Disruption of the Posterior Chamber–Anterior Hyaloid Membrane Barrier During Phacoemulsification and Aspiration as Revealed by Contrast-Enhanced Magnetic Resonance Imaging

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Objective: To determine the effect of phacoemulsification and aspiration (PEA) in different surgical settings on the posterior chamber–anterior hyaloid membrane (AHM) barrier.

Methods: Eighty enucleated porcine eyes divided into 8 groups underwent lens extraction at a bottle height of 35 or 95 cm by 1 of the following 4 procedures: standard PEA, standard PEA without hydrodissection (sPEA–), sPEA– including 5 minutes of irrigation of the anterior chamber, and sPEA– including 20 cycles of deflation (5 seconds each cycle) and inflation (10 seconds each cycle) of the anterior chamber. Distribution of gadopentetate dimeglumine (gadolinium–diethylenetriamine pentaacetic acid [Gd-DTPA]) in the irrigating fluid was assessed by magnetic resonance imaging (MRI).

Results: The most common MRI pattern was the posterior chamber type, where Gd-DTPA was localized in the anterior and posterior chambers, followed by AHM detachment, in which Gd-DTPA was evident beneath the posterior lens capsule. The least common was AHM tear, in which Gd-DTPA entered the vitreous cavity through a tear in the AHM. Logistic regression analysis revealed prolonged irrigation (P < .001) and deflation/inflation of the anterior chamber (P < .001) as risk factors for AHM detachment and hydrodissection (P = .04) as a risk factor for AHM tear.

Conclusion: Changes in intraocular pressure can disrupt the posterior chamber–AHM barrier during PEA.

Clinical Relevance: Cataract surgeons should reexamine their surgical settings to avoid unnecessary stress on the eye.


Although phacoemulsification and aspiration (PEA) has become less invasive and a safer procedure with marked improvements of surgical instruments and techniques, suppurative postoperative endophthalmitis still occurs in 0.05% to 0.22% of cases. On the one hand, rupture of the posterior lens capsule (ie, disruption of the aqueous-vitreous barrier) during surgery leads to a significantly higher incidence of postoperative endophthalmitis. As a consequence, microorganisms can easily migrate into the vitreous cavity in the presence of intraoperative contamination in the aqueous humor, with an incidence estimated to be as high as 5.7% to 21.1%. On the other hand, it is difficult to explain how this devastating complication can also develop in a larger number of patients who undergo PEA without significant surgical complications.

Another possible route for organisms to enter the vitreous cavity is the posterior chamber (PC), which forms a mechanical barrier called the PC–anterior hyaloid membrane (AHM) barrier that is made up of the zonule of Zinn and the AHM. We hypothesize that this barrier may be disrupted by a variety of surgical stresses that occur during PEA.

To investigate this hypothesis, we attempted to evaluate the integrity of the PC-AHM barrier during PEA by assessing the intraocular distribution of the irrigating fluids with the use of an appropriate tracer. Recently, it was documented that contrast-enhanced magnetic resonance imaging (CE-MRI) in combination with gadopentetate dimeglumine (gadolinium–diethylenetriamine pentaacetic acid [Gd-DTPA]) can be used to evaluate the pericapsular distribution or retention of a drug after local or systemic administration. In this study, we applied this method to visualize the intra-
ocular distribution of the irrigating fluid and examined the CE-MRI findings after PEA in different surgical settings.

### METHODS

#### PREPARATION OF CONTRAST MEDIUM

We dissolved Gd-DTPA (Magnevist; Berlex Laboratories, Montville, New Jersey) in balanced salt solution (BSS Plus; Alcon, Fort Worth, Texas) at a concentration of 2 mM. This was expected to produce maximum contrast enhancement on T1-weighted images, with the relativity of Gd-DTPA being $3.4/s/mM^{-1}s^{-1.24}$.

