Objective: To determine the association of changes in anterior chamber angle and anterior chamber depth (ACD) with intraocular pressure (IOP) reduction after uncomplicated phacoemulsification.

Methods: In this prospective study, subjects underwent phacoemulsification with foldable lens implantation. Anterior chamber angle grading of 2 or less (Shaffer grading) in 3 or all quadrants was considered narrow angle (NA). Anterior segment optical coherence tomography and tonometry were performed preoperatively and 10 days and 1, 3, and 6 months after surgery. The ACD and angle opening distance at 500 µm anterior to the scleral spur (AOD500) were assessed from anterior segment optical coherence tomography.

Results: Data were collected from 63 eyes that underwent cataract surgery. Twenty-six eyes were classified as having NA. Before surgery, the mean (SD) AOD500 and ACD in the NA group were 0.179 (0.014) mm and 2.23 (0.07) mm, respectively. Six months after surgery, the mean (SD) AOD500 and ACD in the NA group were 0.389 (0.025) mm and 3.75 (0.05) mm, respectively. The postoperative IOP was reduced significantly in both groups. We found that each 0.1-mm increase in AOD500 corresponded to a mean (SD) 0.42 (0.18)–mm Hg decrease in IOP (P < .001) in the NA group and 0.32 (0.16) mm Hg (P = .046) in the OA group.

Conclusions: Postoperative reduction in IOP was proportional to the increase in angle in both groups, but the IOP reduction per 0.1-mm increase in AOD500 in NA eyes was greater than that in OA eyes.

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It is well known that narrowing of the anterior chamber angle (ACA) is the fundamental mechanism for the development of acute primary angle closure and chronic primary angle-closure glaucoma.1,2 Studies based on advanced imaging have demonstrated that the crystalline lens has an important role in the narrowing of the angle by pushing the peripheral iris anteriorly, in particular with the cataractous lens. Lens extraction for angle-closure and associated glaucoma has increasingly become a plausible alternative and is gaining popularity, especially in Asia.3-9

Numerous studies have demonstrated that intraocular pressure (IOP) is reduced after phacoemulsification with intraocular lens (IOL) implantation in eyes with narrow-angle (NA) glaucoma and open iridocorneal angles. The amount of IOP decrease seems to be inversely related to preoperative anterior chamber depth (ACD).10-18 The correlation between narrow iridocorneal angle widening and IOP reduction after cataract surgery has not been thoroughly investigated.

Anterior segment optical coherence tomography (AS-OCT) has been shown to be effective in assessing ACA structures. Examples of ACA variables that can be assessed by AS-OCT include angle opening distance (AOD), ACD, trabecular iris surface area, and angle recess area, often by using customized software.21-24

We conducted a prospective study to evaluate the effect of cataract extraction by phacoemulsification on the anatomy of the drainage angle in narrow iridocorneal angle eyes. The results were compared with those in eyes with open iridocorneal angles that had the same procedure. The association of IOP reduction after phacoemulsification and the change in the iridocorneal angle width as assessed by AS-OCT was also evaluated.
DATA COLLECTION

Institutional review board approval was obtained from the University of California, San Francisco, Committee on Human Research. Written informed consent was obtained from all the participants. Patients were recruited from the glaucoma service at the University of California, San Francisco, between March 1, 2009, and July 31, 2010. Eyes with open angles (OAs) were defined as those with Shaffer grades of 3 or 4 in 3 or all 4 quadrants. Eyes with NAs were defined as those with Shaffer grades of 2 or less in 3 or all 4 quadrants, as described previously. Patients who had previously undergone laser peripheral iridotomy were recruited if they met the criterion of NA. All the participants possessed visually significant cataracts and had best-correction visual acuity of less than 20/40 in the affected eye. The exclusion criteria included previous penetrating surgery, complications related to the cataract surgery (such as posterior capsular rupture and vitreous loss, primary or secondary glaucoma, and peripheral anterior synechiae), glaucomatous optic neuropathy, topical glaucoma therapy, and loss to follow-up. Optic nerves graded as having a cup-disc ratio greater than 0.6 (vertical meridian) were also excluded from this study. To maintain image quality, eyes with substantial corneal abnormality such as edema, dystrophy, abrasion, marginal degeneration, or pterygium were also excluded. Glaucoma was diagnosed according to the International Society for Geographical and Epidemiological Ophthalmology.

