Mitomycin C dissolved in a reversible thermosetting gel: target tissue concentrations in the rabbit eye

Koji Ichien, Tetsuya Yamamoto, Yoshiaki Kitazawa, Akihiro Oguri, Hiroshi Ando, Yuji Kondo

Abstract

Aims—To determine whether a new, reversible thermosetting gel enhances mitomycin C transfer to target ocular tissues in the rabbit eye.

Methods—A 0.1 ml solution of mitomycin C containing 0.22 µg, 2.9 µg, or 28 µg of the agent dissolved in a reversible thermosetting gel consisting of methylcellulose, citric acid, and polyethylene glycol was injected subconjunctivally in 30 New Zealand albino rabbits. Scleral and conjunctival tissues were excised at 0.5, 1, 2, 4, or 24 hours after the injection and mitomycin C concentrations in these tissues were determined by high performance liquid chromatography. The concentration over time was approximated to a single exponential curve, and initial mitomycin C concentrations, time constants, and half life values were determined. Finally, the areas under the curves (AUCs) between 0.5 and 24 hours were calculated.

Results—The mitomycin C concentrations in the target tissues were dose dependent and decreased rapidly over 24 hours. Both the initial mitomycin C concentrations as well as AUCs in these eyes treated with mitomycin C, dissolved in a reversible thermosetting gel, were higher than those in eyes treated similarly in a previous study in which the gel was not used.

Conclusion—Applied subconjunctivally in the rabbit eye, mitomycin C dissolved in the reversible thermosetting gel enhanced transfer of the agent to the sclera and the conjunctiva.

Mitomycin C (MMC) has been demonstrated to be an effective adjunct in glaucoma filtering surgery. However, this antiproliferative agent, a potent inhibitor of DNA synthesis, can cause severe adverse effects if the dosage is too high. For example, scleromalacia and scleral perforation have been reported following MMC application after pterygium surgery. Such scleral complications have not been reported clinically except for five cases of moderate scleritis that developed following a 3 minute application of 0.05% solution of the agent during inferior trabeculectomy. How-
Resolution on the Use of Animals in Research. After administering topical anaesthesia with 0.4% oxybuprocaine, we subconjunctivally injected 0.1 ml (0.22 µg, 2.9 µg, or 28 µg) of the sterile MMC solution using a 30 gauge needle into the temporal superior quadrant of both eyes of the rabbits; the same dose of MMC was used in both eyes of each rabbit. The needle was inserted 10 mm away from the limbus and the injection raised about 8×8 mm sized circular area of the conjunctiva. The rabbits were killed by injection of an excessive amount of 5% pentobarbitone at 0.5, 1, 2, 4, or 24 hours after the MMC injections. Then we excised a section of conjunctiva and sclera measuring 10×10 mm from each injected site. Aqueous and vitreous specimens were not obtained. Four eyes of two rabbits were used for each designated time point and each drug concentration. The excised tissues were immediately frozen at −80°C and MMC concentrations were measured using the same HPLC method we have described elsewhere.14 The minimum MMC concentration detectable by this method was 5×10⁻³ µg/g.14

The concentration over time was approximated to the single exponential curve of \( C_t = C_0 \exp(-at) \), where \( C_t \) was the MMC concentration (µg/g) at time \( t \), \( C_0 \) the MMC concentration at time 0, \( a \) the time constant of MMC disappearance (h⁻¹), and \( t \) the time after MMC administration. Initial MMC concentrations, time constants and half life values were determined using this equation. Additionally, the areas under the curves (AUCs) between 0.5 and 24 hours were calculated.

### Results

The concentrations of MMC in the target tissues are shown in Table 1 and in Figure 1A and B. The concentration at each time point correlated with the dosage injected: the greater the dose, the greater the concentration and vice versa.

