed in patients with full-thickness eyelid defects greater than 50% of the horizontal length of the upper or lower eyelid. Since we do not have any financial interest in the instrument, only patients living within a 10-km radius from the hospital were re-examined because no refund of transportation costs could be provided.

Nevertheless, 17 eyes of 17 patients (10 women and 7 men; mean age ± standard deviation, 69.12 ± 7.59 years) treated with surgery enclosing Hughes flaps (n = 16) and a Cutler-Beard bridge flap (n = 1) from March 2005 to March 2010 were included in this study and compared to their untreated healthy eyes focusing on dry eye symptoms retrospectively. The healthy eyes had neither ocular pathology nor corneal inflammatory signs. The subjects were not applying topical eye medication or using contact lenses and did not suffer from dry eye symptoms.

All patients were operated after histologically tumour-free resection margins by the same surgeon. Four weeks after lid reconstruction the standardized re-opening of the eyelid was carried out. The follow-up after surgery ranged from 3 to 63 months (mean 24.88 ± 17.86). The ocular surface temperature was measured by new Tomey TG-1000 thermography. The aesthetic result and complications were documented, and digital colour images were taken by the photo device of Tomey TG-1000. Complications were divided into major and minor complications. As major complications were considered marked upper lid retraction after upper lid reconstruction, wound dehiscence, entropion, ectropion and excessive lower lid laxity. Minor complications were classified as notching or mild eversion and inversion of the lid margin, trichiasis, symblepharon and corneal irritation with dry eye symptoms including punctate keratitis, epiphora, pain, redness, burning and foreign body sensation. Afterwards the tear film was evaluated using Schirmer’s test and fluorescein tear film BUT. Additionally, the patients filled out a questionnaire based on the National Eye Institute Visual Functioning Questionnaire 25 to estimate their satisfaction with the aesthetic and functional outcome.

**Thermography**

A newly developed non-contact thermography device (Tomey TG-1000, Tomey Corp., Nagoya, Japan) was used. Kamao et al. [9] first described this ocular surface thermographer. The instrument is equipped with an infrared camera module (HX083M1; NEC, Tokyo, Japan) and a colour charged coupled device board camera (PKD-101; Pacific Co., Tokyo, Japan). Light can be directed into either an infrared camera or visible light camera. The direction of the light is changed by a rotating mirror, and both infrared and visible light images can be recorded co-axially. This instrument ought to detect temperatures in a target range between 30 and 40°C, with a minimum temperature accuracy of ±0.1°C. The frame rate of 4 frames a second was denoted, which means 2 frames a second each when measuring infrared and colour images at the same time. Ten seconds were required to perform each measurement. Using the highest magnification, the infrared sensor can record images at a resolution of 320 × 240 pixels with a pixel size of 23.5 × 23.5 μm and spatial resolution of 70 μm. The infrared radiation detector module is sensitive to infrared radiation between 8 and 14 μm. Colour images are obtained with a coupled device video camera that can record images at a resolution of 640 × 480 pixels, pixel size 5.6 × 5.6 μm, and a detection range of 0.5 lx at 1/30 frames/s. To correct for background radiation entering the infrared camera, a black body plate is inserted automatically to cover the sensor immediately before beginning the measurements. To correct for changes in the temperature of the interior of the instrument during the measurements, a sensor was embedded in the camera and a program was installed in the instrument to correct for changes in the internal temperature. An auto-alignment function is incorporated in the instrument to ensure that the instrument and object are maintained in a fixed location relative to each other. With this auto-alignment function, the position of the cameras with respect to the object to be measured can be held constant, which allows measurements of the ocular surface temperature to be performed at the same position. There is virtually no human error involved in
operating the ocular surface thermographer. This feature is identical to that of the RC-5000 Autorefractor/Keratometer (RC-5000; Tomey Corp.), which recognizes the pupil and aligns the pupil in the centre of the screen when the examiner touches the centre of the touch panel. The head of the ocular surface thermographer also moves along the z-axis automatically to maintain the instrument at a fixed distance from the eye.

Each subject was examined in a room at 24.0 ± 1.5 °C, with standard indoor levels of illumination and no air drafts. The measurements were performed under the conditions described by Mori et al. [11]: the subject blinked normally, then closed both eyes for 5 s, and then kept the eyes open for more than 10 s. The thermography device was set up 20 cm in front of the eye, and the head was held steady by a head-holder frame. First, the subject was instructed to open his eyes naturally and look straight ahead to get a sharp image of the cornea at the implemented monitor. After that, the subject was asked to close the eyes. Now with closed eyes, the surrounding temperature of the ocular surface including the surrounding tissue and the overall room temperature were measured within 5 s. Afterwards, the subjects were requested to open both eyes naturally and look straight ahead again, and after a blink, a measurement was made. The temperature was measured within 10 s of opening the eye. During that time the subject was asked not to blink. If the subject blinked anyway, a new measurement was performed.

