THE PURPOSE OF THIS CHAPTER is to confirm and enlarge some observations which have been published previously, especially in our preliminary reports of 1949 (2) and of 1958 (3).

EARLIER WORK

In 1949, after a series of experiments, we published a preliminary report (2) in which we described, for the first time, the intracorneal inclusion of a lenticule to modify refraction of the ocular globe. This lenticule included in the thickness of the cornea would act mainly to modify the curve of the anterior face of the cornea but also, independently, as a lens, in accordance with its index of refraction.

At first we experimented on cats and rabbits by introducing in a corneal pocket a biconvex Flint Glass lens, 6 mm. in diameter and with a power of 10 positive diopters. In these cases the tolerance was bad, due to the compression exerted by the periphery of the lenticule, which was flat, on the anterior layers of the cornea, causing in a more or less long period of time necrosis of the same layers and the subsequent elimination of the lenticule.

To prevent this inconvenience, small menisci of the same
material were included in the thickness of the cornea, with concave bases of an equal radius of curvature as that of the cornea at the level of the inclusion, which was calculated to be 0.3 mm. shorter than the radius obtained from an ophthalmometric reading of the anterior face. These lenticules, 5 mm. in diameter, were well tolerated, modifying the radius of curvature of the anterior face of the cornea in proportion to its dioptric power, but somewhat later they caused, in all cases, edema of the anterior corneal layers with formation of vesicles in the epithelium, vascularization, and in some cases, necrosis with ulceration, either aseptic or septic by secondary infection, and belated elimination of the lenticule, unless this was prevented by the neoformation of a highly vascularized, opaque tissue. The posterior layers of the cornea, situated behind the lenticule, remained transparent in all cases if they were not involved by the septic complication.

With the advent of Ridley’s lens, we again tried the same intracorneal menisci, which this time were made of Plexiglas. In all cases, loss of the transparency of the anterior layers of the cornea, more or less belated, or elimination of the lenticule, occurred through the processes already described.

These observations provided proof of the fact that the main cause of intolerance of these intracorneal implants is of a physical nature, being determined by the lens as an obstacle which hinders the metabolic exchange between the posterior and anterior layers of the cornea, and only in this sense, since the transparency of the posterior layers was maintained in all cases in which superadded septic complications did not occur. However we do not overlook the possibility of intolerance due to the chemical conditions of the included material.

Guided by these principles, we tried with E. Ariza (1) large size interlamellar inclusions, with a large central perforation for the purpose of not altering the metabolism of the optic zone, and with a curve different than that of the cornea, for the purpose of modifying it and of altering its refractive power. All these inclusions were eliminated, in our opinion, because of the compression they exerted, as being different in shape and greater in size.
From the study of these experiments we concluded that a foreign material, to be tolerated by the cornea, in addition to being chemically inactive, should also be of such a nature that it does not hinder the circulation of the intracorneal fluids and does not submit the cornea to extreme pressure or tension. The solution was in the use of an inclusion chemically inactive, of an adequate form, of very small dimensions, or of a material permeable to the interstitial fluids of the cornea.

In accordance with these conclusions we used for intracorneal inclusion disks in the form of menisci, of an adequate radius of curvature, made with a semipermeable material: semi-hydrated celloidin. The tolerance to celloidin was perfect with regard to the circulation of intracorneal fluids, preservation of transparency of the anterior layers, and lack of alterations in the epithelium, but in all cases a late reaction of intolerance to the foreign body occurred, which was characterized by vascularization of the corneal layers situated in front of and behind the lenticule, and which was attributed to the chemical characteristics of the included material.

During the time we were studying the possibilities of modifying the properties of celloidin, or else of finding some other semipermeable material which could be totally inert, we advanced in another branch of our research by developing a more perfect technique for obtaining the lenticules of corneal tissue (5).

It is obvious that the best material to be included in the cornea is the corneal parenchyma itself, for its physical characteristics of permeability, consistency, etc., as well as for its biological and chemical characteristics.

Although we thought we had obtained the lenticule of the most adequate material, the inclusion of lenticules of homoplastic cornea presented multiple problems still to be solved, such as the following: (1) Would the cornea retain its transparency notwithstanding the change of parallelism between its own fine lamellae and those of the lenticule? (2) Would the lenticule be reabsorbed after a more or less long period? (3) Would the reconstitution of the lenticule by living cells of the recipient be possible even though there is no continuity between the fine
lamellae of the recipient cornea and those of the lenticule? (4) Would the cornea modify its form and in this case would it be at the expense of its anterior or of its posterior face, and to what degree and to what limits? (5) What would be the most suitable dimension for the inclusion? The solution to these unknowns has been the object of our experiments in this field and the purpose of this chapter is to report the results obtained.

**Experimental Work—Rabbits**

**Inclusions of Corneal Lenticules**

After having tried this technique in pigs, dogs, guinea pigs, and rabbits, we decided to limit our experiments only to rabbits, because although the thinness of their cornea is an inconvenience in lamellar surgery, other characteristics which have made this animal the most popular in laboratories abundantly compensate for the greater difficulty of the surgical technique.

