LABORATORY SCIENCE

Comparison of the effect of LASIK parameters on the percent tissue altered (1-dimensional metric) versus percent volume altered (3-dimensional metric)

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Purpose: To determine the theoretical volumes of flap and tissue ablation altered during laser in situ keratomileusis (LASIK) correction of myopic refractive errors.

Setting: Rothschild Foundation, Paris, France.

Design: Experimental study.

Methods: The theoretical volumes of the flap and ablated corneal lenticules for spherical myopic corrections were calculated by mathematical approximations based on a simplified geometric model. These results were then compared for various zone diameters, dioptric corrections, and the percentage of the volumes altered (PVA) with the percentage of tissue altered (PTA).

Results: The volume of the flap varied linearly with flap thickness and with the square of the flap diameter. The volume of ablated corneal tissue was estimated to be proportional to the magnitude of myopia treatment and to the 4th power of the treatment diameter. For the same depth of ablation, the volume of tissue ablated can vary significantly, depending on the magnitude of the correction and the optical zone diameter. As a result, the PTA calculation is not predictive of the actual PVA.

Conclusions: The flap diameters and the laser correction were the most important determinants of the PVA altered during LASIK surgery. New models estimating the volume of the flap and corneal tissue might be necessary to determine their influence on corneal biomechanical stability and each procedure's outcome.

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For lamellar refractive surgery, it has been assumed that the residual stromal bed (RSB) thickness might be the critical factor in the cornea's postoperative biomechanics and stability. This concept was developed from empirical data and previous observations and promulgated without formal investigations. The concept of the percentage of tissue altered (PTA) was introduced by Santhiago et al.[1–3] and Santhiago[4] as a screening metric for refractive surgery candidates. The PVA is an estimation of the percentage of central corneal tissue modified during the creation of the laser in situ keratomileusis (LASIK) flap and subsequent stromal photoablation. It considers the relationship between preoperative corneal thickness, the tissue altered through excimer laser ablation and flap creation, and the ultimate RSB thickness.

In their study introducing the PTA, Santhiago et al.[1] investigated the association between the PTA and the occurrence of ectasia after LASIK in eyes with normal corneal topography. Their study included 30 eyes of 16 patients with bilateral normal preoperative Placido-based corneal topography that developed ectasia after LASIK and 174 normal eyes of 88 consecutive patients that had uneventful LASIK and at least 3 years of postoperative follow-up. In the ectasia group, a PTA of 40% or greater was the most prevalent risk factor (97%). This value was selected from receiver operating characteristic curves, which showed that a cutoff of 40% led to a specificity of 91% and a sensitivity of 87%. In a recent study comprising 593 eyes,[5] we assessed the specificity value of this PTA metric to 78.7%. In their paper, Santiago et al.[1] reported that all cases with a PTA value above 47% developed this complication. In our study,[5] 19 eyes (3.2%) that had a PTA above 47% did not develop ectasia after 2 years (mean 31 months) of follow-up.

The term *tissue* for the *T* in the acronym PTA suggests that a volume, not a simple thickness of the elements, is used in the calculation. However, the cornea is a

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3-dimensional (3-D) structure and its volume can be computed and expressed in volume units (mm^3). The quantity of tissue cut, as in automated lamellar keratoplasty, and the quantity of tissue photoablated, as in photorefractive keratectomy (PRK) or LASIK, can also be expressed as a volume instead of a distance. However, the metrics involved in PTA calculation correspond to axial (1-dimensional [1-D]) measurements and are expressed as a distance measured along the axis of symmetry of the system and in general given in microns. The measurements have been estimated using expected flap thicknesses or measured by ultrasonic pachymetry, optical coherence tomography, or Scheimpflug technology.

The goal of our current study was to establish the importance of the volume of tissue altered in LASIK surgery for myopia and evaluate how the PTA estimated from axial measurements predicts the percentage of volume altered (PVA), a new metric computed from the estimation of implicated modified tissue volumes. Can purely axial metrics predict with reasonable accuracy the ratios of tissue volumes implied in LASIK surgery? To our knowledge, the ratios between the volume of the cornea and that of the tissues involved in LASIK surgery have never been computed. This might allow clinicians to better appreciate the respective importance of the combined volume of the LASIK flap incised plus the removed (photoablated) corrective lenticule on the corneal tissue.