To avoid any unsteadiness, all thermographic measurements were performed in an examination room used for ocular thermography by one examiner.

Following these investigations all images were converted to infrared and colour pictures and were made visible on a monitor for analysing. Minimum and maximum temperature readings as well as the temperature over the course of the 10 s of eye opening were given in graphical order. Special points of interest of the ocular surface could be selected by moving a cross on the colour or infrared picture. At these selected points the temperature data were given as mentioned.

Representative examples of ocular surface temperature measurements are shown in figures 1–3.

Schirmer’s Test without and with Anaesthesia
Schirmer’s test without anaesthesia was performed by lightly dabbing the inferior fornix with a cotton tip applicator to remove excess tears, bending the Schirmer strip at the notch, and placing the strip beneath the temporal lid margin with the notch at the lid margin. The patient was then instructed to close the eyelids gently, not to speak or make facial expressions that could result in the movement of the facial musculature, and to position the chin on the chin rest of the slit lamp. This was done to maintain the subject’s head in an erect position. The subject was also instructed not to move the eyes in order to minimize or avoid contact between the cornea and Schirmer’s test paper. All of the above precautions were taken to minimize reflex tearing. Schirmer’s test results were then recorded after 5 min. The wet portion of the litmus paper was measured in millimetres per 5 min.

Fifteen minutes later, Schirmer’s test was performed with one drop of topical anaesthetic (Conjuncain®, EDO) to measure the basic secretion rate.

Measurement of Fluorescein BUT
The BUT is an indirect measure of tear film stability with instability indicated by a BUT of <10 s. The BUT was measured following a 15-min rest interval using 2% sodium fluorescein solution that was instilled onto the inferior palpebral conjunctiva after gentle depression of the lower eyelid. The subject was then
asked to blink gently, but completely, 3 times. The tear film was then examined with a broad beam and the cobalt blue filter of a slit lamp. The interval between the last blink and the appearance of the first precorneal hypofluorescent spot, streak or other irregularity interrupting the normal homogenous fluorescein pattern was recorded as the BUT (seconds).

**Fig. 2.** Screenshot of an ocular surface temperature measurement with the Tomey TG-1000. Same subject as in figure 1. Average temperature during 10 s of eye opening in a graphical order top right. Almost horizontal course of the temperature line in a stable tear layer.

**Fig. 3.** Screenshot of an ocular surface temperature measurement with the Tomey TG-1000. Average temperature during 10 s of eye opening in a graphical order top right. Sloping course of the temperature line in an unstable tear layer, may be due to dry eye syndrome, in this case without any subjective complaints. The lower eyelid was reconstructed with a Hughes bridge flap in October 2005.

**Statistics**

All eyes (n = 34) of the subjects were included in the analysis. Statistical analysis was conducted with the analysis program PAWS (version 18.0, version for Mac). In all groups, non-parametric distribution of the data was found (Kolmogorov-Smirnow test). Parameters of interest were statistically compared between
groups using the Mann-Whitney U Wilcoxon rank sum test. The level of significance was set at $p < 0.05$.

Statement of Ethics
We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during this research.

Results
Table 1 shows the means and standard deviations of minimal and maximal ocular surface temperature and temperature gradient between eyes after full-thickness eyelid reconstruction and a control group. Even though the mean gradient of ocular surface temperature ($p = 0.586$) after 10 s of eye opening and minimal ($p = 0.708$) and maximal ($p = 0.786$) ocular surface temperature were lower in the group with reconstructed eyelids, no significant difference could be found. Accordingly there was neither a significant difference in Schirmer’s test with ($p = 0.865$) and without ($p = 0.339$) anaesthesia nor BUT ($p = 0.067$; table 2).

After surgery 64.7% of the patients had minor complications such as notching of the lid margin (11/17), trichiasis (2/17), epiphora (1/17), superficial punctate keratitis (6/17) and a mild tendency to eversion of the lid margin (6/17) which did not require revision. No major complications could be seen. The patient satisfaction rate with the aesthetic outcome after reconstruction of full-thickness eyelid defects was very good. More than 75% of the patients rated their aesthetic appearance good or even excellent after surgery (table 3).

Discussion
Compared to formal devices, TG-1000, the latest commercially available generation of ocular surface thermographers, has several advantages. Including an infrared sensor with a dissolution of $320 \times 240$ pixels and an infrared wavelength range between 8 and 14 $\mu$m, the measurement of the ocular surface leads to a high dissolving colour-coded infrared image. Therefore, the ocular surface thermographer is able to perform measurements in the same manner as a standard autorefractor/keratometer with an auto-alignment function, enabling data to be collected quickly, objectively and non-invasively with high intra-observer reproducibility [9, 13]. Secondary to a photo picture, the ocular surface thermographer displays visible light and thermal images simultaneously. Therefore regions of the thermal image can easily and accurately be compared to real ocular conditions [9]. Additionally, this kind of repetition gives the opportunity to document changes in both temperature and anatomy in an easy way. This possibility is very helpful in many diseases of the ocular surface [14], e.g. in screening for dry eye symptoms after full-thickness eyelid reconstruction.