The technique followed for the intracorneal inclusion of lenticules of corneal tissue has been similar in all cases: (1) Intravenous general anesthesia with phenobarbital and pentobarbital; local anesthesia by instillation of epinephrinized cocaine collyrium. (2) Plastic-covered operative field, with an opening the size of the palpebral fissure. (3) Colibri blepharostat. (4) Four scleral stitches for fixation of the globe to the blepharostat. (5) Rectilinear incision of the cornea at about 2 or 3 mm. from the limbus in front of the insertion of the superior rectus muscle, 5 to 6 mm. in length and more or less deep, according to the situation in which we wish to place the inclusion (Figure 1A). (6) Dissection of an interlaminar pocket, maintaining a uniform plane of dissection as much as possible. Dissection was carried out sometimes with a piriform spatula, at other times with Bonnet's dissector of synechiae, or with scissors and, finally, with a new dissector especially adapted to the characteristics of eyes of rabbits, which simplifies the operation considerably (Figure 2). The corneal pocket should be wider at the area of the pupil than at the opening of entrance, and its bottom should be centered with the pupil (Figure 1B). (7) Introduction of the lenticule, previously cut and prepared, with its convex face to-
FIGURE 1. Technique of interlamellar inclusion: (A) nonperforating rectilinear incision, (B) dissection of the pocket, and (C) inclusion of lenticule.

ward the front. Extension of the lenticule and centering it with aid of a spatula (Figure 1C). (8) The incision is not sutured unless it remains slightly open, and in this case, one or two stitches of virgin silk are sufficient. (9) We used homoplastic fresh and silico-desiccated lenticules, 6 and 7 mm. in diameter, on the basis of: (a) The experience in keratoplasty in human eyes, which has fully demonstrated that these dimensions are the most favorable. (b) This dimension allows for obtaining lenticules of a relatively high refractive power and with a moderate thickness which is compatible with the thickness of the donor material. (c) It is the minimal dimension which permits obtaining a reasonably exact postoperative ophthalmometric measurement, and also the fact that the edges of the lenticule are somewhat far from the reading zone.

We used ophthalmometers which effect the measuring in spots which are separated from each other by from 2 to 4 mm.

FIGURE 2. Dissector of interlamellar pockets (J. I. Barraquer).
We included positive lenticules between +5.00 and +10.00 diopters and negative lenticules of −5.00 diopters.

To evaluate the approximate refractive value of the corneal lenticules we used a simplified method, which consists of accepting as power of the lenticule the difference existing between the dioptric value of its anterior and posterior faces, considering for the posterior face not its actual value but rather the value of a curve parallel to it at a point where the lenticule has no thickness (Figure 3).

![Figure 3](https://via.placeholder.com/150)

**Figure 3.** As dioptric value of the utilized lenticules, the difference between the value of the anterior face of the lenticule and that of a curve parallel to the posterior face was accepted, as if the lenticule had no thickness (dotted line in schema). (*AO* = radius of the anterior surface. *BO* = radius of the posterior surface. Dotted line = calculated power.)

The turning of the posterior face with the lathe is evaluated, keeping in mind the increase of thickness that the corneal tissue undergoes during freezing. Being approximate, the technical data are considered of little interest and their description in detail will be given in a later section rather than here.

**POSTOPERATIVE COURSE**

The postoperative course is extremely simple in all cases. The eye remains without hyperemia and, seen with the naked eye, the cornea appears perfectly transparent, or it shows a very thin veil due to edema in the zone in which the pocket was dissected; this edema disappears in 8 or 10 days. The lenticule is almost invisible. With oblique illumination, its presence can be
noticed by the shadow it projects on the iris. In some cases even
the edges of the lenticule can be seen. Sometimes it is also pos-
sible to notice the effect of magnification or reduction by com-
parative examination of the crypts and delineations of the iris,
through the lenticule and the corneal periphery.

Profile examination shows central turgescence of the an-
terior corneal layers similar to a small keratoconus in cases of
positive inclusion, and in the periphery of the lenticule in cases of
negative inclusion. In these cases the zone corresponding to the
lenticule shows a flat center and the fine turgescence corre-
sponds to the thickest segment of the lenticular edge.

The reflex of the ocular fundus when examined with the
plane mirrors shows the good transparency of the ocular media
of refraction, the skiascopic shadow being sometimes similar to
that of the keratoconus. The edges of the lenticule are seen as
an obscure line and are easily recognizable.

Keratoscopy with the Placido’s disk shows irregular astig-
matism of moderate magnitude which is progressively regulated
as the weeks go by and even attains complete disappearance. In
cases of a positive lens, the size of the disk’s image is smaller
and the separation between the concentric lines diminishes. In
cases of inclusion of a negative lens, the size of the image is
evidently larger and the separation of the lines is more precise. In
these cases, the peripheral lines of the disk’s image are crowded
in the zone corresponding to the edge of the lenticule, due to
an increase of curve determined by the heavier thickness of the
said edge. This image slowly disappears during the postopera-
tive course as regularization of the anterior corneal surface pro-
gresses. The fundus of the eye is easily visible with the direct-
image ophthalmoscope, the focusing of which gives also an idea
of the degree of ametropia gained from the operation. More
exact data are obtained by ophthalmometric examination, the
slit lamp skiascopy, and histologic examination.

