Temperature profiles in the anterior chamber during phaco-emulsification. R. M. BENOLKEN, JARED M. EMERY, AND D. J. LANDIS.

Phaco-emulsification has been applied to over 8,000 cataract extractions. The procedure involves incising the anterior lens capsule, prolapsing the lens nucleus into the anterior chamber, inserting an ultrasonic probe with aspirator through a small limbal incision, fragmenting the lens, and aspirating lens fragments from the eye. This procedure has several advantages over other methods of extraction. Benefits include a much smaller incision, a shorter 36-hour hospital admission, and return to full activity in a day or two. Furthermore, the risk of retinal detachment should be reduced, since the posterior portion of the lens capsule remains intact during extraction. However, clinical experience indicates persistent corneal edema in a small percentage of patients treated with phaco-emulsification.

We have measured temperature profiles in the eye of the cat during phaco-emulsification. In attempting to assess the thermal hazards during phaco-emulsification, three questions need to be answered: (1) what, if any, is the thermal hazard, (2) how far from the sonic probe does the hazard extend and, (3) how quickly does thermal hazard develop? For the first question, either substantial temperature increase or corneal opacification was our gross measure of serious hazard. The second question has been approached by estimating temperature gradients in the eye, that is, by measuring temperature as a function of the distance between a temperature sensor and the sonic probe. The third question has been approached by following the time course of temperature changes in the anterior chamber.

Extractions were performed with a Cavitrone/Kelman Model 7001 phaco-emulsifier at a resonant frequency of 40,000 Hz with a 0.003 inch stroke. Irrigation fluid was plasmalyte 148 at pH 7.4. Five cats were anesthetized with 22 mg per kilogram of Nembutal; three drops of 1:1,000 epinephrine were used to maintain dilation of the pupil and six lenses were extracted with Kelman’s surgical procedure. Temperatures within the cornea were measured with a sensor of 0.3 mm. diameter (the 0.025 mm. diameter leads of a glass-enclosed thermistor, GB43MC1 supplied by Fenwal Electronics Inc., Framingham, Mass., were insulated for a length of 25 mm. in Duro E-poxy-5 and this entire assembly was glass-enclosed in epoxy for 75 mm.). Temperatures within the anterior chamber were measured with a second sensor of 2.5 mm. diameter (again the leads of a glass thermistor, 31a52-12 supplied by Victory Engineering Corp., Springfield, N. J., were thermally insulated). Conduction losses were minimal since temperature measurements were identical, within reading uncertainty, at immersion depths from 2 mm. to 75 mm. with a temperature difference of 40° C. at an air-water interface.

Each temperature sensor formed one arm of a Wheatstone bridge circuit in which the other arms were fixed precision resistors within 1 per cent of the nominal thermistor resistance. Bridge unbalance was monitored with a Hewlett Packard 412A vacuum-tube voltmeter. Response times were about one second for 95 per cent of steady-state value following a 10° C. step in temperature. Thermistor power dissipation was limited to 25 micro-watts or less (25 micro-watts would increase the temperature of one cubic centimeter of water by 0.02° C. per hour). Calibration curves were run before and after most surgical procedures. Calibrations were against a Bureau of Standards mercury thermometer in intervals of 1° C. over the range 25° C. to 70° C. Maximum difference between corresponding points on 16 calibration curves was 0.5° C., and we estimate a precision of ± 0.5° C. for all steady-state temperature measurements.

A. Standard phaco-emulsification procedure. A cat was prepared for standard phaco-emulsification procedures. A temperature sensor was inserted in a lamellar fashion 2 mm. into the corneal stroma at a distance 1 mm. from the point of entry of the sonic probe, and a second sensor was embedded into the lens about 2 mm. from the tip of the sonic probe. With maximum sonic power and with the manufacturer’s recommended flow rate of 25 ml. per minute, maximum corneal temperature was 32° C. and maximum lens temperature was 35° C.; baseline values without sonic power or aspirator flow were 33.5° C. and 37° C., respectively. Since temperatures observed during phaco-emulsification were less than baseline temperatures of the cornea and lens in the absence of sonic power and aspirator flow, the data indicate no thermal hazard under these conditions.