Patients with dry eyes show an altered tear film layer [5, 15, 16]. The most common cause of dry eye syndrome is decreased production of the lipid layer (from meibomian glands), which results in destabilization and evapo-

<table>
<thead>
<tr>
<th>Study group</th>
<th>Minimal OST</th>
<th>Maximal OST</th>
<th>Gradient of OST after 10 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconstructed eyelid (n = 17)</td>
<td>34.32 ± 1.07</td>
<td>34.73 ± 0.84</td>
<td>−0.04 ± 0.54</td>
</tr>
<tr>
<td>Control group (n = 17)</td>
<td>34.49 ± 0.78</td>
<td>34.82 ± 0.59</td>
<td>−0.09 ± 0.47</td>
</tr>
</tbody>
</table>

$p > 0.05$, no significant difference.

<table>
<thead>
<tr>
<th>Study group</th>
<th>Schirmer’s test without anaesthesia, mm</th>
<th>Schirmer’s test with anaesthesia, mm</th>
<th>BUT (fluorescein), s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconstructed eyelid (n = 17)</td>
<td>14.53 ± 9.95</td>
<td>19.71 ± 11.60</td>
<td>9.59 ± 4.05</td>
</tr>
<tr>
<td>Control group (n = 17)</td>
<td>16.12 ± 11.35</td>
<td>23.00 ± 9.87</td>
<td>12.12 ± 4.05</td>
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</table>

$p > 0.05$, no significant difference.

Table 3. Patient satisfaction (%) with aesthetic outcome after reconstruction of full-thickness eyelid defects

<table>
<thead>
<tr>
<th>Excellent</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
<th>Very poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients (n = 17)</td>
<td>35.4</td>
<td>41.2</td>
<td>17.6</td>
<td>5.8</td>
</tr>
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Gonnermann/Klein/Klamann/Maier/Pleyer/Joussen/Bertelmann
mechanically altering the corneoscleral and conjunctival in-ly to have a decrease in ocular surface temperature. This indicates that eyes with a shorter BUT are more like-
dered keratitis (6/17) and a mild tendency to ectropion (11/17), trichiasis (2/17), epiphora (1/17), superficial punc-
tate keratitis (6/17) and a mild tendency to ectropion (6/17) which did not require revision. This accords with minor complications such as notching of the lid margin (11/17), trichiasis (2/17), epiphora (1/17), superficial puntate keratitis (6/17) and a mild tendency to ectropion (6/17) which did not require revision. This accords with previous studies regarding the possible complications associated with the use of tarsconjunctival grafts to reconstruct full-thickness eyelid defects.

In our study the functional and aesthetic outcomes after tarsconjunctival grafting were generally satisfactory throughout a 5-year follow-up. 64.7% of our patients had minor complications such as notching of the lid margin (11/17), trichiasis (2/17), epiphora (1/17), superficial punctate keratitis (6/17) and a mild tendency to ectropion (6/17) which did not require revision. This accords with previously published studies [2, 4, 22]. We did not see any major complications that would have required revision. More than 75% of the patients rated their aesthetic outcome as good or even excellent after surgery. Analysing dry eye symptoms, Schirmer's test without anaesthesia as well as BUT (9.59 ± 4.05 s) were lower in reconstructed eyelids compared to the control group. These findings were not statistically significant (p > 0.05) and in agreement with the measurements of the ocular surface thermography. Even though the mean gradient of ocular surface temperature (−0.04 ± 0.54 °C) after 10 s of eye opening and minimal (34.32 ± 1.07 °C) and maximal (34.73 ± 0.84 °C) ocular surface temperatures were also lower in the group with reconstructed eyelids, no significant difference could be found.

In summary, the new TG-1000 could be a simple, non-invasive and quick tool for screening of dry eye syndrome. Temperature is one of the fundamental characteristics of tissue metabolism and is certainly of major interest to investigate ocular physiology and especially pathophysiology of dry eye symptoms. Ocular surface thermography has several advantages to other dry eye tests. Compared to impression cytology, the device gives objectively measurements without being invasive, painful and time consuming. The downside to ocular surface thermography is its price. This study shows that despite frequent minor complications and occasional major complications the use of tarsconjunctival grafts offers a good aesthetic and functional outcome with sufficient tear film composition and stability. To the best of our knowledge, this is the first paper focusing on these factors after reconstructive eyelid surgery. Tarsconjunctival grafting remains a valuable procedure in the surgeon’s choice for reconstruction of major eyelid defects. To evaluate alternatives in eyelid reconstruction, further investigation regarding tear film composition and stability using TG-1000 need to be done.

Disclosure Statement

There is no conflict of interest to declare.

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