Ophthalmometric examination. During the first eight days
of the postoperative course, the keratometric images are dis-
torted, which makes exact measurement impossible. Keratome-
try is already possible during the second week, habitually regis-
tering high ophthalmomeric figures due to postoperative corneal edema. These figures progressively decrease and become stabilized in about 30 days after the operation. At this moment, the ophthalmomeric figures are small in cases of positive inclusion and large in cases of negative inclusion. Astigmatism as a rule is moderate.

In evaluating the results of the operation, it is important to keep in mind that the operation was performed on young rabbits, in which the development of the ocular globe results in flatness of the cornea approximately of two diopters in the course of the eighth to eighteenth month of the animal's life. It is for this reason that we evaluated the results of the operation by comparing the ophthalmomeric modification of the eye in which the operation was performed to that of the nonoperated eye, and we proceeded in the same manner in evaluating the skiascopic modification.

**Biomicroscopy with slit lamp.** Early examination with the slit lamp and biomicroscope shows the presence of corneal edema which involves the lenticule and the recipient cornea, far beyond the limits of the operation, with moderate alteration of transparency. The lenticule is clearly visible with the optic cut in a meniscus of great regularity, positive or negative, in accordance with the cases. Its optic density is similar to that of the recipient cornea. As the corneal edema progressively disappears, the thickness of the peripheral cornea becomes regularized, the cornea remaining modified in the central zones in accordance with the form and thickness of the included lenticule. The optic section of the lenticule, which during the first two weeks appears optically filled and of a density similar to that of the recipient cornea, progressively becomes optically empty. This image suggested at first that the lenticule was reabsorbed, especially since we discovered during subsequent examinations that the diameter and thickness of the optically empty zone had diminished. Further examinations complemented with histologic examinations furnished us with proof that the optic emptiness of the lenticule corresponds to lysis and reabsorption of the cor-
neal cells of the lenticule; the interstromal spaces remain filled with an amorphous, transparent interstitial liquid which lacks a biomicroscopic structure (Figure 4).

As weeks pass, zones of optic density appear in the thickness of the lenticule; these zones are preferably distributed in the periphery and in the anterior and posterior faces of the lenticule, causing progressive diminution of the diameter and thickness of the optically empty zone, which retains the form of a meniscus, either positive or negative in accordance with the cases. These

[Image: Figure 4. Histologic section of an interlamellar inclusion of silico-desiccated lenticule in rabbit. The histologic structure of the lenticule has completely disappeared.]

optically filled zones progress from the periphery toward the center causing progressive reduction of the optically empty residual space, up to its complete disappearance, which is due, not to reabsorption of the lenticule, as was thought in the first cases, but rather to reconstitution of the lenticule and its definitive incorporation into the recipient cornea. This biomicroscopic image which logically should correspond to the repopulation of the interstromal spaces of the lenticule by parenchymatous cells of the recipient, and precisely in an arranged form from the periphery and the anterior and posterior surfaces toward the center, does not coincide with our histologic observations in which the migration of interstitial cells appeared simultaneously and in a disorderly fashion in the entire lenticule and progressively increased in density without any order as time passed.
Finally, the biomicroscopic structure of the cornea is apparently normal showing only the changes of thickness and of curvature determined by the inclusion.

The anterior and posterior planes of junction are scarcely visible. They can only be seen when some particles of dust or of other foreign substance delineate their limits, being seen then either by direct vision or by the histic reaction caused by the presence of the foreign body.

The intracorneal inclusion causes, during the first few days of the postoperative course, a flattening of the endothelial face and a turgescence of the epithelial face of the cornea. This effect is more marked upon the posterior face if the lenticule has been placed very deeply, and upon the anterior face if it has been placed very superficially. Later, the endothelial face recovers its former curve, perhaps as a result of ocular tension, and the change of corneal curvature noticeably affects the anterior face only.

*Histologic examination.* The histologic examination of these lenticules discloses great regularity in section (4, 5). The histologic structure of the cornea, especially of the parenchymatous cells, is well preserved, and microscopically it cannot be distinguished from a normal cornea.

The case is quite different when the lenticule has been included. The histologic examination of eyes operated upon with interlamellar inclusion of homoplastic corneal lenticules of desiccated cornea discloses the following: (1) The normal histologic structure of the lenticule has completely disappeared in the early postoperative period. In preparations stained with hema-toxylin-eosin, the lenticule appears as though it were an amorphous mass, its trabecular system visible in fresh preparations examined under the phase-contrast microscope. The presence of cellular nuclei can not be rendered evident by any method. In this phase there is no metachromatic reaction to the toluidine blue in that tissue of the lenticule. The cells of the inclusion have been lysed and the supporting tissue of the lenticule is empty of cellular material and filled with interstitial corneal fluid. These changes do not hinder the perfect transparency of
the lenticule and explain the optic vacuity observed at examination in vivo with the slit lamp and the biomicroscope. (2) As the weeks pass, the reconstitution of the lenticule by cells of the recipient progresses. Nucleated cells appear in several spots within the lenticule, but a regular location of the zones in which nucleation starts cannot be observed. This observation is in opposition with biomicroscopy. (3) The cases of inclusion of fresh cornea with evolution of more than one year show that the tissue of the lenticules is completely repopulated by nucleated cells with a structure practically indistinguishable from that of cells of normal corneal stroma (Figure 5), showing metachromatic reaction to toluidine blue.