PREOPERATIVE AND POSTOPERATIVE EVALUATION

Preoperative evaluation included slitlamp examination, visual acuity testing, routine fundus examination, gonioscopy, and IOP determination. The IOP was measured using Goldmann applanation tonometry by a single observer (S.C.L.). We checked patients in a narrow period of the day (1-3 PM) to avoid the effect of diurnal IOP fluctuation. Two values were assessed, and the average value was used for analysis. If the 2 values differed by more than 2 points, then a third value was obtained, and the middle figure was chosen as the measurement. Gonioscopy was performed using a Zeiss-style 4-mirror gonioscopic lens (model OPDSG; Ocular Instruments Inc, Bellevue, Washington) by a single glaucoma specialist physician (S.C.L.) in a dark room. Angles were graded based on the Shaffer method in all 4 quadrants (superior, nasal, temporal, and inferior). Funduscopy was performed using +90° and +20-diopter lenses. When funduscopy was impossible, the posterior segment was evaluated using B-scan ultrasonography. Follow-up time points included preoperative and 10 days and 1, 3, and 6 months after surgery.

AS-OCT FINDINGS

Images of the anterior segment were obtained using a commercially available AS-OCT device (Visante OCT; Carl Zeiss Meditec Inc, Dublin, California) by 2 experienced operators (G.H. and E.G.) who were masked to the results of the clinic ophthalmology. A detailed description of the AS-OCT’s functionality has been previously discussed. Standard-resolution scans captured the temporal and nasal quadrants (nasal-temporal 0°-180°) in 1 image with participants looking straight ahead and having a good central corneal reflex. All the images were taken in the same dark conditions (0-1 lux by digital light meter [EasyView model EA30; Extech Instruments Inc, Walling, Massachusetts]) with patients in a sitting position. After several scans were acquired, the operator selected the best image with no motion artifacts or image artifacts from the eyelids. Assessment of the superior and inferior quadrants often requires manual manipulation of the eyelids, which may distort the angle. To prevent systematic bias in angle assessment of groups of patients who may require eyelid manipulation, only images of nasal and temporal quadrants were included in this study.

Images were analyzed using the Zhongshan Angle Assessment Program (ZAAP, Guangzhou, China), which has been shown to have good reproducibility for iris measurements. Initial attention was focused on quality control of the images, especially for NAs. Images in which we could not clearly detect the scleral spur were removed from the analysis because quantitative evaluation of the anterior chamber variables by AS-OCT depends on correctly identifying the scleral spur as the landmark. To prevent mechanical influence on the angle due to the temporal clear corneal tunnel incision of phacoemulsification for cataract, only the nasal quadrant image of AS-OCT was chosen to be analyzed in this study.

SURGICAL TECHNIQUE

All the operations were performed by the same surgeon (S.C.L.) using conventional surgical procedures. In brief, eyes were prepared for surgery by instilling tropicamide, 0.5%, and phenylephrine hydrochloride, 10%, for pupil dilation, and tetracaine hydrochloride, 0.5%, for topical anesthesia. All the surgical procedures were undertaken using a 3.2-mm temporal clear corneal tunnel incision. After the incision, the continuous curvilinear capsulorhexis measuring approximately 5.5 mm in diameter was performed using a cystitome and Utrata forceps. Hydrodissection/hydrodilation, in-the-bag phacoemulsification using the divide-and-conquer technique, cortical aspiration, and insertion of a foldable acrylic IOL in the capsular bag were performed step by step. At the end of the operation, the surgeon always confirmed that the IOL was accurately implanted in the capsular bag. All the eyes received a single-piece acrylic IOL (model SA60AT; Alcon Laboratories, Fort Worth, Texas).