#### INTRACAMERAL OR INTRAVITREAL INJECTION OF Gd-DTPA

Porcine eyes obtained from a local abattoir were stored at 4°C and used within 12 hours of enucleation. We used a 1-mL disposable syringe with a 27-gauge needle to inject 0.1 mL of Gd-DTPA solution intracameral via the superior temporal limbus without paracentesis. Under the same condition, we injected 0.1 mL of Gd-DTPA solution into the vitreous cavity through the pars plana. We performed these procedures while using an operating microscope.

#### STANDARD PEA

The standard PEA procedure was performed as follows using enucleated porcine eyes. After making a 3.2-mm corneal incision, the anterior chamber (AC) was filled with 0.4 mL of viscoelastic material (Healon; Advanced Medical Optics, Santa Ana, California), and a continuous curvilinear capsulorrhexis was performed with a mean (SD) diameter of 6.0 (0.5) mm. Eyes undergoing incomplete or small continuous curvilinear capsulorrhexis were excluded at this stage. Then, the hydrodissection was performed as consistently as possible by injecting 3.0 mL of the gadopentetate solution in about 15 seconds with the use of a phacoemulsification instrument equipped with a straight 19-gauge tip (Sovereign Compact; Advanced Medical Optics). We used the following PEA setup: the bottle height was adjusted to 95 cm above eye level, and the procedure was performed at an aspiration rate of 28 mL/min, a vacuum limit of 250 mm Hg, and a phacoemulsification power limit of 40%.

After phacoemulsification, we used an injector to implant an intraocular lens (AR40e Sensor; Advanced Medical Optics) into the capsular bag filled with viscoelastic material. After the implantation, the viscoelastic material was thoroughly washed out by irrigation/aspiration with a fixed flow rate of 22 mL/min and a maximum linear vacuum pressure of 500 mm Hg. The corneal incision was closed with 10-0 nylon sutures. The whole surgery generally ended in 4 minutes, including an ultrasonic time of 30 to 40 seconds.

#### MODIFICATION OF SURGICAL SETTINGS

To compare the effect of the changes in intraocular pressure (IOP) during the surgery, PEA was performed with 8 different modifications of the surgical settings (Table 1).

First, standard PEA was performed without hydrodissection (sPEA−95; the original sPEA was designated as sPEA + 95). Second, standard PEA was performed without hydrodissection in the same way, and the AC was irrigated for a prolonged period (5 minutes) (iPEA−95). Third, the AC was repeatedly deflated and inflated for 5 minutes after standard PEA without hydrodissection (dPEA−95). This manipulation consisted of 20 cycles of deflation (5 seconds) and inflation (10 seconds). In addition, PEA was performed at a bottle height of 35 cm under the same conditions as described for the bottle height of 95 cm (sPEA−35, iPEA−35, and dPEA−35), including the standard procedure (sPEA + 35).

As a result, a total of 8 groups, each consisting of 10 eyes, were included in this study. Throughout the experiment, we exclusively used eyes in which PEA was successfully completed without complications. The volume of irrigating solution for each operation was measured to evaluate the surgical stress during the procedure.

#### CONTRAST-ENHANCED MRI

Contrast-enhanced MRI was performed on each eye immediately after the surgery to determine the intraocular distribution of the irrigating fluid. All imaging experiments were performed with a 1.5-T, 65.5-cm bore MRI system (Vantage XGV; Toshiba Medical Systems Corp, Tokyo, Japan) with a 7-cm surface coil (Flex coil; Toshiba Medical Systems Corp). Multislice spin-echo T1-weighted images were acquired under the following conditions: repetition time, 45 milliseconds; echo time, 15 milliseconds; field of view, $10 \times 10$ cm; and matrix, $256 \times 256$. The measurements were repeated 3 times and the images were summed to obtain adequate gadopentetate intensity. The entire procedure took about 5 minutes.

