CASE REPORT

Thermodynamic measurement after cooling the cornea with intact epithelium and lid manipulation

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**KEYWORDS**  
Temperature; Corneal surface; Cooling; Balanced salt solution; BSS

**Abstract**  
**Purpose:** To characterize the rate of change of ocular surface temperature (OST) under lid manipulation after cooling the intact cornea with balanced salt solution (BSS).  
**Methods:** In a patient for refractive surgery, prior to the ablation, the temperature of the cornea was continuously recorded with a high speed infrared (350 Hz) camera. Two millilitre of chilled BSS with a temperature of 8.6 \( ^\circ \)Celsius (\( ^\circ \)C) was instilled for about 3 s. Using exponential functions, the three contributions have been determined, subjacent corneal layers, environment, and chilled BSS.  
**Results:** The mean temperature of the cornea preoperatively was 34.5 \( ^\circ \)C. After applying the chilled BSS the temperature decreased about 14 \( ^\circ \)C down to an OST of 20 \( ^\circ \)C and the time needed afterwards to get the normal (OST) temperature of about 30 \( ^\circ \)C was 40 s. Due to the inserted speculum and missing blink, OST did not reach the original OST of 34.5 \( ^\circ \)C and faded at about 32.5 \( ^\circ \)C. According to our best fitted model, absolute value of each contributing component was 31.4 \( ^\circ \)C (subjacent corneal layers), 26.8 \( ^\circ \)C (environment) and 8.6 \( ^\circ \)C (BSS).  
**Conclusions:** Applying chilled BSS to the cornea quickly reduces the temperature of the cornea with a thermal relaxation time of 3 s and a amplitude decrease of 8.6 \( ^\circ \)C. This together with a relaxation time of 7 s for subjacent corneal layers, and 184 s for environment after instillation of BSS combined with a well-controlled environment provides a period of 40 s of corneal temperature below baseline, which may be of clinical benefit when applying chilled BSS immediately before or immediately after ablation.

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Monitorización termodinámica tras el enfriamiento de la córnea con el epitelio intacto y manipulación del párpado

Resumen

Objetivo: Describir el índice de cambio de la temperatura de la superficie ocular (OST) con manipulación del párpado tras el enfriamiento de la córnea intacta con solución salina balan-

cedada (BSS).
Métodos: En un paciente sometido a cirugía refractiva, con anterioridad a la ablación, re-
gistramos continuamente la temperatura de la córnea con una cámara de infrarrojos de alta velocid-
dad (350 Hz). Instilamos durante alrededor de 3 s dos mililitros de BSS a una temperatura de 8,6 ºC. Utilizando funciones exponenciales, se determinaron los valores de las tres contribuciones: capas corneales subyacentes, ambiente, y BSS fría.

Resultados: Preoperatoriamente, la temperatura media de la córnea fue de 34,5 ºC. Tras aplicar
la BSS fría, la temperatura descendió alrededor de 14 ºC hasta alcanzar una OST de 20 ºC,
precisándose un tiempo posterior de 40 segundos para alcanzar la OST normal de unos 30 ºC. De

Debido a la inserción del espéculo y a la ausencia de parpadeo, la OST no alcanzó el valor original
de 34,5 ºC, permaneciendo en unos 32,5 ºC. De acuerdo a nuestro modelo de mejor ajuste, el
valor absoluto de cada componente participante fue de 31,4 ºC (capas corneales subyacentes),
26,8 ºC (ambiente) y 8,6 ºC (BSS).

Conclusiones: La aplicación de BSS fría a la córnea reduce rápidamente la temperatura de
la misma, con un tiempo de relajación térmica de 3 s y un descenso de amplitud de 8,6 ºC. Estos

hallazgos, junto con tiempos de relajación de 7 s para las capas corneales subyacentes, y de 184 s
para el ambiente tras la instilación de BSS, junto con un entorno bien controlado, proporciona
unos 40 s de temperatura corneal inferior a la basal, lo que puede suponer un beneficio clínico

cuando se aplica BSS fría inmediatamente antes o inmediatamente después de la ablación.