STATISTICAL ANALYSIS

All the data are reported as mean (SD). Longitudinal changes in ACD, AOD at 500 µm anterior to the scleral spur (AOD500), IOP, and the other continuous variables between 2 groups were compared statistically using linear mixed models. We also used linear mixed models to compare preoperative and postoperative values of each variable. In each case, before testing for differences between preoperative and postoperative values, we first tested whether the postoperative values of the variable under consideration showed statistically significant differences. Specifically, we fit models including an effect for each time point (10 days and 1, 3, and 6 months) and compared these with a model that collapsed all postoperative time points and contrasted these using the likelihood ratio test. We also compared the NA and OA groups within each time stratum. Differences in the preoperative and postoperative groups were assessed by testing the significance of the interaction term between time and group. Correlations between measurements taken on each eye over time and between the 2 eyes of each patient were addressed by the inclusion of random effects. Hypothesis testing was conducted using the likelihood ratio test. Differences between preoperative and postoperative values were analyzed and compared using the paired t test. P < .05 was considered statistically significant. Data analysis was conducted using a commercially available statistical package (R version 2.12 for Macintosh, R Foundation for Statistical Computing, Vienna, Austria).
Table 1. Demographic and Clinical Information for the Narrow-Angle and Open-Angle Groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Narrow-Angle Group</th>
<th>Open-Angle Group</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes, right/left, No.</td>
<td>14/12</td>
<td>18/19</td>
<td>.80a</td>
</tr>
<tr>
<td>Patients, M/F, No.</td>
<td>5/13</td>
<td>13/18</td>
<td>.37a</td>
</tr>
<tr>
<td>Age, mean (SD), y</td>
<td>77.22 (9.22)</td>
<td>78.13 (8.05)</td>
<td>.80b</td>
</tr>
<tr>
<td>CDE, mean (SD)</td>
<td>15.79 (4.86)</td>
<td>24.28 (3.30)</td>
<td>.17c</td>
</tr>
<tr>
<td>Axial length, mean (SD), mm</td>
<td>22.91 (1.23)</td>
<td>24.04 (1.25)</td>
<td>.03c</td>
</tr>
<tr>
<td>Inability to detect SS, No./Total No. (%)</td>
<td>6/32 (18.75)</td>
<td>5/42 (11.90)</td>
<td>.69a</td>
</tr>
</tbody>
</table>

Abbreviations: CDE, cumulative dissipated energy; SS, scleral spur.

a The χ² test was used for between-group comparison.
b The Mann-Whitney test was used for between-group comparison.
c The linear mixed-effects model was used for between-group comparison.

Table 2. Anterior Chamber Depth and Changes in Depth Induced by Cataract Surgery

<table>
<thead>
<tr>
<th>Variable</th>
<th>Narrow-Angle Group</th>
<th>Open-Angle Group</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior chamber depth, mean (SD), mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative</td>
<td>2.23 (0.07)</td>
<td>2.76 (0.08)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>10 d</td>
<td>3.72 (0.05)</td>
<td>3.96 (0.05)</td>
<td>.003</td>
</tr>
<tr>
<td>1 mo</td>
<td>3.76 (0.05)</td>
<td>3.93 (0.05)</td>
<td>.02</td>
</tr>
<tr>
<td>3 mo</td>
<td>3.75 (0.05)</td>
<td>3.94 (0.05)</td>
<td>.009</td>
</tr>
<tr>
<td>6 mo</td>
<td>3.75 (0.05)</td>
<td>3.95 (0.05)</td>
<td>.01</td>
</tr>
<tr>
<td>Changes in the depth, mean (SD), mm</td>
<td></td>
<td></td>
<td>&lt;.001</td>
</tr>
<tr>
<td>10 d</td>
<td>1.48 (0.04)</td>
<td>1.21 (0.06)</td>
<td></td>
</tr>
<tr>
<td>1 mo</td>
<td>1.53 (0.06)</td>
<td>1.18 (0.06)</td>
<td></td>
</tr>
<tr>
<td>3 mo</td>
<td>1.51 (0.04)</td>
<td>1.20 (0.06)</td>
<td></td>
</tr>
<tr>
<td>6 mo</td>
<td>1.52 (0.04)</td>
<td>1.20 (0.06)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1 shows the correlation between ACD deepening postoperatively and preoperative ACD; that is, shallower depth before surgery was associated with greater ACD increase after surgery. Although the relationship between ACD deepening and IOP change was not significant (P = .08), the trend was toward an inverse correlation (decrease of 0.083 mm Hg per 0.1-mm increase in ACD) of those 2 factors.