### Table 1. Profile of the Surgical Settings

<table>
<thead>
<tr>
<th>Group</th>
<th>Hydrodissection</th>
<th>Bottle Height, cm</th>
<th>Prolonged Irrigation of AC</th>
<th>Deflation/Inflation of AC</th>
<th>Average Volume of Irrigating Solution Mean (SD), mL</th>
<th>CE-MRI Type, No. of Eyes</th>
</tr>
</thead>
<tbody>
<tr>
<td>sPEA + 35</td>
<td>Yes</td>
<td>35</td>
<td>No</td>
<td>No</td>
<td>19.5 (7.2)</td>
<td>PC 8 0 2</td>
</tr>
<tr>
<td>sPEA + 95</td>
<td>Yes</td>
<td>95</td>
<td>No</td>
<td>No</td>
<td>33.5 (10.0)</td>
<td>PC 8 1 1</td>
</tr>
<tr>
<td>sPEA−35</td>
<td>No</td>
<td>35</td>
<td>No</td>
<td>No</td>
<td>25.0 (6.2)</td>
<td>PC 10 0 0</td>
</tr>
<tr>
<td>sPEA−95</td>
<td>No</td>
<td>95</td>
<td>No</td>
<td>No</td>
<td>34.5 (7.2)</td>
<td>PC 10 0 0</td>
</tr>
<tr>
<td>iPEA−35</td>
<td>No</td>
<td>35</td>
<td>Yes</td>
<td>No</td>
<td>63.0 (11.6)</td>
<td>PC 4 6 0</td>
</tr>
<tr>
<td>iPEA−95</td>
<td>No</td>
<td>95</td>
<td>Yes</td>
<td>No</td>
<td>52.0 (11.1)</td>
<td>PC 7 3 0</td>
</tr>
<tr>
<td>dPEA−35</td>
<td>No</td>
<td>35</td>
<td>Yes</td>
<td>Yes</td>
<td>86.0 (15.8)</td>
<td>PC 5 5 0</td>
</tr>
<tr>
<td>dPEA−95</td>
<td>No</td>
<td>95</td>
<td>Yes</td>
<td>Yes</td>
<td>98.0 (16.0)</td>
<td>PC 3 7 0</td>
</tr>
</tbody>
</table>

Abbreviations: AC, anterior chamber; AHD, anterior hyaloid membrane detachment; AHT, anterior hyaloid membrane tear; CE-MRI, contrast-enhanced magnetic resonance imaging; d, deflation/inflation; i, irrigation; PC, posterior chamber type; PEA, phacoemulsification and aspiration; s, standard.

a Indicates irrigation of the AC for 5 minutes.

b The AC was deflated and inflated 20 times for 5 minutes.

c Each group included 10 eyes.
Table 2. Assessment of Risk Factors for AHD or AHT

<table>
<thead>
<tr>
<th>Type</th>
<th>Hydrodissection</th>
<th>Bottle Height of 95 cm</th>
<th>Prolonged Irrigation ( ^a )</th>
<th>Deflation/Inflation ( ^b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHD</td>
<td>.23</td>
<td>.21</td>
<td>&lt;.001 ( ^c )</td>
<td>&lt;.001 ( ^c )</td>
</tr>
<tr>
<td>AHT</td>
<td>.04 ( ^d )</td>
<td>.53</td>
<td>&gt;.99</td>
<td>&gt;.99</td>
</tr>
</tbody>
</table>

Abbreviations: AHD, anterior hyaloid membrane detachment; AHT, anterior hyaloid membrane tear.

\( ^a \) Indicates irrigation of the anterior chamber for 5 minutes.

\( ^b \) The anterior chamber was deflated and inflated 20 times for 5 minutes each.

\( ^c \) \( P < .01 \) by logistic regression.

\( ^d \) \( P < .05 \) by logistic regression.

Some of the eyes were examined macroscopically or prepared for examination by means of conventional light microscopy after being fixed in 10% formalin for 48 hours.

**STATISTICAL ANALYSES**

We used analysis of variance to determine the significance of any differences among the volumes of irrigating solution used, and the level of significance was set at \( P < .05 \). When analysis of variance indicated that statistical significance has been reached, we performed the Tukey-Kramer multiple comparison test (Table 2).

