Optimal Size and Location for Corneal Rotational Autografts

A Simplified Mathematical Model

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Objective: To calculate clinical guidelines for the optimal location and size of a rotational autokeratoplasty.

Methods: The ideal graft size and trephine decentration for a rotational autograft were calculated based on scar location using geometric models. Mathematical variables were set to maximize postoperative visual acuity and for generalization of the geometric model. This model was used in a rotational autokeratoplasty of a patient with a history of a corneal scar and diplopia. An 8-mm autograft was decentered 0.5 mm superiorly and rotated 180° to relocate the scar to the superior aspect of the cornea, out of the patient’s vision.

Results: For cases that satisfy the given variables, a graft diameter of 8 mm with a decentration of 0.5 mm balances maximization of scar removal and scar movement superiorly, with minimization of discrepancy in corneal thickness after rotation. For scars that are α° from horizontal, the graft should be rotated 180° − α°. By using these calculations, the autograft in this case successfully resolved the diplopia and improved visual acuity.

Conclusions: A rotational autograft can be an effective alternative to standard penetrating keratoplasty for some patients with corneal scars. We establish a mathematical model for most clinical instances of a rotational autograft, in which an 8-mm graft with a decentration of 0.5 mm best satisfies the goals of surgery.

Arch Ophthalmol. 2006;124:410-413

Central Corneal Opacities, such as scars secondary to perforating corneal injuries, may severely reduce visual acuity. In these situations, a penetrating keratoplasty is usually indicated. Penetrating keratoplasties are the most commonly performed organ transplantation in the United States, yet the risk of rejection and graft failure can be high, especially in younger patients.1,2 The advantages of using the patient’s own cornea for corneal transplantation were first appreciated in 1908.3 The procedure has been performed using either the ipsilateral or the contralateral cornea.2-18 The main advantages of using autokeratoplast are that there are no immunological problems, healing time is reduced, corticosteroids are not needed as frequently, and donor corneas are not necessary.2-18

Autokeratoplasty using the contralateral eye has been used relatively infrequently because the set of circumstances that indicate this procedure are rare (ie, the patient must have a nonfunctioning contralateral eye with a clear cornea).3,4 Several authors have suggested the use of different geometric shapes for the ipsilateral autokeratoplasty, such as a triangle,2 a rectangle,7 or a figure eight4,8,9; however, none have replaced the standard circular graft with an eccentric center.6,10-16 In this form of penetrating keratoplasty, the area of clear cornea is placed in the geometric center of the cornea and the opacity is rotated toward the limbus. The objective is to achieve the largest possible optically clear zone.

There are few reports of ipsilateral rotational autografts because of its limited indications and the lack of a clear and easily understandable model. The goal of this article is to provide a brief, easily applicable, and clinically relevant set of guidelines and tables that surgeons can reference to perform rotational autografts. Specifically, we want to identify the amount of decentration, the size, and the angle of rotation for a corneal rotational autograft. The calculations in this article aim to minimize the following variables: (1) the decentration of the graft, (2) adjacency of the graft edge and sutures in the visual axis, (3) the scattering of light by the scarred corneal area, and (4) the discrepancy between peripheral and central corneal thickness. One last goal of the calculations is to maximize the amount of scar tissue mobilized.
A 21-year-old man was first seen at the Massachusetts Eye and Ear Infirmary after a ruptured globe wound repair. When he was first seen, he had undergone multiple procedures, including anterior segment repair, pupilloplasty, iridotomy, lenectomy, vitrectomy, cryotherapy, and scleral buckling for retinal detachment. This patient could not tolerate aphakic contact lenses, and complained of diplopia and triplopia. He was referred for secondary intraocular lens placement and corneal transplantation. He had an uncorrected visual acuity of 20/15 OD and counting fingers OS. The anterior segment examination was remarkable for a large left corneal scar, extending from limbus to limbus and involving the visual axis (Figure 1A). The patient provided written informed consent for surgery, and institutional review board approval was unnecessary in this case. The patient's cornea was trephined with a 0.5-mm superior edge and the edge of the cornea (Figure 1B). The final placement and corneal transplantation repair, pupilloplasty, iridotomy, and scleral buckling for retinal detachment. The 8.0-mm autograft was rotated approximately 180° to relocate the scar to the superior aspect of the cornea, above the eyelid and pupillary margin (Figure 1B). The patient tolerated the procedure well, without any complications. During the second postoperative week, he had a corrected visual acuity of 20/70 OS, with resolution of diplopia and triplopia.

Mathematical models and geometric calculations were formulated (Figures 2, 3, 4, and 5) to calculate the ideal autograft size. We made the following assumptions to permit generalization of our model (Figure 2).