Table 3 gives the mean ACA widening after cataract surgery. The mean preoperative width of AOD500 in the NA group was found to be significantly shallower than that in the OA group (P < .001). Immediately after cataract surgery, the ACA widened significantly (P < .001), and no further significant change occurred throughout the postoperative period in each group (P > .05). The NA group had lower values, but they increased more. The mean (SD) change in AOD500 in eyes with NAs was 0.062 (0.021) mm larger than that in eyes with OAs (P = .003), and the percentage of widening in the NA group was almost twice that in the OA group. Six months after surgery, changes in AOD500 were significantly related to their respective preoperative variables in both groups (slope = −0.766 mm/mm, P < .001; slope = −0.785 mm/mm, P < .001; no evidence of a difference was seen in the slope in the NA group vs the OA group, P = .95). Figure 2 shows the correlation between postoperative ACA widening and preoperative ACA width in the 2 groups.

The mean IOPs and the changes in IOP are given in Table 4. Before surgery, no significant difference in IOP was noted between the 2 groups. After surgery, the mean IOP decreased significantly in both groups, and no further significant changes were found throughout the postoperative period in each group compared with 10 days after surgery. The NA group had higher IOP but dropped more so that the IOPs after surgery were approximately the same. The mean (SD) IOP reduction in the NA group was 1.07 (0.369) mm Hg more than that in the OA group after surgery (P = .004). Six months after surgery, the mean (SD) amount of IOP reduction was 2.75 (0.60) mm Hg (17.82%) in the NA group and 1.35 (0.47) mm Hg (9.60%) in the OA group (P = .004). The percentage of

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IOP reduction in the NA group was almost twice that in the OA group 6 months postoperatively. Finally, we assessed the relationship between AOD and IOP using a linear mixed-effects model with time and the AOD500 at each time point, together with interaction terms (and random effects to include the correlation between measurements longitudinally on the same eye and between the eyes of a given person). We found no evidence of interaction or of a difference between the postoperative times. In the NA group, we found that each 0.1-mm increase in AOD corresponded to a mean (SD) 0.47 (0.12)−mm Hg decrease in IOP (averaging across all 4 postoperative measurements) (P < .001) but that there was a significant effect of time as well (not all the change in IOP is attributable to changes in AOD). Restricting the analysis to the 6-month postoperative visit only (compared with preoperative value), the same results were found; in the NA group each 0.1-mm increase in AOD resulted in a mean (SD) decrease of 0.42 (0.18) mm Hg in IOP (P = .001). In the OA group, each 0.1-mm increase in AOD corresponded to a mean (SD) decrease of 0.32 (0.16) mm Hg (P = .046).

Axial length (from IOLMaster [Carl Zeiss Meditec Inc]) was not associated with IOP change (P = .33) or angle widening (P = .84). Figure 3 shows the anterior chamber configuration before and after surgery in NA and OA eyes.

The results of this study suggest that phacoemulsification with IOL implantation results in deepening of the central anterior chamber and widening of the ACA in NA and OA eyes based on quantitative assessment of AS-OCT imaging. Furthermore, these results suggest a correlation between IOP reduction and angle widening in the 2 groups. To our knowledge, this is the first study to demonstrate that the postoperative reduction in IOP is related to the increase in angle width after phacoemulsification for NA and OA eyes.