![Figure 5](image.jpg)

**Figure 5.** Microphotograph of an inclusion of lenticule of fresh cornea one year after the operation. The limits of the lenticule are nearly invisible and the histologic structure of the lenticule is practically indistinguishable from that of the recipient: (A) anterior layers of the recipient, (B) lenticule, and (C) posterior layers of the recipient.

**RESULTS**

The results obtained in a series of 11 rabbits in which the operation was carried out using the technique described above are summarized in Table I. It is obvious that there is a clear
relation between the dioptric value of the included lenticule and that of the variation of the curve of the cornea and of refraction, as measured by skiascopy. In some cases, very significant discrepancies between the value of the ophthalmometric modification and that of skiascopy existed. These discrepancies were probably due to: (1) an insufficient precision in evaluating the dioptric value of the lenticule, (2) its more or less deep inclusion in the thickness of the corneal stroma, and (3) inaccurate measurement due to the fact that accurate measurement cannot be made upon the true optic axis because rabbits do not have a fixed focusing during the examination.

From the clinical and histological study of these cases it is concluded that the lenticule should be included as superficially as possible, and that it should be of a minimal thickness, because of its diameter and its refractive power, as in case R.

Rabbit R

July 16, 1961
Weight: 2,000 gm.
Anesthesia: Pentobarbital and phenobarbital
Operation: L.E.
Incision of 6 mm. near the upper limbus; dissection of a superficial pocket, 7 mm. wide and up to 4 mm. beyond the center of the cornea; inclusion of the lenticule and centering it; two stitches with virgin silk.

Characteristics of donor cornea:
Ophthalmometry: 49.00 diopters as an average
Diameter: 6.00 mm.
Thickness: 0.36 mm.

Characteristics of the cutting:
Utilized base: 50.00 diopters
Freezing: 5 minutes at 0 degrees C.; 3 minutes chamber carbon dioxide snow-alcohol at 79 degrees C. Xyrol as intermediary

Thickness of frozen cornea: 0.45 mm.
Cutting of posterior face: 45.00 diopters
Thickness after cutting: 0.22 mm.

Thickness after thawing: 0.20 mm.

Sterilization: Thimerosal at 1 × 5.000 aqueous solution for 8 minutes; it is not washed before it is included.

Dioptric value: +7.00 diopters

Postoperative:

July 20, 1961 Without reaction to surgical trauma; very moderate corneal edema.

July 22, 1961 Ophthalmometry: +66.00 diopters with distortion of mires due to corneal edema.

July 29, 1961 Minimal edema; at examination with the slit lamp, positivity of the lenticule and change of corneal curvature at the expense of the anterior layers of the cornea are noted; the lenticule appears optically empty.

August 13, 1961 The same characteristics persist; the optically empty zone has been reduced to approximately 3 mm.

January 15, 1962 Ophthalmometry:
R.E. 45.00–46.00 (control eye)
L.E. 54.00–48.00 (operated eye)

April 8, 1962 Skiascopy Dr. Henao:
R.E. +3.75 sph.
L.E. −3.00 sph. −0.50 cyl × 10
Ophthalmometry:
R.E. 44.50 −45.50
L.R. 50.75 −50.25

Keratographs were taken.

April 14, 1962 Photographs in the slit lamp; the change of curvature of the anterior face of the cornea and the increase of thickness at the center are visible; junction planes without opacities; optically filled graft.
<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 14, 1962</td>
<td>Photographs of the pupillary reflex with Nordenson camera; no opacities.</td>
</tr>
<tr>
<td>May 5, 1962</td>
<td>Cinematography with slit lamp in Kodachrome*</td>
</tr>
<tr>
<td>June 20, 1962</td>
<td>Skiascopy Dr. Henao: R.E. +4.25 sph. −1.00 × 5 L.E. −6.00 sph. −1.00 × 165</td>
</tr>
<tr>
<td></td>
<td>Ophthalmometry: R.E. 44.50–44.50 L.E. 50.00–53.00</td>
</tr>
<tr>
<td>July 21, 1962</td>
<td>Skiascopy Dr. Henao: R.E. +4.25 sph. −1.00 cyl. × 150 L.E. −4.25 sph. −0.37 cyl. × 170</td>
</tr>
<tr>
<td>July 22, 1962</td>
<td>Ophthalmometry: R.E. 44.50–45.00 (control eye) L.E. 50.25–52.50 (operated eye)</td>
</tr>
<tr>
<td>July 22, 1962</td>
<td>The animal is sacrificed for anatomicopathological examination.</td>
</tr>
</tbody>
</table>

In this case the modification of the refraction induced by the corneal tissue lens included can be evaluated in about 8.00 diopters.

The cornea of the left eye was fixed in a 10 percent solution of formaldehyde and cut in the freezing microtome. Sections taken at different levels were examined fresh, by phase contrast, and stained with hematoxylineosin and toluidine blue. The cornea has preserved its macroscopic morphology well, maintaining regularity of its curvature both at the anterior and posterior faces. The cornea is thicker at the center of the sections than at the ends. At the center of the cornea, situated near the epithelial face, the inclusion of a fragment of corneal stroma with the form of a positive meniscus is visible (Figure 6). The curve of the epithelial face shows a small convexity that begins exactly in front of the inclusion. The thickness of the cornea is 0.6 mm. at the ends of the specimen and 0.8 mm. at its center. The thickness of the inclusion at its center is 0.2 mm.