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Temperature of the cornea is a function of the equi-
librium of heat transfer between the cornea and the sur-
rounding tissues or atmosphere. Therefore, any change
that affects the heat loss or gain may affect the corneal
temperature. The normal corneal surface temperature
has been reported to range between 32.9 and 36 ºC. Under LASIK
settings, when lid speculum has been applied, the dynamic
heat balance shifts towards heat loss from the cornea to the
surrounding cooler air and baseline corneal tempera-
ture (prior to initiating surgery) decreases to approximately
31 ºC. When excimer laser is initiated, every single pulse
adds heat to the cornea and contributes to the marginal
increase in the local corneal temperature. Laser refrac-
tive surgery is based on the sequential delivery of multiple
laser pulses, with each pulse ablating a small amount of

corneal tissue and in the process causing a marginal increase
in the local corneal temperature around the laser spot. In
general, Excimer laser treatments may cause a significant
increase in corneal temperature mainly due to the heat
generation exceeding the heat dissipation during the laser
treatment.

These thermal effects may cause tissue damage and
potentially reduce the predictability of the refractive
outcomes. Usually cold balanced salt solution (BSS) is
applied after the ablation procedure to reduce the post-
operative increment of the ocular surface temperature
(OST) which leads to several problems which by defini-
tion can be later introduced as haze and scattering. It
is really important to use either a laser technology like
the flying spot and spot size, or other ways to reduce
the temperature with cold fluid prior or after the abla-
tion. Our motivation is to characterize the response in OST
with the use of BSS, and explore a potential method to
reduce OST below the baseline temperature prior to abla-
tion, to compensate the heat generation during the laser
treatment.

Methods

Our objective was to characterize the rate of change of
the temperature of the corneal surface after cooling the
cornea with balanced salt solution (BSS). We used cooled
balanced salt solution (BSS) from the refrigerator with a
temperature of 8.6 ºC and 2 ml of this solution was applied
on an eye prior to excimer laser refractive surgery. For mea-
suring the cornea temperature, we used a high frequency
infrared camera, VarioCAM® HR (Jena, Germany), which
takes 350 measurements per second. The camera provides
thermal images with a resolution of 640 × 480 pixel and
measures the ocular surface temperature (OST) within the
spectral range of 7.5–14 μm with a resolution of ±0.08 K
using a micro bolometer-FPA detector. The typical error
of a similar set up used in one of our previous study was
approximately ±0.5 ºC, but we did not measure the typical
error with this set up although this error was expected to
be less than ±0.5 ºC. An elliptical region of interest of size
~9 mm was positioned manually such that it covered the
The central ocular surface temperature [OST] was of 34.5 °C before beginning the procedure of epithelial removal. The OST decreased by 14 °C due to the application of chilled BSS for 3s. After this time the temperature increases again by 8 °C, 10 °C, and 12 °C after 10, 20, and 40 s respectively. The decreased temperature of at least 2 °C from the initial OST baseline can be ascribed to the effect of room temperature (23.4 °C), the effect of the lid speculum and the missing blink frequency.

According to our best fitted model, the absolute value of each contributing component was 31.4 °C (subjacent corneal layers), 26.8 °C (environment) and 8.6 °C (BSS). The corresponding relaxation time relevant to these exponential functions was, for subjacent corneal layer (48 s and 7 s before and after the application of BSS), for environment (80 s and 184 s before and after the application of BSS) and for BSS (3 s).

Please notice that the inverted spike observed at ~4 s is due to the manipulation in measurement during the instillation of chilled BSS.

Figure 1 The central ocular surface temperature [OST] was of 34.5 °C before beginning the procedure of epithelial removal. The OST decreased by 14 °C due to the application of chilled BSS for 3 s. After this time the temperature increases again by 8 °C, 10 °C, and 12 °C after 10, 20, and 40 s respectively. The decreased temperature of at least 2 °C from the initial OST baseline can be ascribed to the effect of room temperature (23.4 °C), the effect of the lid speculum and the missing blink frequency.