### Table 3. AOD500 and Change in Width Induced by Cataract Surgery

<table>
<thead>
<tr>
<th>Variable</th>
<th>Narrow-Angle Group</th>
<th>Open-Angle Group</th>
<th>P Valuea</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOD500, mean (SD), mm, nasal Preoperative</td>
<td>0.179 (0.014)</td>
<td>0.297 (0.019)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>10 d</td>
<td>0.399 (0.017)</td>
<td>0.427 (0.019)</td>
<td>.02</td>
</tr>
<tr>
<td>1 mo</td>
<td>0.405 (0.024)</td>
<td>0.452 (0.014)</td>
<td>.005</td>
</tr>
<tr>
<td>3 mo</td>
<td>0.403 (0.024)</td>
<td>0.452 (0.017)</td>
<td>.008</td>
</tr>
<tr>
<td>6 mo</td>
<td>0.389 (0.025)</td>
<td>0.451 (0.015)</td>
<td>.002</td>
</tr>
<tr>
<td>Changes in AOD500, mean (SD), mm, nasal 10 d</td>
<td>0.215 (0.018)</td>
<td>0.129 (0.024)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>1 mo</td>
<td>0.215 (0.019)</td>
<td>0.154 (0.020)</td>
<td>.003</td>
</tr>
<tr>
<td>3 mo</td>
<td>0.217 (0.023)</td>
<td>0.156 (0.020)</td>
<td>.003</td>
</tr>
<tr>
<td>6 mo</td>
<td>0.196 (0.023)</td>
<td>0.155 (0.021)</td>
<td>.003</td>
</tr>
</tbody>
</table>

Abbreviation: AOD500, angle opening distance at 500 µm anterior to the scleral spur.

aThe first 5 P values refer to comparisons between the narrow- and open-angle groups at each of 5 times; the last P value refers to the comparison of preoperative and postoperative anterior chamber depth. All of the P values are significant using linear mixed-effects models.
nonglaucomatous eyes. Wide variation in mean IOP reductions (1.1-13.5 mm Hg) have been reported in such studies. The present study also found wide variation in the IOP response in the study cohort. We found that the postoperative IOP was reduced significantly in both groups. Six months after surgery, the mean (SD) IOP reduction was 2.75 (0.60) mm Hg (17.82%) in the NA group and 1.55 (0.47) mm Hg (9.60%) in the OA group, which were significantly different between the 2 groups (P = .004). Phacoemulsification with IOL implantation seems to reduce IOP more in NA eyes than in OA eyes. There is potential clinical relevance of these findings to the treatment of patients with glaucoma. Patients with glaucoma who have more NAs before phacoemulsification may have greater IOP lowering afterward and a greater possibility of discontinuing 1 or more medications postoperatively. Perhaps a further clinical implication is that preoperative angle assessment is helpful in predicting the IOP benefit of cataract extraction.

The exact mechanism of this IOP reduction after cataract surgery is still not fully understood. Hypothetically, cataract surgery removes the anatomical cause of NAs, resulting in deepening of the ACD and widening of the ACA. It would be expected that access of aqueous
to the filtering portion of the trabecular meshwork would be improved due to widening of the drainage angle. The results of this study support this scenario as a likely contributory mechanism for IOP lowering. In both groups, the IOP reduction was statistically significantly associated with angle widening as assessed by AOD500, with the IOP reduction per 0.1-mm increase in AOD500 greater in NA eyes than in OA eyes. Nolan et al36 investigated the changes in angle configuration after phacoemulsification in 21 patients using AS-OCT and found that the mean AOD500 for the nasal quadrant (in dark conditions) increased from 243 to 457 µm, similar to the findings in the present OA group. Their study cohort included 7 eyes with iridotrabecular contact or peripheral anterior synchiae in 1 or more quadrants and 14 OA eyes. However, IOP information was unavailable to correlate with the degree of angle opening. In the present study, there was a trend toward greater IOP lowering with more ACD deepening, although it did not reach statistical significance (P = .08). Previous studies19,20 have supported a significant relationship. This slight discrepancy may be related to the mixed population of open and closed angles and the fact that the angle opening is a more significant factor than is central ACD increase.

Studies have also focused on changes in angle configuration after cataract surgery using either Scheimpflug or ultrasound biomicroscopic images and support the finding that IOP reduction is greater in angle-closure eyes. Hayashi et al10 demonstrated by Scheimpflug imaging that the width and depth of the ACA of angle-closure glaucoma and OA glaucoma increase significantly after cataract extraction and IOL implantation. They also found that the IOP decreased significantly after surgery and that the amount of reduction in the angle-closure glaucoma group was higher than that in the OA glaucoma and OA groups. However, no association was noted between ACA widening or deepening and IOP decrease in this study. Clinically, though, it is difficult to avoid image artifacts because the light of the rotating Scheimpflug camera often cannot penetrate the corneoscleral limbus.37,38 A study based on ultrasound biomicroscopy by Tham et al39 demonstrated that the mean AOD500 in pseudophakic primary angle-closure glaucoma eyes approached or exceeded the reported value in normal phakic eyes. The present findings agree with these studies, although they are based on different technologies for measurement of the anterior chamber configuration.