1. The pupil is centered on the geometric center of the cornea, and the vertical length of the cornea is 11 mm.
2. X is the radial distance from the corneal center to the scar; r, the radius of the corneal autograft; and E, the amount of decentration (in millimeters).
3. The distance between the graft edge and the edge of the cornea (L) should be at least 1 mm, to allow enough room for the sutures to be placed.
4. The minimum distance between the center of the cornea and the graft edge (Y) should be at least 3 mm, to allow the edge of the scar to be outside the visual axis.
5. The length of scar removed (S) should be at least 5 mm, so that enough scar is removed for the procedure to be beneficial to the patient.
6. The scar should be able to be rotated so that it is superior to the eyelid margin or the pupillary margin (distance D, measured from the corneal center), whichever is smaller. This prevents the scar from remaining in the visual axis after it is rotated.

Based on Figure 2, we derived geometric equations for the amount of decentration (E) and autograft size.

Combining 2 equations, \( Y + E = r \) and \( E + L + r = 5.5 \text{ mm} \) (half of the normal corneal diameter of 11 mm), yields the following equation:

\[
Y + 2E + L = 5.5 \text{ mm}.
\]

Because \( Y > 3 \text{ mm} \) and \( L > 1 \text{ mm} \), then \( E < 0.75 \text{ mm} \); and because

\[
E < 0.75 \text{ mm}, \quad L > 1 \text{ mm}, \quad \text{and} \quad E + L + r = 5.5 \text{ mm}, \text{ then } r > 3.75 \text{ mm}.
\]

By using these equations, we find that a decentration of 0.75 mm requires a graft size of 7.5 mm; for a decentration of 0.5 mm, the graft size can be 8 mm. A graft size of 8 mm and a decentration of 0.5 mm best satisfies the goals of maximizing scar removal, minimizing discrepancy in graft and corneal bed thickness (which can create unwanted astigmatism), and maximizing the distance the scar is superiorly mobilized.

The amount of scar removed is analyzed in Figure 3. A perpendicular line can be drawn from C (the center of the cornea) to the scar, which geometrically divides the amount of scar removed in half (0.5S). Therefore, using r, 0.5S, and the perpendicular line drawn from the center, a right triangle can be formed, and the Pythagorean theorem can be used to determine the amount of scar removed. Table 1
Figure 4. Sample calculations of S, Y, and L values for different graft sizes for cases of X = 2 mm. The asterisk indicates that an 8-mm graft satisfies all 3 requirements for S, Y, and L. All abbreviations are explained in the legend to Figure 2.

Table 1. Surgery Outcomes Showing Amount of S Removed Based on Different X and D Values, With a Graft Diameter of 8 mm and Decentration of 0.5 mm

<table>
<thead>
<tr>
<th>X Value, mm</th>
<th>2.0</th>
<th>2.5</th>
<th>3.0</th>
<th>3.5</th>
<th>4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>7.42†</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1.5</td>
<td>6.93†</td>
<td>6.93†</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2.0</td>
<td>Large central graft‡</td>
<td>6.24†</td>
<td>6.24†</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2.5</td>
<td>Large central graft‡</td>
<td>Large central graft‡</td>
<td>5.29†</td>
<td>5.29†</td>
<td>NA</td>
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<tr>
<td>3.0</td>
<td>Large central graft‡</td>
<td>Large central graft‡</td>
<td>Large central graft‡</td>
<td>3.87</td>
<td>3.87</td>
</tr>
<tr>
<td>3.5</td>
<td>Large central graft‡</td>
<td>Large central graft‡</td>
<td>Large central graft‡</td>
<td>Large central graft‡</td>
<td>0</td>
</tr>
</tbody>
</table>

Abbreviations: D, distance from the center of the cornea to the eyelid or pupillary margin; NA, data not applicable (the scar cannot be rotated superior to the eyelid or pupillary margin, and traditional keratoplasty is indicated); S, amount of scar that is mobilized by the graft; X, distance from the cornea center to the scar.

* S = 2 − (X cos α) − (E sin α), and D ≤ 2E + X, where E is the amount of decentration (in millimeters) and r is the radius of the graft.

† The length of scar removed is larger than 5 mm, and ipsilateral rotational autokeratoplasty is indicated.

‡ The scar can be rotated superior to the eyelid or pupillary margin without decentration; therefore, a large central graft is indicated using keratoplasty or autokeratoplasty.

Figure 5. Geometric proof that, in the case of a nonhorizontal scar, \( Z = 180 - \alpha \), using the following established variable: \( D = X + E \cos \alpha \). \( b \) indicates the opposite angle of the angle of scar from horizontal; \( C \), the center of the cornea; \( D \), the distance from the center of the cornea to the eyelid or pupillary margin; \( E \), the distance between the cornea center and the graft center; \( G \), the center of the graft; \( r \), the radius of the graft; \( X \), the distance from the cornea center to the scar; and \( Z \), the angle of scar rotation.

Table 3 gives the values for the distance that the scar will be moved superior to the center of the cornea and the amount of rotation to use with respect to different angles of scars; 0.5 mm was used as the decentration value.