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Please notice that the inverted spike observed at ~4 s is due to the manipulation in measurement during the instillation of chilled BSS.

**Results**

The OST decreased by 14 °C (down to 20 °C) due to the application of chilled BSS for 3 s (Fig. 1 red background, from about 12 to about 16 s). After this time, the temperature increased again by 8 °C (28 °C, 57% of original OST) after 10 s (Fig. 1 green background, at about 25 s), by 10 °C (30 °C, 71% of original OST) at 20 s (Fig. 1 green background, at about 35 s) and by 12 °C after 40 s (32 °C, 86% of the original OST) (Fig. 1 green background, at about 55 s). The decreased temperature of at least 2 °C from the initial OST baseline can be ascribed to the effect of room temperature (23.4 °C), the effect of the lid speculum and the missing blink frequency (Fig. 1 blue background, from 0 to about 12 s).

According to our best fitted model, the absolute value of each contributing component was 31.4 °C (subjacent corneal layers), 26.8 °C (environment) and 8.6 °C (BSS). The corresponding relaxation time relevant to these exponential functions was, for subjacent corneal layer (48 s and 7 s before and after the application of BSS), for environment (80 s and 184 s before and after the application of BSS) and for BSS (3 s).

The relaxation time represents here the time required for the OST to reach the baseline temperature recorded at the beginning of the experiment. These exponential functions have been regarded here as representative of human corneas.
Discussion

Applying chilled BSS to the cornea quickly reduces the temperature of the cornea with a thermal relaxation time of 3 s and an amplitude decrease of 8.6 °C. This together with the relaxation time of 7 s for subjacent corneal layers, and 184 s for environment after instillation of BSS combined with a well-controlled environment provides a period of 40 s of corneal temperature below baseline, which may be of clinical benefit when applying chilled BSS immediately before or immediately after ablation. However, the application of cold BSS after the ablation leads to several problems which by definition can be later introduced as haze and scattering.

We know that surface ablation causes haze in some cases whereas the causes of this are not well known, but a temperature increase over 40 °C during the ablation is one potential cause of denaturation and haze. There are several ways to minimize the temperature increase of the cornea during the surgery, one is the development of flying-spot ablation pattern that controls the local repetition rates to minimize the thermal load of the treatment for a smooth ablation with minimized risk of thermal damage. In addition to such methods, our results suggest that using chilled BSS preoperatively could help maintain OST below the baseline temperature and eventually help compensate the increase in OST due to laser ablation. The overall relaxation time we observed under the effect of chilled BSS (about 40 s) are long enough to provide a time window that can be used to design safer refractive procedures over and above the existing methods (described above) used to minimize the temperature increase.

Studies of the use of cold fluids postoperatively have presented the action of the reduced temperature as postop results or postop terms like reduced pain or reduced haze. However, these studies have not looked for a quantified method like the one we describe. Furthermore, our method essentially quantifies the result of preoperative BSS application and its potential benefits on thermal effects postoperatively.

We acknowledge the strong limitation that we have not measured more than one patient in this comprehensive manner. Furthermore, the temperature before and after the instillation of anaesthesia and the temperature of the speculum and anaesthetic drops were not analysed in our study. The temperature was measured continuously throughout the procedure and the manipulations in the measurements during the instillation of anaesthesia were avoided. More patients and a strong statistical analysis would also help elucidate the implications of our work. In this sense, our study can be regarded as a qualitative study. This study is meant more to engender thoughts, and we think it brings up some interesting points. To truly know the quantitative changes a more detailed study will need to be performed in a prospective fashion. Typical variation in surface temperature over the cornea, inter-subject variations and how these factors affect the procedure needs to be explored in details. Hopefully, this case study will be a good precursor for a formal prospective study to clarify some of the issues raised in this paper.

Conflict of interest

The authors have no proprietary interest in the materials presented herein.

References