### Table 1. Keratophakia in rabbit

<table>
<thead>
<tr>
<th>Case</th>
<th>Ophthalmometry, Preoperative</th>
<th>Lenticule Without Epithelium</th>
<th>Situation</th>
<th>Ophthalmometry, Postoperative</th>
<th>Skiascopy</th>
<th>Ophthalmometic Correction</th>
<th>Skiascope Correction</th>
<th>Days of Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>II-D</td>
<td>48.50 FC + 7.50</td>
<td>Middle third</td>
<td>66.00</td>
<td>+ 17.50</td>
<td>Edema</td>
<td>+ 17.50</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>II-I</td>
<td>49.75 FC + 8.00</td>
<td>Middle third</td>
<td>66.00</td>
<td>+ 16.25</td>
<td>Edema</td>
<td>+ 16.25</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>III-D</td>
<td>46.00 FC + 9.25</td>
<td>Middle third</td>
<td>55.00</td>
<td>+ 6.00</td>
<td></td>
<td>+ 5.00</td>
<td></td>
<td>34</td>
</tr>
<tr>
<td>III-I</td>
<td>48.00 FC - 5.00</td>
<td>Middle third</td>
<td>43.00</td>
<td>- 5.00</td>
<td></td>
<td>- 5.00</td>
<td></td>
<td>34</td>
</tr>
<tr>
<td>R</td>
<td>44.75 FC + 7.00</td>
<td>Superficial</td>
<td>51.50</td>
<td>- 4.25 - 0.37 × 170</td>
<td>+ 6.75</td>
<td>+ 8.25</td>
<td></td>
<td>372</td>
</tr>
<tr>
<td>3</td>
<td>43.00 DC - 5.00</td>
<td>Anterior third</td>
<td>35.25</td>
<td>+ 5.00 - 1.00 × 170</td>
<td>- 7.75</td>
<td>- 2.50</td>
<td></td>
<td>112</td>
</tr>
<tr>
<td>8</td>
<td>46.25 DC - 5.00</td>
<td>Deep</td>
<td></td>
<td></td>
<td>Negative</td>
<td></td>
<td></td>
<td>63</td>
</tr>
<tr>
<td>10</td>
<td>45.00 DC - 5.00</td>
<td>Posterior third</td>
<td>40.00</td>
<td>+ 8.00</td>
<td></td>
<td>- 5.00</td>
<td>- 5.00</td>
<td>131</td>
</tr>
<tr>
<td>13</td>
<td>45.50 DC - 5.00</td>
<td>Middle third</td>
<td>41.00</td>
<td>+ 12.00</td>
<td></td>
<td>- 4.50</td>
<td>- 9.00</td>
<td>348</td>
</tr>
<tr>
<td>18</td>
<td>43.50 DC + 10.00</td>
<td>Middle third</td>
<td>52.50</td>
<td>- 3.00 - 1.00 × 5</td>
<td>+ 9.00</td>
<td>+ 6.50</td>
<td></td>
<td>109</td>
</tr>
<tr>
<td>19</td>
<td>44.00 DC + 10.00</td>
<td>Anterior third</td>
<td>51.00</td>
<td>- 4.00 - 1.00 × 1</td>
<td>+ 7.00</td>
<td>+ 7.50</td>
<td></td>
<td>109</td>
</tr>
</tbody>
</table>

FC = Fresh cornea; DC = Dry cornea silico-desiccation
The dimensions of the inclusion vary in accordance to the situation of the sections. In central sections it has a length of 6 mm.

At examination under low magnification it is apparent that the inclusion is formed by corneal tissue of identical structure as that of the rest of the corneal parenchyma. The inclusion is nucleated but not as much as the rest of the cornea, near the center of which there are some zones at which the nuclei are very scanty.

Under greater magnification, the limits between recipient and the inclusion are easily identified near the ends of the inclusion, by the different direction of the fine corneal lamellae. However, the limits are less marked toward, and at the center of, the inclusion, where the fine corneal lamellae and those of the inclusion are parallel (Figure 7).

The thickness of the layer of parenchyma which exists between the inclusion and the epithelium is uniform in the whole extent of the inclusion, being of less than 0.12 mm.

No presence of neoformed vessels was observed in the preparations examined.

Examination shows absolute regularity in the form and situation of the implant, and regularity of the curves which have not been involved by zones of necrosis or reabsorption.
The change of curvature of the epithelial face of the cornea is in perfect relation to the curve of the lenticule included in the thickness of the cornea. Nucleation of the lenticule is nearly complete and perfect, which definitely assures its vitality. The endothelium is poorly preserved because of artifacts of histologic technique.

**Experimental Work—Humans**

The results of our experiments gave proof of the good tolerance of the cornea toward the inclusion of a lenticule of homoplastic corneal parenchyma, as well as of the complete repopulation of the lenticule by cells of the recipient. The latter condition, although more or less belated, definitely assures permanence of the lenticule with preservation of transparency. Thus, we proceeded to perform intracorneal inclusions
in eight patients who were in need of extraction of the crystalline lens. All inclusions were performed by using silico-desiccated positive lenticules (Table II).