We used logistic regression analysis to assess the risk factors causing the abnormal CE-MRI findings. \( P < .05 \) was considered statistically significant.

**RESULTS**

In a preliminary study on intravitreal or intracameral injections, the distribution of the injected Gd-DTPA was well depicted using CE-MRI. In the case of intracameral injection (Figure 1A), the AC was clearly enhanced by Gd-DTPA, whereas the vitreous cavity remained dark. In the case of intravitreal injection, however, most of the vitreous cavity was enhanced by Gd-DTPA, whereas a faint signal was noted in the AC (Figure 1B). These results indicated that this imaging technique worked well for monitoring within the vitreous cavity. However, the volume was significantly greater in eyes receiving prolonged irrigation or repeated deflation/inflation (iPEA−35, iPEA−95, dPEA−35, and dPEA−95) compared with the eyes in each of the standard PEA groups (sPEA+35, sPEA+95, sPEA−35, and sPEA−95). The \( P \) values were less than .001 for each combination of these groups, except for iPEA−35 vs sPEA+95 (\( P = .01 \)) and iPEA−35 vs sPEA−95 (\( P = .02 \)). Among the 4 groups receiving prolonged irrigation or repeated deflation/inflation, statistically significant differences existed between each of the groups (iPEA−95 vs iPEA−35; dPEA−95 vs iPEA−35; dPEA−35 vs dPEA−95; and iPEA−95 vs dPEA−35 [\( P < .001 \) for all]), except for iPEA−35 vs dPEA−35 (\( P = .37 \)) and iPEA−95 vs dPEA−95 (\( P = .26 \)).

When the eyes that had undergone PEA in different surgical settings were compared, the CE-MRI findings were classified into 3 distinct patterns (Figure 1C-E). Most commonly, Gd-DTPA was localized in the AC and PC, whereas the dark anterior vitreous cavity formed a convex interface, suggesting that the AHM was attached to the posterior lens capsule (Figure 1C). The implanted intraocular lens was well depicted as a dark shadow within the capsular bag. This imaging pattern was designated as the “PC type” and was preferentially seen in the eyes receiving standard PEA (sPEA+35, sPEA+95, sPEA−35, and sPEA−95). Thus, all 10 eyes in the sPEA+35 and sPEA−95 groups and 8 of 10 eyes (80%) in the sPEA+35 and sPEA+95 groups were the PC type. In support of this observation, light microscopy demonstrated that the AHM was firmly attached to the posterior lens capsule at the region of the Wieger ligament in these eyes (Figure 2A).
Frequently, Gd-DTPA was found distributed in the space beneath the posterior lens capsule along with the AC and PC (Figure 1D). As clearly demonstrated by light microscopy, the AHM was detached from the posterior lens capsule in this type of eye (Figure 2B).\textsuperscript{25} This imaging pattern was designated as the “AHM detachment (AHD) type” and had a relatively strong association with eyes that received prolonged irrigation or repeated deflation and inflation (Table 1). Three of 10 eyes (30%) in the iPEA−35 group, 5 of 10 eyes (50%) in the iPEA−95 group, 6 of 10 eyes (60%) in the dPEA−35 group, and 7 of 10 eyes (70%) in the dPEA−95 group were the AHD type. The rest of the eyes in these groups were the PC type. The AHD type was infrequently seen in the eyes that underwent standard PEA.

In 2 of 10 eyes (20%) in the sPEA−35 group and 1 of 10 eyes (10%) in the sPEA+95 group, a large amount of Gd-DTPA was found to have spread into the vitreous cavity (Figure 1E), indicating that the AHM was disrupted somewhere around the posterior lens capsule. Pathological examination disclosed tear formation in the AHM that did not affect the posterior lens capsule (Figure 2C). This imaging pattern was designated as the “AHM tear (AHT) type” and was not seen in any eyes undergoing PEA without hydrodissection. When we directly dissected 1 of the eyes with the AHT type under the surgical microscope, a round tear was discovered in the AHM when we peeled away the intact posterior lens capsule (Figure 3). The location of the tear strongly suggested that this event occurred at the attachment site of the Wieger ligament.