Although angle opening is an apparent mechanism that can partially account for IOP lowering, there are other potential contributory factors, such as ultrasound activation of cytokines, endogenous prostaglandin F2 release, and increase in aqueous outflow by expansion of the trabecular meshwork and lumen of the Schlemm canal. Wang et al40 demonstrated that phacoemulsification ultrasound activates the interleukin 1β/nuclear factor kappa B/endothelial leukocyte adhesion molecule 1 pathway, facilitating aqueous outflow and reduction in IOP. Mathalone et al41 suggested that the endogenous prostaglandin F2 released postoperatively may enhance uveoscleral outflow. Theoretically, postoperative shrinkage of the lens capsule can result in increasing posterior traction on the scleral spur, expanding the trabecular meshwork and lumen of the Schlemm canal.12,42,43

Figure 3. Anterior segment optical coherence tomography images show a narrow angle before surgery (A), angle widening after phacoemulsification and intraocular lens implantation in the narrow-angle eye (B), an open angle before surgery (C), and angle widening after phacoemulsification and intraocular lens implantation in the open-angle eye (D).
This study has important limitations. The cohorts were relatively small, with only 26 eyes that met the criterion for the NA group and 37 eyes in the OA group. In addition, a longer follow-up duration would provide more valuable evaluation of the long-term effects of phacoemulsification with IOL implantation in eyes with NAs.

In summary, phacoemulsification with foldable IOL implantation can significantly deepen the ACD, widen the anterior chamber drainage angle, and lower IOP in NA and OA eyes. The amount of IOP reduction was approximately 18% in NA eyes and 10% in OA eyes. The postoperative reduction in IOP was proportional to the increase in angle width in NA and OA eyes. Future studies will further help to elucidate the long-term relationship of the anterior chamber configuration and IOP after phacoemulsification with foldable IOL implantation.

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Author Contributions: Drs Huang and Gonzalez contributed equally to this article.

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Online-Only Material: This article is features in the Archives Journal Club. Go to http://www.archophthalmol.com to download teaching PowerPoint slides.

REFERENCES


Ophthalmic Images

Visualization of Bilateral Cataracts and Optic Neuropathy Secondary to an Electrocution Injury

Anjali S. Maheshwary, MD
Michael Goldbaum, MD

In the childhood Varivax vaccine, by contrast, a varicellalike rash occurred in approximately 4%, with a peak incidence 5 to 26 days after vaccination. The fact that varicellalike rashes are observed after vaccination with the live attenuated virus suggests that reactivation of varicella in any organ, including the eye, is physiologically possible.

Herein, we describe 2 cases of VZV-positive ARN in short temporal relation to the VZV vaccine. In the first instance, the retinitis was noted 6 days after vaccination, fitting with the time noted in the Shingles Prevention Study. This patient certainly could have developed ARN prior to vaccination, but the temporal relationship between vaccination and the rapid development of vision loss is suspicious.

In case 2, the patient was immunosuppressed from medications and exhibited disseminated varicella shortly after vaccination. His immunosuppression may have predisposed him to a systemic varicella infection and ARN (immunodeficiency and immunosuppression are contraindications to the vaccine). Despite intravenous antiviral therapy, the patient developed symptomatic ARN several weeks after vaccination. In both cases, it is unclear whether the viral retinitis represents reactivation of varicella or a primary infection from the vaccine strain virus. As detection of the vaccine strain virus is rare in patients who develop a varicella rash after vaccination, it is more likely that these represent reactivation of varicella. In the second case, however, infection from the vaccine strain virus is possible given the presence of immunosuppression.

In conclusion, we report 2 cases of ARN following varicella vaccination. While postimmunization infections are rare, clinicians should be aware of this potential complication of vaccination.

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