Thermal effects of reducing aspirator flow rates below the recommended value were also examined. A temperature sensor was positioned a few millimeters away from the sonic probe in the central...
Fig. 1. Ordinate is temperature in °C, and abscissa is time in seconds after start of max power at t = 0. Values of d specify the distance between the temperature sensor and the fixed position of the sonic probe. Circles specify points of the first run at d = 8 mm., triangles specify points of run 2 at d = 3 mm., and squares specify points of run 3 at d = 1 mm. The insert is a schematic of the experimental arrangement.

Table I

<table>
<thead>
<tr>
<th>Sonic power</th>
<th>Aspirator pump rate (ml/min.)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
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<tr>
<td>None</td>
<td>None</td>
<td>33.5</td>
</tr>
<tr>
<td>None</td>
<td>9</td>
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</tr>
<tr>
<td>None</td>
<td>12</td>
<td>29.5</td>
</tr>
<tr>
<td>None</td>
<td>17</td>
<td>29.5</td>
</tr>
<tr>
<td>Maximum</td>
<td>9</td>
<td>33.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>12</td>
<td>32.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>17</td>
<td>31.5</td>
</tr>
</tbody>
</table>

Ambient and irrigation fluid temperatures = 26° C ± 1° C.

Fig. 2. Ordinate is corneal temperature in °C, and abscissa is time in seconds after start of max power at t = 0. Circles specify corneal temperatures of the first run, triangles are temperatures of run 2, squares are temperatures of run 3, semicircles are temperatures of run 4. Lens temperatures were measured concurrently and generally followed corneal temperatures. Maximum lens temperatures for these 4 runs were 49° C, 60° C, 60° C, and 56° C, respectively. The insert is a schematic of the experimental arrangement.

region of the anterior chamber. Baseline temperature was measured without sonic power or irrigation-aspirator flow. Temperatures were also measured at various flow rates without sonic power. Finally, temperatures were measured with maximum ultrasonic power at various flow rates. Typical results are shown in Table I. With maximum power and the flow rates indicated in Table I, maximum temperatures were less than or equal to baseline temperatures measured in the absence of sonic power and flow. Throughout the extraction procedure, various locations in the anterior chamber were scanned with a temperature sensor. Substantial temperature variations were not observed at any locations up to and including sensor positions within 1 mm. of the sonic probe. Temperature gradients and the rate of change of temperature per unit time were essentially zero. Similar results were observed in a second cat.

As will become apparent later from stop-flow experiments, irrigation-aspiration is just as important for removing heat as it is for removing lens fragments from the anterior chamber. Although good flow is extremely important, the data indicate a substantial safety margin for flow rates below the recommended value of 25 ml. per minute. For instance, in Table I, thermal hazard was not indicated for a flow rate as low as 9 ml. per minute.

B. Phaco-emulsification with stop flow. The magnetostriuctive transducer of the Model 7001 emulsifier is cooled with circulating water; this primary coolant is completely isolated from the sterile fluid circulating through the aspirator system in the titanium probe tip. In all of the stop-flow experiments reported here, primary coolant circulated as usual. Stop-flow refers to arresting flow in the irrigation-aspiration system only.

In order to estimate temperature gradients under
Fig. 3. A, Eye with opacified cornea photographed after run 4 of Fig. 2. Sonic probe (1), corneal temperature sensor (2), and lens sensor (3), are shown in approximate experimental locations. B, Section of opacified cornea from the eye of Fig. 3. A showing extensive coagulative necrosis of corneal stromal collagen, and swelling of corneal stroma to twice the thickness of normal cornea from the contralateral eye shown in C. (Hematoxylin and eosin stain.)

