Intraoperative changes in intraocular temperature during vitrectomy procedures with irrigating solutions differing in temperature

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Background: Intraoperative intraocular media and irrigation fluid temperature monitoring is not performed during vitreo-retinal surgery in current clinical practice. Purpose: To investigate intraoperative changes in intraocular temperature at the major steps of vitreoretinal surgery with irrigating solutions differing in temperature. Materials and Methods: Thirty-nine patients (39 eyes) were observed before, during and after vitrectomy. Group 1 (20 patients; 20 eyes) and Group 2 (19 patients; 19 eyes) differed with respect to the baseline temperature (24.2 ± 0.52 °С, or 10.3 ± 1.1 °С, respectively) of the irrigating fluid. Room air temperature, irrigating fluid temperature, patient’s body temperature, blood pressure, heart rate and blood oxygen saturation, vitreous temperature, and duration of every step of the vitreoretinal procedure were recorded in all cases. Results: Vitrectomy with 24°C or 10°C irrigating solutions resulted in a substantial decrease in temperature in vitreous compartments to the level of moderate or deep hypothermia, respectively. In addition, immediately after vitrectomy, the lowest temperatures were found in the anterior vitreous, and were 30.1 ± 0.45 °С for the 24°C group and 24.37±0.52 °С for the 10°C group. Moreover, after additional surgical manipulations, in the presence of discontinued irrigation, the temperatures in the vitreous compartments were found to gradually increase. Conclusion: Vitreoretinal surgery is performed under conditions of induced uncontrolled local hypothermia, which requires intraoperative monitoring of intraocular temperature and irrigating solution temperature. During a vitreoretinal procedure lasting up to 30 minutes, the intraocular contents may be safely cooled to the level of deep hypothermia.
less postoperative inflammation in the Jabbar et al [6]
study evaluating local ocular hypothermia with irrigating
balanced salt solution cooled to 7 °C in rabbits. Romano
and colleagues [7] found that the variations in temperature
during vitreoretinal surgery are clinically significant, as
the rheology of tamponades can be better manipulated by
modulating intraocular pressure and temperature.

In our previous rabbit study [8], in the 22°C or 5°C
irrigation solution groups, after vitrectomy with 60-minute
continuous vitreous cavity cooling, there have been light
microscopy evidence of retinal structural changes in the
form of uneven edema in the inner and outer retinal
layers, and these changes were more common and more
substantial in the latter group. However, after vitrectomy
with 30-minute continuous vitreous cavity cooling, there
has been no evidence of retinal structural changes in the
rabbit eyes [1].

Therefore, by monitoring the intraocular temperature
and the duration of exposure time of low-temperature
irrigating solution the intraocular structures are exposed to
during vitreoretinal surgery conducted under hypothermic
conditions, thermal changes in the eye may be able to be
controlled. This in turn will result both in improved use of
beneficial effects of local hypothermia and reduced rates of
intra- and post-operative complications in eye disease
management.

The purpose of the study was to investigate
intraoperative changes in intraocular temperature at the
main steps of vitreoretinal surgery with irrigating solutions
differing in temperature.

Materials and Methods

This was an open pilot study. The study protocol was
approved by a local Bioethics Committee of the Filatov
Institute. Written informed consent was obtained from all
individual participants included in the study. Thirty-nine
patients (39 eyes, including 16 with diabetic retinopathy,
4 with vitreous hemorrhage, 15 with rhegmatogenous
retinal detachment, and 4 with macular tear; age, 37 to
65 years) were under observation before, during and after
vitrectomy. They were divided into two groups, Group 1
(20 patients; 20 eyes) and Group 2 (19 patients; 19 eyes),
which differed with respect to the baseline temperature of
the irrigating solution, and operating room.

For measuring temperatures of various ocular structures,
patients were supervised for 5-7 days immediately
after surgery, and had follow-up visits at 1 and 3 months.