In five cases the indication for the operation was aesthetic, since there were irreversible lesions of the fundus of the eye. These cases served to prove once more the good tolerance of the cornea and of the eye to the operation. Later, in an attempt to diminish anisometropia, we performed the operation in three patients with mononuclear senile cataract but with good conditions of perception and projection of light.

SURGICAL TECHNIQUE

We utilized anesthesia and akinesia by curare in all cases. The technique for the inclusion was the same as that used in rabbits and already described (Figure 8), only in some cases the incision was lateral rather than superior. In all cases dissection of a very superficial corneal pocket was difficult, and in no case did we find it possible to place the lenticule within the anterior layers of the cornea, as we wanted to do. In two cases in which we attempted to do this (not included in our reports), the anterior layers of the cornea were torn and this prompted us to desist in our attempt. The corneal pocket healed in a few days without opacity.

Figure 8. Four scleral stitches knotted to the Colibri blepharostat secure perfect fixation for dissection of the interlamellar pocket.
<table>
<thead>
<tr>
<th>Case</th>
<th>Preoperative Ophthalmometry (average)</th>
<th>Silico-desiccated Lenticule</th>
<th>Postoperative Ophthalmometry (average)</th>
<th>Ophthalmometric Modification</th>
<th>Refraction</th>
<th>Vision</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>42.25</td>
<td>Stroma only + 6.00</td>
<td>43.00</td>
<td>+ 0.75</td>
<td>+ 12.00 - 0.50 × 135</td>
<td>0.05</td>
<td>Cicatricial macular choroiditis; observation after 18 months; optically full</td>
</tr>
<tr>
<td>2</td>
<td>43.00</td>
<td>Stroma only + 5.00</td>
<td>43.50</td>
<td>+ 0.50</td>
<td>L.P.</td>
<td></td>
<td>Old retinal detachment; observation after 18 months; optically full</td>
</tr>
<tr>
<td>3</td>
<td>43.00</td>
<td>Stroma only + 15</td>
<td>46.25</td>
<td>+ 3.25</td>
<td>0.00</td>
<td></td>
<td>Old retinal detachment; observation after 18 months; optically full</td>
</tr>
<tr>
<td>4</td>
<td>46.25</td>
<td>Stroma only + 7.00</td>
<td>51.00</td>
<td>+ 4.75</td>
<td>+ 10.50</td>
<td>0.10</td>
<td>Hemorrhages hypertensives of the macula; observation after 18 months; optically full</td>
</tr>
<tr>
<td>5</td>
<td>42.25</td>
<td>Bowman + 10</td>
<td>50.00</td>
<td>+ 7.75</td>
<td>+ 4.00 - 1.00 × 170</td>
<td>0.05</td>
<td>Cicatricial macular choroiditis; observation after 13 months; optically full</td>
</tr>
<tr>
<td>6</td>
<td>43.00</td>
<td>Bowman + 10</td>
<td>47.50</td>
<td>+ 4.50</td>
<td>+ 8.00 - 1.00 × 65</td>
<td>0.50</td>
<td>Healthy eye; aphakia correct; observation after 1 year; optically empty</td>
</tr>
<tr>
<td>7</td>
<td>45.00</td>
<td>Stroma only + 5.00</td>
<td>47.50</td>
<td>+ 2.50</td>
<td>+ 11.50 - 3.00 × 140</td>
<td>0.50</td>
<td>Healthy eye; aphakia correct; observation after 1 year; optically full</td>
</tr>
<tr>
<td>8</td>
<td>44.24</td>
<td>Stroma only + 10</td>
<td>49.00</td>
<td>+ 4.75</td>
<td>+ 6.50 - 1.25 × 60</td>
<td>0.80</td>
<td>Healthy eye; aphakia correct; observation after 11 months; optically full</td>
</tr>
</tbody>
</table>
All the lenticules we utilized were silico-desiccated because of our lack of fresh donor material at the opportune moment. We used lenticules of two classes: (a) exclusively of stroma, that is, cut at a lathe on both faces and (b) of stroma and Bowman’s membrane, that is, cut on only one face, but with the epithelium carefully removed. Epithelium detaches very easily after freezing. Human lenticules were aseptically cut and used without previous antisepsis.

The presence of Bowman’s membrane does not cause any objective alteration in transparency, although it is possible that it might retard keratoblastic migration. Our case No. 6 remains optically empty one year after the operation.

POSTOPERATIVE COURSE

The postoperative course is favorable and in everything comparable to that in rabbits, with the exceptions that the anterior and posterior planes of junction are more visible and that frequently there are small foreign bodies included, to which the cornea reacts with small zones of opacity.

The ophthalmometric modification is not as marked as it is in rabbits, probably because of the lesser elasticity of the anterior corneal layers or perhaps, because of the presence of Bowman’s membrane, a structure which rabbits do not have. The biomicroscopic image, with the exception of the opacity of the anterior and posterior planes of junction, is superimposable to that of rabbits. The lenticule is optically empty and progressively becomes refilled. However, in one of our very first cases, the lenticule continues to be transparent but optically empty one year after the operation, under examination with the slit lamp.