MATERIALS AND METHODS

Preliminary Considerations for Theoretical Volume Calculations

Figure 1 shows the formulas using the various parameters that enable the computations for the tissue volumes required for this study. When the corneal surface is modeled as a spherical cap, its cross-section profile is an arc of circle. The sagittal height, denoted s, is the distance of the highest point of the arc from the midpoint of the chord. This parameter is necessary for volume calculations. Using the Pythagorean theorem, the sagittal height can be computed from the radius of curvature (r) of the considered spherical cap and its base radius (half of the chord), denoted d.

$$s = r - \sqrt{r^2 - d^2} \tag{1}$$

The anterior and posterior corneal surfaces are modeled as spherical caps of respective radii or curvature R_a and R_p. Each cap would correspond to the region of a given sphere, both of which lie above the same plane; here, we assume the plane is that of the limbus.

The volume of a cap (V_{cap}) is equal to

$$V_{cap} = \frac{1}{6}\pi s(3d^2 + s^2) \tag{2}$$

and its surface (S_{cap}) is given by

$$S_{cap} = \pi(d^2 + s^2) \tag{3}$$

The formula producing the volume of a cylinder of radius d and height h is

$$V_{cyl} = \pi h d^2 \tag{4}$$

These formulas allow one to calculate the volume of the cornea contained within a concentric cylinder and the volume of a LASIK flap of constant thickness within a specified diameter zone.

Volume Calculations

Corneal Volume The corneal flap volume was approximated as the volume contained between 2 spherical surfaces of different radii of curvature (anterior surface radius R_a; posterior surface radius R_p) whose apical distance is the central corneal thickness t_c. Figure 2 shows the parameters used for this calculation, which was restricted to the corneal volume contained within a cylindrical section C1 of radius d_p (semi chord of the posterior corneal surface) and height equal to ($s_p + t_c$) where s_p is the sagittal height of the posterior surface and t_c the central corneal thickness. The volume of C1 is equal to

$$V_{c1} = \pi\left(s_p + t_c\right)d_p \tag{5}$$

The corneal volume can be computed as the difference between the total volume of the cylinder C1 and 2 hollow volumes delineated by the cylinder base and the posterior corneal surface as boundaries for the first empty volume and by the cylinder top and the anterior corneal surface as boundaries for the second empty volume

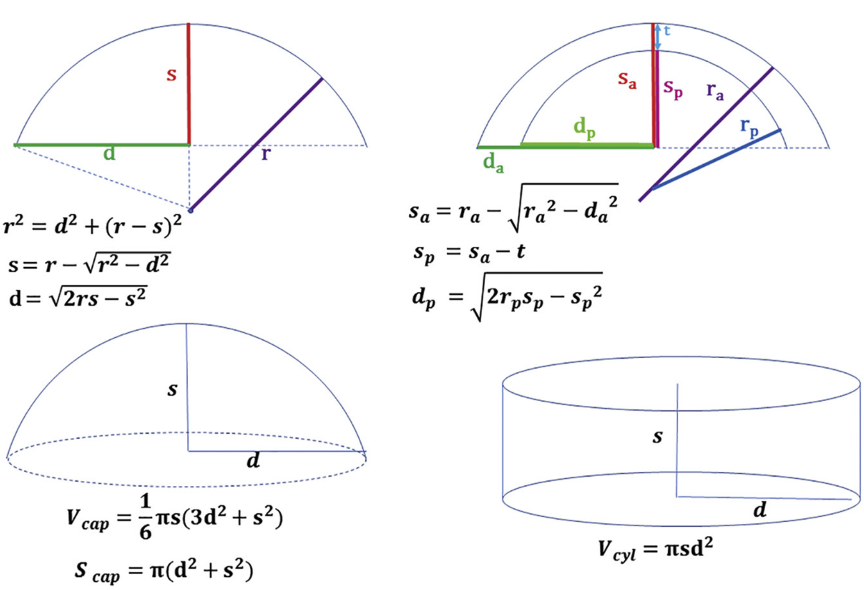

Figure 1. Basic geometric elements and primitives used in volume calculations. The corneal profile can be modeled as an arc of a circle of radius r and hemi chord d, from which the sagittal height s can be computed (*top left*). These calculations can be applied to both the anterior corneal profile (radius r_a, sagittal height s_a, and hemi chord d_a) and posterior corneal profile (radius r_p, sagittal height s_p, hemi chord d_p) (*top right*). A corneal surface can be modeled as a spherical cap, the region of a sphere that lies above the limbal plane. Its volume can be computed from the sagittal height s and base radius d (*bottom left*). The volume of a cylinder can be computed from the values of its height s and base radius d (*bottom right*). (See text for full description of the formulas.)