Statistics

Means and standard deviations (SD) were calculated.
The level of significance p ≤ 0.05 was assumed. For
between group comparisons, the Student’s t-test was used
for normally distributed and the Mann-Whitney test was
used for non-normal data. For pairwise comparison of
temperatures in different vitreous compartments, repeated
measures ANOVA with Bonferroni correction were used
for normally distributed data, whereas Friedman test for
related samples and Conover tests were used for non-
normal data. Logistic regression models were used to
examine the relationships of baseline vitreous temperature
with patient’s diagnosis, body temperature, heart rate and
blood oxygen saturation. Regression analysis was used to
identify the relationship of a change (Δ) in midvitreous
temperature at the time point after additional surgical
manipulations, compared to the time point immediately
after vitrectomy), with time for additional surgical
manipulations.

Statistical analyses were conducted using Statistica
10.0 (StatSoft, Tulsa, OK, USA) and MedCalc 18.10
(MedCalc Software Inc, Broekstraat, Belgium) software.

Results

At the first stage of the study, vitreous temperatures were
measured in both groups at baseline (before vitrectomy).
There was a significant transvitreous temperature gradient
(p < 0.001, rANOVA) from the lens toward the retina
(Table 1). Posterior vitreous temperatures were higher than
mid- and anterior vitreous temperatures. There was no
association of baseline vitreous temperature with patient’s
diagnosis, body temperature, blood pressure, heart rate or
blood oxygen saturation (p > 0.05). Mean patient body temperatures in groups 1 and 2 were 36.58±0.08 °C and 36.6±0.08 °C, respectively (p =0.44).

At the second stage of the study, vitreous temperatures were measured in both groups immediately after vitrectomy. Mean durations of vitrectomy in groups 1 and 2 were 6.4±0.75 min and 6.7±1.1 min, respectively (p =0.3). Immediately after vitrectomy (time point 2), in groups 1 and 2, posterior, mid- and anterior vitreous temperatures were significantly lower compared to baseline (p < 0.001, Table 2), and posterior vitreous temperatures were higher than mid- and anterior vitreous temperatures. In addition, temperatures in each compartment of the vitreous in group 2 were substantially (by approximately 5 °C) lower than those in group 1 (p<0.001). Table 2 presents the results of the analysis of mean temperature measurements for the three vitreous compartments in both groups at time point 2.

Table 3 presents changes in temperature for the three vitreous compartments in both groups immediately after vitrectomy compared to baseline. In group 1, the lowest temperature decrease (3.35 ± 0.51 °C) was for the anterior vitreous, and the highest (3.8 ± 0.59 °C), for the posterior vitreous (p<0.05). We found no statistically significant differences in temperature decrease between various vitreous compartments (p=0.15) among patients of group 2. In addition, among patients of group 2, a magnitude of temperature decrease (8.4 °C – 10.5 °C) after vitrectomy for each vitreous compartment was more substantial than that among patients of group 1 (2.4 °C – 5.9 °C; p<0.001).

After additional surgical manipulations, the increase in midvitreous temperature compared to immediately after vitrectomy to compare to baseline. In group 1, the lowest temperature increase (3.35 ± 0.51 °C) was for the anterior vitreous, and the highest (3.8 ± 0.59 °C), for the posterior vitreous (p<0.05). We found no statistically significant differences in temperature increase between various vitreous compartments (p=0.15) among patients of group 2. In addition, among patients of group 2, a magnitude of temperature increase (8.4 °C – 10.5 °C) after vitrectomy for each vitreous compartment was more substantial than that among patients of group 1 (2.4 °C – 5.9 °C; p<0.001).

Table 3 presents changes in temperature for the three vitreous compartments in both groups immediately after vitrectomy compared to baseline. In group 1, the lowest temperature decrease (3.35 ± 0.51 °C) was for the anterior vitreous, and the highest (3.8 ± 0.59 °C), for the posterior vitreous (p<0.05). We found no statistically significant differences in temperature decrease between various vitreous compartments (p=0.15) among patients of group 2. In addition, among patients of group 2, a magnitude of temperature decrease (8.4 °C – 10.5 °C) after vitrectomy for each vitreous compartment was more substantial than that among patients of group 1 (2.4 °C – 5.9 °C; p<0.001).