Case No. 8
September 1962. 50 years.
R.E. Senile cataract; good perception and projection of light
L.E. Transparent crystalline lens; +2.00 sph. −0.50 × 180 V = 1.00

Ophthalmometry:
R.E. 44.00−44.50 × 165
L.E. 43.00−43.50 × 180
**Operation:**

Rectilinear incision of the cornea, 2 mm. from the limbus, at the upper part, 6 mm. in length and 0.2 mm. in depth. Dissection of corneal pocket with piriform spatula and with Bonnet's spatula, 7½ mm. in diameter and centered with the pupil. Introduction of a lenticule of silico-desiccated cornea, previously rehydrated and of +10.00 dioptic value. Centering the lenticule in relation to the pupil, with the aid of a repositor of the iris. Total extraction of crystalline lens according to routine technique. Operation without any incidents. Results: Round, central and black pupil. Chamber partially reformed by air with persistence of meniscus of aqueous humor in all the cameral perimenter. Lenticule well centered. The corneal incision was not sutured.

**Postoperative Course**

1st day  
Round, central and black pupil; good chamber; air bubble persists; brilliant cornea; atropine is instilled

3rd day  
Upon examination with the slit lamp, intumescence observed at the center of the cornea; flattening of the curvature of the posterior face; lenticule situated somewhat in front of half the thickness of the corneal parenchyma; evident form of positive meniscus; optically filled; difficult ophthalmometry due to presence of epithelial edema.  
Approximately 46.00 dipters

24th day  
Without edema; recuperated normality of curvature of posterior faces; lenticule optically empty; ophthalmometry: 48.00-49.00 × 95

3 months  
Lenticule quite visible because of small zones of reaction around foreign bodies in both planes of junction; meniscus retains its primitive form; optically filled at periphery and empty at center

Ophthalmometry R.E. 48.50-50.25 × 90  
Refraction R.E. +6.00-1.50 × 60 V = 20/40  
Optic correction and prednisone collyrium are prescribed

6 months  
Subjective: R.E. +6.50-1.25 × 90 V = 20/30 (operated eye)  
L.E. +2.00-0.50 × 180 V = 20/20 (control eye)

There is fusion and stereopsis
8 months  The corneal thickness, as measured with the Zeiss microscope with Maurici and Giardini's device gives the following data:

<table>
<thead>
<tr>
<th>Thickness cornea R.E. (operated eye)</th>
<th>Temporal side</th>
<th>0.70 mm.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Center</td>
<td>0.85 mm.</td>
</tr>
<tr>
<td></td>
<td>Nasal side</td>
<td>0.65 mm.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thickness cornea L.E. (control eye)</th>
<th>Temporal side</th>
<th>0.70 mm.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Center</td>
<td>0.60 mm.</td>
</tr>
<tr>
<td></td>
<td>Nasal side</td>
<td>0.65 mm.</td>
</tr>
</tbody>
</table>

There is an increase of thickness in the center of the cornea of the right eye of 0.25 mm. which corresponds to the thickness of the inclusion.

11 months  Slight opacities persist in the plane of junction, very attenuated in relation to December; optically filled lenticule.

<table>
<thead>
<tr>
<th>Ophthalmometry:</th>
<th>R.E. 48.50 -49.50 X 70</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refraction:</td>
<td>R.E. +6.50 - 1.25 X 60 V = 20/25</td>
</tr>
</tbody>
</table>

**COMMENTS**

There is no doubt that from a practical point of view, the use of lenticules manufactured with a foreign substance by industrial firms would be ideal for intracorneal inclusions. Lenticules thus manufactured would have the possibilities of having a high index of refraction and therefore a diminished thickness. They would represent great advantage for surgeons, in having them always at hand in an unlimited quantity, etc. However, the previous experiences with the materials which are readily available at the present time are totally discouraging. The use of lenticules of silico-desiccated corneal tissue gives good results but the results of histologic examinations on eyes of experimental animals demonstrate an obvious superiority of the use of fresh cornea (Figure 6).

In man, the inclusion of lenticules cut by only one face, that is, provided with Bowman's membrane (without epithelium), does not seem to alter the properties of the lenticule. However, in our case No. 6, the lenticule remains optically empty one year after the operation, whereas the lenticules are already rehabili-
tated in patients who had the operation performed more recently, by using a lenticule cut on both faces, that is, exclusively consti-
tuted by stroma.

The use of lenticules of stroma only, cut fresh, without freezing, with our technique as previously described (3) seems to be the most adequate, except for the difficulties inherent to the lack of donor material at the very opportune moment. The sil-
co-desiccated material obviated in part this inconvenience.

Because of the fact that this operation is performed by in-
troducing a lens in the thickness of the cornea, we have named it keratophakia, from the Greek: κερατοφάκιος, cornea, and φακος, lens. By use of this technique, the results are gratifying. How-
ever, the facts that the operation demands utilization of donor cornea (which is not always available), that there are two planes of junction, and that there is a slight residual opacity of these planes—leads us to decide that at the present time we should continue our research with the autoplastic technique, already described in our preliminary report and which we have named keratomyleisis.