### Table 1 Mitomycin C (MMC) concentration changes in ocular tissues (µg/g, mean (SD))

<table>
<thead>
<tr>
<th>Ocular tissue measured</th>
<th>MMC dosage applied (µg)</th>
<th>Hours after MMC application</th>
<th>0.5</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conjunctiva</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.22</td>
<td>0.51 (0.18)</td>
<td>0.17 (0.18)</td>
<td>0.02 (0.02)</td>
<td>Trace*</td>
<td>Trace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>3.62 (3.25)</td>
<td>1.50 (0.86)</td>
<td>0.18 (0.13)</td>
<td>Trace</td>
<td>Trace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>62.15 (20.71)</td>
<td>21.83 (4.29)</td>
<td>5.31 (5.22)</td>
<td>0.18 (0.16)</td>
<td>Trace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sclera</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.22</td>
<td>0.13 (0.14)</td>
<td>0.06 (0.07)</td>
<td>0.01 (0.01)</td>
<td>Trace</td>
<td>Trace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>0.61 (0.48)</td>
<td>0.52 (0.45)</td>
<td>0.07 (0.05)</td>
<td>Trace</td>
<td>Trace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>23.18 (6.80)</td>
<td>10.25 (3.41)</td>
<td>1.36 (0.93)</td>
<td>0.10 (0.10)</td>
<td>Trace</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Less than the minimum detectable mitomycin C concentration—that is, 5×10⁻³ µg/g.14

### Table 2 Pharmacokinetic analyses of mitomycin C (MMC) concentration changes in the conjunctiva

<table>
<thead>
<tr>
<th>Method of MMC application</th>
<th>MMC dosage applied (µg)</th>
<th>Initial concentration (µg/g)</th>
<th>Time constant (h⁻¹)</th>
<th>Half life (h)</th>
<th>AUC† (µgh/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current study with reversible thermosetting gel</td>
<td>0.22</td>
<td>1.23</td>
<td>2.40</td>
<td>0.29</td>
<td>0.40</td>
</tr>
<tr>
<td>Subconjunctival injection with sterile water*</td>
<td>2</td>
<td>1.05</td>
<td>2.28</td>
<td>0.31</td>
<td>0.29</td>
</tr>
<tr>
<td>Application with sponges for 5 minutes and copious irrigation*</td>
<td>200</td>
<td>158.0</td>
<td>3.92</td>
<td>0.18</td>
<td>23.49</td>
</tr>
</tbody>
</table>

*Numbers are quoted from or calculated using data that appeared elsewhere.14

†Area under the curve between 0.5 and 24 hours.

### Table 3 Pharmacokinetic analyses of mitomycin C (MMC) concentration changes in the sclera

<table>
<thead>
<tr>
<th>Method of MMC application</th>
<th>MMC dosage applied (µg)</th>
<th>Initial concentration (µg/g)</th>
<th>Time constant (h⁻¹)</th>
<th>Half life (h)</th>
<th>AUC† (µgh/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current study with reversible thermosetting gel</td>
<td>0.22</td>
<td>0.10</td>
<td>1.31</td>
<td>0.53</td>
<td>0.11</td>
</tr>
<tr>
<td>Subconjunctival injection with sterile water*</td>
<td>2</td>
<td>0.12</td>
<td>1.54</td>
<td>0.45</td>
<td>0.14</td>
</tr>
<tr>
<td>Application with sponges for 5 minutes and copious irrigation*</td>
<td>200</td>
<td>3.16</td>
<td>2.19</td>
<td>0.32</td>
<td>0.67</td>
</tr>
</tbody>
</table>

*Numbers are quoted from or calculated using data that appeared elsewhere.14

†Area under the curve between 0.5 and 24 hours.
used, the initial MMC concentrations as well as AUCs in the eyes treated with the MMC solution dissolved in the reversible thermosetting gel were higher than those in the eyes in our previous study in which no gel was used.

Discussion
The reversible thermosetting gel we used becomes a sol at relatively low temperature and turns into a gel as the temperature nears body temperature. The constituents—methylcellulose, citric acid, and polyethylene glycol—have been proved to be non-toxic to ocular tissues. The compound is now being tested in several clinical trials in Japan as a potential solvent for timolol maleate, and it has already been shown that once daily instillation of 0.5% timolol maleate prepared with the gel is as effective as twice daily use of 0.5% timolol aqueous solution (unpublished data). An animal study revealed that the AUCs of tissue concentration of timolol in the cornea, the aqueous, and the iris and the ciliary body increased by 1.8 to 2.2 times with 50 µl of 0.25% timolol maleate prepared with the gel compared with the same amount of the same concentration of aqueous solution (unpublished data). These favourable effects possibly derive from the increased drug–corneal contact time made possible by the gel. That is, it is likely that subconjunctivally injected MMC dissolved in the gel remains longer subconjunctivally and therefore that the concentration of MMC in the target tissues is higher than when MMC dissolved in saline or water is injected subconjunctivally.