After additional surgical manipulations, the increase in midvitreous temperature compared to immediately after vitrectomy in group 1 was greater than in group 2 (2.21±1.11 °C vs 1.29±0.57 °C, p=0.004) and there was no significant between-group difference in terms of duration of additional surgical manipulations (7.3±3.9 min vs 8.15 ± 5.1 min, p=0.46).

There was a positive linear relationship between change in midvitreous temperature after additional surgical manipulations and duration of additional surgical manipulations both for group 1 (r=0.64, p=0.002) and group 2 (r=0.76, p < 0.001). Therefore, in both groups, vitreous temperatures increased with an increase in duration of manipulations, but they increased faster among patients of group 1 than among patients of group 2 (at an average rate of 0.18 °C per minute vs 0.085 °C per minute).

In addition, in both groups, during and after vitrectomy, there were no complications (like retinal detachment or tear, vitreous hemorrhage, or endophthalmitis) that could be attributable to the introduction of additional probes into the vitreous. Moreover, no corneal changes were observed, and lens clarity was maintained in all eyes during surgery.

Discussion

Therapeutic controlled hypothermia has been successfully applied in various medical fields (like cardiac surgery, neurosurgery, and resuscitation science) for improving brain cell resistance to ischemic conditions [11-15]. The neuroprotective efficacy of therapeutic hypothermia is directly related to the decrease in temperature and the decrease in oxygen consumption by neurons [16].

Hypothermia can be classified based on the depth of cooling from a normal body temperature of 37–38°C. Mild hypothermia describes a body temperature in the range 32–35°C, moderate hypothermia (28–32°C), and deep hypothermia (<28°C) [13].

Mild therapeutic hypothermia in critical care patients has been found to be effective for neuroprotection, with improvements in overall survival and neurologic outcomes [14, 17]. Moderate hypothermia has been widely used in cardiac surgery for brain protection. It has been reported [18] that deep hypothermia (24–26°C) allows for a safe prolong (>60 minutes) cardiac arrest in patients with severe heart disease or aortic arch disease.

Total body cooling may result in side effects as severe as marked cardiovascular system depression [7, 12]. These side effects limit the safe level of body cooling, and, correspondingly, the degree of neuroprotective effect provided by therapeutic hypothermia.

In the current study, we found that application of room temperature irrigating solutions during intraocular surgery resulted in a substantial decrease in vitreous temperature to the level of moderate local hypothermia. In addition, application of 10 °C irrigating solutions resulted in a decrease in intraocular temperature to the level of deep (below 28 °C) local hypothermia. Although the magnitude of between-group difference in the temperature of irrigating fluid was approximately 14 °C, the magnitude of between-group difference in vitreous temperature after vitrectomy with continuous vitreous cavity irrigation was just 5 °C (with no between-group differences in vitrectomy duration and baseline intraocular temperatures). This may indicate that choroidal blood flow is an important contributor to the maintenance of intraocular heat balance.

In addition, the groups were found to differ in the increase in vitreous temperature after discontinuance of irrigation. After the irrigating fluid was turned off, vitreous temperature recovered to baseline levels in group 1 at a rate (0.18 °C/min) greater than in group 2 (0.085 °C/min), probably also due to the capacity of choroidal blood flow for maintenance of heat balance in the eye.

Moreover, there were no complications during or after vitreoretinal procedures lasting up to 30 minutes, which confirmed our previous experimental findings [1]. Therefore, during a vitreoretinal procedure, the intraocular contents may be safely cooled to the level of deep hypothermia, which might confer additional neuronal protection and homeostasis. Nevertheless, further research is warranted to determine optimal conditions (target temperature, duration, and re-warming rate) for the induction of intraoperative controlled local ocular hypothermia during vitrectomy.
Conclusion

First, vitreoretinal surgery is performed under conditions of induced uncontrolled local hypothermia, as the irrigation fluid temperature is lower than that of the intraocular media, and intraoperative intraocular temperature monitoring is not common practice.