When risk factors for AHD or AHT, such as the height of the bottle, hydrodissection, prolonged irrigation of the AC, and repeated deflation/inflation of the AC, were assessed using logistic regression analysis, prolonged irrigation of the AC and repeated deflation/inflation of the AC (\(P<.001\) for both) were significantly associated with AHD, whereas hydrodissection (\(P=.04\)) was significantly correlated with AHT, as the data demonstrate in Table 2.

\textbf{COMMENT}

From the analysis of CE-MRI findings, we have demonstrated that the PC-AHM barrier was disrupted in some cases owing to the abnormal elevation or fluctuation of IOP during the surgery. There were 2 distinct, abnormal MRI patterns, including the AHT type in which the AHM was torn near the Wieger ligament, and the AHD type in which the AHM was totally detached from the posterior surface of the lens.

The AHT type was observed in a small number of the eyes receiving standard PEA. This type was found only in the eyes undergoing standard PEA with hydrodissection at either bottle height (sPEA+35 and sPEA+95) and was not seen in the eyes undergoing standard PEA without hydrodissection (sPEA−35 and sPEA−95). Thus, hydrodissection can be considered to be the most probable causative factor in eyes of the AHT type because the IOP becomes highest at this stage during PEA.\textsuperscript{26} In support of this assumption, a significant correlation between AHT and hydrodissection was shown by logistic regression analysis. In the presence of the injected viscoelastic materials, the increased IOP may place great stress on the Wieger ligament, forming a tear in the AHM.
In fact, using a specially designed side-view technique, we have observed that the AHT occurred near the Wieger ligament during hydrodissection in enucleated porcine eyes (data in preparation by S.K.).

The AHD type was frequently seen in the eyes that received prolonged irrigation or repeated inflation/deflation of the AC, and this association was found to be significant by logistic regression analysis. This finding suggests that continuous elevation or abrupt fluctuation of IOP may place stress on the Wieger ligament and induce a total detachment of the AHM. In fact, the detachment of the AHM can be artificially created by increasing the IOP with intracameral injections of irrigating fluid as first reported by Ikeda et al,27 who applied this technique in removing vitreous hemorrhage attached to the posterior lens capsule. Later, Torii et al25 reported that the intentional detachment of the AHM was possible in about half of the patients on the basis of endoscopic observation.

Although the PC-AHM barrier can be disrupted in 2 different ways, these events do not always lead to the onset of suppurative endophthalmitis, because suppurative endophthalmitis requires microbial contamination in the aqueous humor. Of the 2 patterns, the AHT is apparently more dangerous, because microorganisms can enjoy direct access to the vitreous cavity through the tear in the AHM. In the case of AHD, microorganisms need to be not only in the vitreous cavity but also virulent if they are to attach to and penetrate the AHM. Further studies using an animal model are under way in our laboratory to investigate whether bacterial endophthalmitis can occur in eyes with AHT or AHD.

Contrast-enhanced MRI has been widely used to determine the pharmacokinetics of drugs in periocular and intraocular implants19 or to detect Gd-DTPA after local administration.20-22 As shown in this study, the distribution patterns of the irrigating fluid associated with various PEA procedures can be well illustrated in sagittal images. This method is noninvasive and relatively easy to perform and probably would be useful for studying the fluid dynamics of in vivo eyes undergoing intraocular surgery or estimating the pharmacodynamics of small molecules such as antibiotic agents.

On the other hand, there are some limitations in interpreting our results because our study was conducted on enucleated porcine eyes. For instance, because physiological aqueous flow was absent, the distribution of Gd-DTPA as revealed by MRI may be different to some degree from that in actual human eyes. In addition, the structural integrity of the anterior segment may have been somehow impaired, although all eyes were properly stored and used within 12 hours after death.