The current study demonstrated that a sub-conjunctival injection of 0.1 ml of 2.9 × 10⁻²% MMC solution (MMC dosage, 2.9 µg) dissolved in the reversible thermosetting gel allowed maintenance of an MMC concentration in the sclera and conjunctiva during the first 24 hours at a level similar to that found in our previous study in eyes in which 0.2 mg of the agent were applied with surgical sponges and the wound copiously irrigated 5 minutes later. The MMC concentration in the conjunctiva detected in the current study was higher than that in the sclera. This finding is compatible with that in our previous study, where MMC aqueous solution was used and in another study using 5-fluorouracil, although it is noted that a portion of MMC injected still remained unreleased. The AUCs of the eyes treated using the gel solution were 62% and 119% of those in the eyes in our previous study in the conjunctiva and sclera, respectively, even though the MMC dosage we used in the current study was only 1.45% of that used in that earlier study. Thus, the MMC dose transferred to the target ocular tissues by injecting it in a gel solution was about 69 times (200 µg versus 2.9 µg) greater than that transferred by the usual current clinical method. Moreover, compared with MMC application via subconjunctival injections with sterile water, the tissue concentrations as well as the AUCs were some 10 times higher.

One, though not the only reason, why MMC is not topically applied or subconjunctivally injected in glaucoma filtering surgery is to avoid contact with ocular and periorcular tissues of concentrations of the agent high enough to cause adverse effects such as those found after its use following pterygium surgery. However, a great disadvantage of the prevalent clinical method of MMC administration is that far greater dosages than are actually needed in the target ocular tissues must be administered. Also, the dose of MMC released to the ocular tissues is highly variable when it is applied intraoperatively, because the amount of the agent that remains unreleased is quite variable. In the current study, tissue MMC concentration was as variable as that following injection of aqueous MMC solution in the previous experiment.

We showed that a smaller amount of MMC is needed to maintain the tissue concentration of the agent by dissolving it into a thermosetting gel. Although the effects of this method of administering MMC on filtering bleb formation and complications must be further investigated in animal filtration models and we have to administer it preoperatively, a smaller amount of MMC in gel may prove to be at least as effective as the current method.

The authors thank Wako Pharmaceutical Co., Japan, for providing and preparing the reversible thermosetting gel.

None of the authors has any proprietary interest in the development and marketing of any products mentioned or of any competing products.

Figure 1 Mitomycin C (MMC) concentrations in the conjunctiva (A) and in the sclera (B) after a single subconjunctival injection of the agent dissolved in a reversible thermosetting gel. The open squares show the 0.22 µg dose; the closed circles the 2.9 µg dose, and the open circle the 28 µg dose. The closed squares show the tissue concentrations following an application of 200 µg of the agent with sponges for 5 minutes and copious irrigation.

Table 1 Mitomycin C (MMC) concentration (µg/g) or 0.25% timolol maleate prepared with the gel and has been shown to be effective as twice daily use of 0.5% timolol aqueous solution (unpublished data). An animal study revealed that the AUCs of tissue concentration of timolol in the cornea, the aqueous, and the iris and the ciliary body increased by 1.8 to 2.2 times with 50 µl of 0.25% timolol maleate prepared with the gel compared with the same amount of the same concentration of aqueous solution (unpublished data). These favourable effects possibly derive from the increased drug–corneal contact time made possible by the gel. That is, it is likely that subconjunctivally injected MMC dissolved in the gel remains longer subconjunctivally and therefore that the concentration of MMC in the target tissues is higher than when MMC dissolved in saline or water is injected subconjunctivally.

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