The results obtained and reported in this article have also been verified, at least in part, by some authors, and especially by the following: Stone (11) verified the uniformity of the cut-
ting of lamellar grafts cut during freezing on a lathe. Krwa-
wicz (8), in 1960, following our ideas, performed intralamellar implants of plastic lenticules and disks of corneal tissue for the purpose of modifying refraction. From his experiments in rab-
bits he reaches the following conclusions: (1) intracorneal im-
plantation of plastic lenses which change refraction of the eye cannot be performed by leaving the lens in permanently be-
cause late reactions of the corneal tissue endanger its transpar-
ency; (2) temporal implantation of plastic lenses and subse-
quent extraction change the curvature of the cornea without causing significant alterations of its transparency; and (3) the intracorneal implantation of a lamellar section of cornea mark-
edly changes the curvature of the cornea. The same author, in

*My gratitude to Professor J. Charamis for furnishing the Greek roots that form the word keratomyleisis from the Greek: κερατοφάκιος, cornea, and σμίληνς, chiseling.
a more recent article (9), reports the results obtained with this technique in eight cases in human beings, but he does not mention the modification of refraction he obtained. Martínez and Katzin (10), in 1963, published a brief preliminary report in which they spoke of modifications of up to 25 diopters in eyes of cats which had intralamellar inclusions of disks of fresh cornea. Also, at Baylor University, Houston, Texas, J. I. Barraquer, L. Girard, L. Daily, and V. Golovin (6) performed anterior lamellar keratoplasties in rabbits by using Krowawicz's technique (7), which involves intracorneal inclusion of the graft and secondary resection of the anterior layers, and by using refractive lamellar grafts they were able to verify the change of refraction caused by the intracorneal presence of the lenticule, even before resection of the anterior layers of the cornea would have been performed. The observations were limited to a period of only from 30 to 40 days, at the end of which the anterior layers were resected for other purposes. The results are summarized in Table III.

In studying these results, it is amazing that by using lenticules of equal dioptric power, greater corrections were obtained in corneas of a low dioptric power (case Nos. 118, 119, 120) than in those of a high dioptric power (case Nos. 129, 131,

<table>
<thead>
<tr>
<th>Case</th>
<th>Preoperative Ophthalmometry (average)</th>
<th>Silicoded Lenticule</th>
<th>Postoperative Ophthalmometry (average)</th>
<th>Transparence</th>
<th>Refractive Corneal Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>118</td>
<td>47.00</td>
<td>+ 10.00</td>
<td>53.50</td>
<td>Perfect</td>
<td>+ 6.50</td>
</tr>
<tr>
<td>119</td>
<td>45.00</td>
<td>+ 10.00</td>
<td>54.00</td>
<td>Perfect</td>
<td>+ 9.00</td>
</tr>
<tr>
<td>120</td>
<td>46.50</td>
<td>+ 10.00</td>
<td>54.00</td>
<td>Perfect</td>
<td>+ 7.50</td>
</tr>
<tr>
<td>128</td>
<td>51.00</td>
<td>+ 10.00</td>
<td>42.50</td>
<td>Perfect</td>
<td>− 8.50</td>
</tr>
<tr>
<td>129</td>
<td>52.00</td>
<td>+ 10.00</td>
<td>54.00</td>
<td>Perfect</td>
<td>+ 2.00</td>
</tr>
<tr>
<td>131</td>
<td>49.00</td>
<td>+ 10.00</td>
<td>54.00</td>
<td>Perfect</td>
<td>+ 5.00</td>
</tr>
<tr>
<td>135</td>
<td>52.50</td>
<td>+ 10.00</td>
<td>55.00</td>
<td>Perfect</td>
<td>+ 2.50</td>
</tr>
<tr>
<td>136</td>
<td>50.00</td>
<td>+ 10.00</td>
<td>55.00</td>
<td>Perfect</td>
<td>+ 5.00</td>
</tr>
</tbody>
</table>
135, 136) and also that these changes were proportional to the preoperative dioptic value of the cornea. Thus, in case No. 119 with the flattest cornea (45.00) a correction of 9.00 diopters was obtained, whereas in case No. 135 with a more curved cornea (52.50) by using an identical lenticule, a correction of only 2.50 diopters was obtained. Table III shows that the degree of correction gained with a given lenticule is in inverse ratio to the preoperative dioptic value as though the cornea would oppose resistance to exceed values of the order of 55.00 diopters. In case No. 128 certainly there must have been some error or else the lenticule was implanted upside down.

Conclusions

1. Intracorneal inclusion of lenticules of foreign material results in the modification of ocular refraction but they are badly tolerated by the cornea.

2. Inclusion of lenticules of corneal tissue within the lamellae of the cornea produces permanent and stable modification of the dioptic power of the cornea, with good tolerance and definitive incorporation of the lenticules.

3. This modification depends mainly upon the change in the radius of curvature of the anterior face of the cornea produced by the presence of the lenticule.

4. Modification of refraction is in relation to the form (power) of the lenticule and to its location (more or less deep) in the thickness of the corneal parenchyma.

5. Lenticules of homoplastic corneal tissue, either fresh or silico-desiccated, are completely refilled in the eyes of rabbits in a period of one year, at the end of which histologic signs of abnormal cellular activity around the lenticule cannot be noted.

6. In man, tolerance to silico-desiccated lenticules is not so good. Intolerance is shown by slight opacity at the lenticule-recipient level of the anterior and posterior planes of junction, and the opacity causes a significant diminution of visual acuity.

7. We suggest the name of *keratophakia* for this operation.
REFERENCES