Stop-flow conditions, the lens was almost completely emulsified to permit free positioning of the temperature sensor in the anterior chamber. The sonic probe was positioned near the center of the anterior chamber, while the temperature sensor was positioned at various distances, d, from the fixed position of the sonic probe. At each position of the sensor, a steady-state baseline temperature was established with 25 ml. per minute of flow and no sonic power. At time t = 0, flow was switched off and maximum ultrasonic power was switched on. Temperatures were measured as a function of time beginning with t = 0. At the end of a run, sonic power was switched off, and 25 ml. per minute of flow quickly brought the temperature back to a steady baseline. After the temperature sensor was relocated, the procedure was repeated at a new value of d and t = 0.

Results for three values of d are shown in Fig. 1. The temperature and the change of temperature per unit time increase rapidly as the temperature sensor approaches the sonic probe and falls off.
rapidly with distance from the sonic probe. The cornea surrounding the sonic probe incision began to cloud at 60 seconds in run 2 of Fig. 1. Extensive corneal opacification was obvious by the end of run 3.

Opacification was always observed first in the corneal tissue at the incision site surrounding the sonic probe. The crucial temperature seems to be the temperature of the cornea in this region. Consequently, stop-flow experiments were repeated with a temperature sensor inserted 2 mm. into the corneal mid-stroma about 1 mm. from the sonic probe incision. A second sensor was embedded in the lens about 2 mm. from the tip of the sonic probe. Probe and sensor positions were constant, and the lens nucleus was intact prior to the first run. Baseline temperatures were measured in the absence of both sonic power and flow. Maximum sonic power was switched on at t = 0 and switched off at t = 60 seconds. Then 25 ml. per minute of flow quickly brought temperatures below baseline values, and subsequently, steady-state baselines were established in the absence of sonic power and flow. This procedure was repeated for each run of Fig. 2, and similar results were observed with a second cat.

The corneal temperature reached a peak value of 49° C. by the end of the first run shown in Fig. 2, and no corneal damage was apparent. The cornea surrounding the probe incision was cloudy by the end of the second run, and opacification of the cornea proceeded to completion during the third run. The last run was started after corneal opacification (see Fig. 3, A) had proceeded to completion in run 3 of Fig. 2. In general, before corneal damage was extensive, lens temperatures followed corneal temperatures in value and time course. However, after extensive corneal damage, the rate of change of corneal temperature increased relative to the rate of change of lens temperature. With the Cavitron sonic probe properly positioned in the anterior chamber, serious hazard of corneal opacification develops within 50 to 60 seconds after flow malfunction. In the event of flow failure during phaco-emulsification, sonic power should be shut down immediately.

The thermally damaged cornea of Fig. 3, A was examined histologically. Histologic sections such as Fig. 3, B revealed extensive coagulative necrosis of corneal stromal collagen, and swelling of corneal stroma to twice the thickness of the contralateral cornea shown in Fig. 3, C.

Returning to the problem of the small percentage of patients with persistent corneal edema after phaco-emulsification, we conclude from the present data that the source of corneal insult in these cases is not related to thermal hazard from standard phaco-emulsification procedures where the surgeon has ensured (1) a limbal incision of the proper size to permit leakage of irrigation fluid around the incision, and (2) continuous irrigation-aspirator flow at the recommended rate of 25 ml. per minute.

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REFERENCES


The effect of aerobic exercise on intraocular pressure.* KENNETH J. MYERS.

The effect of moderate to severe aerobic exercise on intraocular pressure was determined. Aerobic exercise is limited by general systemic fatigue with steady-state heart rates of 130 to 160 indicating moderate exercise and rates above 160 indicating severe exercise. An athlete, for example, builds endurance by maintaining rates above 150 while training.

Earlier studies have shown exercise decreases intraocular pressure (IOP). These studies, while valid, used relatively few IOP measurements and/or tonometers (Goldmann or Schiötz), that produce procedural difficulties (corneal anesthetic) and slight (1 to 2 mm.), but significant, sequential lowerings in indicated pressure. Two aerobic exercises (bicycle ergometry and marathon running) were used while IOP measurements were made with the American Optical noncontact tonometer which illuminates with an air puff and displays IOP, to the nearest milli-