Scars that are superior to the center of the cornea are treated similarly to nonhorizontal scars that are inferior to the center of the cornea. The scar angle is determined again by the angle from horizontal. The scar will be rotated \( \alpha \), not \( 180 - \alpha \), and the formula for the superior rotation of the scar becomes the following: \( X + E + E \cos \alpha \). Based on these equations, if there is a horizontal scar superior to the center of the cornea, then the scar cannot be rotated further superiorly and an ipsilateral rotational autokeratoplasty would not be appropriate. Also, a scar that runs through the center of the visual axis cannot be moved superiorly through surgical rotation. Therefore, a traditional keratoplasty is indicated for these special cases.

**COMMENT**

Ipsilateral rotational autokeratoplasty has many advantages over keratoplasty using a donor cornea. First, there is no risk of immunological rejection of the graft, which is a special concern in the pediatric population. Because there are no immunological risks, postoperative corticosteroids are not needed as frequently, which is an added advantage in many patients with long-standing ocular problems. Finally, autokeratoplasty is important in places where donor corneas are not readily available.

Our data show that an 8-mm graft with 0.5-mm decentration best satisfies the goals of surgery. This is because a decentration of 0.5 mm strikes a balance between maximizing superior movement of the scar and maximizing the amount of scar removed, and 0.5-mm decentration permits sufficient corneal tissue for confident su-
Table 2. Surgery Outcomes Showing Amount of S Removed Based on Different X and D Values, With a Graft Diameter of 7.5 mm (r = 3.75 mm) and an E Value of 0.75 mm

<table>
<thead>
<tr>
<th>X Value, mm</th>
<th>2.0</th>
<th>2.5</th>
<th>3.0</th>
<th>3.5</th>
<th>4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>6.63†</td>
<td>6.63†</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1.5</td>
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<td>6.00†</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2.0</td>
<td>Large central graft†</td>
<td>5.10†</td>
<td>5.10†</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2.5</td>
<td>Large central graft†</td>
<td>Large central graft†</td>
<td>3.74</td>
<td>3.74</td>
<td>3.74</td>
</tr>
<tr>
<td>3.0</td>
<td>Large central graft†</td>
<td>Large central graft†</td>
<td>Large central graft†</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Abbreviations: D, distance from the center of the cornea to the eyelid or pupillary margin; E, amount of decentration; NA, data not applicable (the scar cannot be rotated superior to the eyelid or pupillary margin, and traditional keratoplasty is indicated); r, radius of the graft; S, amount of scar that is mobilized by the graft; X, distance from the cornea center to the scar.

Table 3. Reference for the Distance That a Scar Is Moved Superiorly and the Z Value Based on Different α Values

<table>
<thead>
<tr>
<th>α Value, Degrees</th>
<th>Distance Moved Superiorly From Center of Cornea, mm*</th>
<th>Z Value, Degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1 + X</td>
<td>180</td>
</tr>
<tr>
<td>15</td>
<td>0.98 + X</td>
<td>165</td>
</tr>
<tr>
<td>30</td>
<td>0.93 + X</td>
<td>150</td>
</tr>
<tr>
<td>45</td>
<td>0.85 + X</td>
<td>135</td>
</tr>
<tr>
<td>60</td>
<td>0.75 + X</td>
<td>120</td>
</tr>
<tr>
<td>75</td>
<td>0.63 + X</td>
<td>105</td>
</tr>
<tr>
<td>90</td>
<td>0.50 + X</td>
<td>90</td>
</tr>
</tbody>
</table>

Abbreviations: α, angle of scar; X, distance from the cornea center to the scar; Z, angle of rotation.

* X = E + E cos α, where E is the distance between the cornea center and the graft center, and is 0.5 mm.

The analyses provided herein are based on defined variables. We intentionally set these variables to optimize clinical outcome. While the obtained values for decentration and graft size are consistent with previous reports, we provide a new mathematical model that provides clinicians with one simple guideline—in most cases, an 8-mm graft with a decentration of 0.5 mm will successfully rotate a corneal scar. Furthermore, we made reference tables designed to help the surgeon quickly decide whether an ipsilateral rotational autokeratoplasty is indicated.

If the distance from the graft center to the scar (X + E) is larger than the radius of the graft, then none of the scar will be removed because the scar lies outside of the graft. Fortunately, this problem will rarely appear because a scar that lies more than 3.5 mm from the center of the cornea is probably outside of the visual axis and will unlikely cause a visual problem. Our strategy also applies to nonhorizontal scars and scars superior to the central cornea, as previously described.

Our simplified mathematical model has important clinical implications. Ipsilateral rotational autokeratoplasty is not a widely used technique because of the limited indications and the lack of clear and easily understandable guidelines. This article simplifies the guidelines for autokeratoplasty. Physicians planning to perform ipsilateral rotational autokeratoplasty can use the tables in this article to determine when the procedure is indicated and to choose the ideal graft size and decentration. Ideally, this article will allow ipsilateral rotational autokeratoplasty to be performed more often.

Submitted for Publication: October 4, 2004; final revision received January 25, 2005; accepted January 25, 2005.

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Financial Disclosure: None.

Funding/Support: Dr Afshari is the recipient of a Career Development Award from Research to Prevent Blindness, New York, NY.

REFERENCES