Second, vitrectomy with application of irrigating solutions of 24°C or 10°C resulted in a substantial decrease in temperature in vitreous compartments to the level of moderate or deep hypothermia, respectively. In addition, immediately after vitrectomy, the lowest temperatures were found in the anterior vitreous, and were 30.1±0.45 °C for the 24°C group and 24.37±0.52 °C for the 10°C group.

Third, the rate of an increase in vitreous temperature after completion of vitrectomy and discontinuance of irrigation was found to depend on the temperature of irrigating fluid. Thus, vitreous temperatures increased faster among patients undergoing vitrectomy with the 24°C irrigating solution than with the 10°C irrigating solution (at an average rate of 0.18 °C per minute vs 0.085 °C per minute).

Finally, during a vitreoretinal procedure lasting up to 30 minutes, the temperature of the irrigating fluid may be safely lowered to 10°C.

References

Table 1. Baseline temperatures (°C) in various vitreous compartments

<table>
<thead>
<tr>
<th>Group</th>
<th>Characteristic</th>
<th>Anterior vitreous</th>
<th>Mid-vitreous</th>
<th>Posterior vitreous</th>
<th>Significance of differences between compartments, p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1, (n=20)</td>
<td></td>
<td>33.45±0.31</td>
<td>33.85±0.39</td>
<td>34.17±0.36</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Group 2, (n=19)</td>
<td></td>
<td>33.45±0.38</td>
<td>34.05±0.49</td>
<td>34.65±0.62</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Significance of differences between groups, p</td>
<td>0.35</td>
<td>0.17</td>
<td>0.006</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: *, significant difference (p<0.05) in temperature compared to the anterior vitreous; #, significant difference (p<0.05) in temperature compared to the midvitreous; &, significant difference (p<0.05) in temperature compared to the posterior vitreous.

Table 2. Temperatures (°C) in various vitreous compartments immediately after vitrectomy

<table>
<thead>
<tr>
<th>Group</th>
<th>Characteristic</th>
<th>Anterior vitreous</th>
<th>Mid-vitreous</th>
<th>Posterior vitreous</th>
<th>Significance of differences between compartments, p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1, (n=20)</td>
<td></td>
<td>30.1±0.45</td>
<td>30.27±0.44</td>
<td>30.37±0.45</td>
<td>&lt;0.001</td>
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<tr>
<td>Group 2, (n=19)</td>
<td></td>
<td>24.37±0.52</td>
<td>24.83±0.51</td>
<td>25.37±0.54</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Significance of differences between groups, p</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: *, significant difference (p<0.05) in temperature compared to the anterior vitreous; #, significant difference (p<0.05) in temperature compared to the midvitreous; &, significant difference (p<0.05) in temperature compared to the posterior vitreous.

Table 3. Changes in temperature (°C) in various vitreous compartments after vitrectomy

<table>
<thead>
<tr>
<th>Group</th>
<th>Characteristic</th>
<th>Anterior vitreous</th>
<th>Mid-vitreous</th>
<th>Posterior vitreous</th>
<th>Significance of differences between compartments, p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1, (n=20)</td>
<td></td>
<td>3.35±0.51</td>
<td>3.58±0.65</td>
<td>3.8±0.59</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Group 2, (n=19)</td>
<td></td>
<td>9.08±0.41</td>
<td>9.22±0.36</td>
<td>9.28±0.55</td>
<td>0.15</td>
</tr>
<tr>
<td>Significance of differences between groups, p</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: *, significant difference (p<0.05) in temperature compared to the anterior vitreous; #, significant difference (p<0.05) in temperature compared to the midvitreous; &, significant difference (p<0.05) in temperature compared to the posterior vitreous.
Fig. 1. Scatter plots showing correlations between $\Delta$ (a change in midvitreous temperature at the time point after additional surgical manipulations, compared to the time point immediately after vitrectomy) and time for additional surgical manipulations for the two groups of patients. Regression equations and correlation coefficient ($r$) values are shown in rectangles.

Notes: 1, Group 1; 2, Group 2.