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BASIS OF REFRACTIVE KERATOPLASTY

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To the memory

of my Father and Teacher.

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I
PREFACE

Refractive surgery is a new branch of ocular surgery that is destined to have great significance in the course of the next years. Although it aims at the total correction of significant refractive defects, its actually employment is limited to the prevention of ametropias, resulting from pathological or surgical processes, and the correction of those cases of ametropia in which usual clinical procedures would not lead to a satisfactory result.

The limitation of our knowledge and experience in this field makes the presentation of this material, and even more its organization, a dificult task. We shall be forced, in the course of this presentation, to mix both theoretical concepts and knowledge acquired through experimentation with facts that have been proven through long years of clinical observation.

The subject in itself does not need any justification since any field of endeavour which contributes to the increase of knowledge, even be it a knowledge of things to avoid, is justified for its own sake. At the present time, it is evident that the traditional methods for the correction of ametropias are not completely satisfactory in all cases. Even the most modern of these methods, the employment of contact lenses, may prove and often does to be totally ineffectual in the correction of some cases of ametropia. We refer particularly to cases of severe monocular myopia and monocular aphakia, especially in children, in which it is sometimes impossible to resolve the problem of anisometropia, amblyopia and subsequent loss of binocular vision by the traditional methods.

On the other hand, Medicine and Surgery must be oriented towards the establishment of normal organic functions. without resorting to external prosthesic devices, because no matter how perfect these devices may be, their users are hindered in the traditional fields of endeavour, such as agriculture and mining, and also in the more recent ones, arising from modern scientific and technical development, such as space exploration.

Any surgical procedure such as a well-placed incision of the saturing of a wound, which has the result of diminishing ametropia, may be termed refractive surgery. However, in this presentation we shall not concern ourselves with those topics that have already been widely dealt with.

Since 1949, our research has been directed, principally, towards the assessment of those factors which govern the shape of the cornea and the possibility of altering these factors surgically with the aim of correcting the refractive error.

The subject is so vast that one man's entire lifetime will not suffice for even its partial development. This presentation has as its principal object to order concepts, to arouse interest in the subject and to serve as a basis for further investigation.

This presentation emphasizes the synthesis of the subject of Refractive Keratoplasty in terms of a logical, step by step development of the basic concepts rather than in terms of a historical or chronological development. However, we do not depart entirely from the historical approach to the subject without briefly noting in the subsequent pages a chronological summary or outline of the major events in the development of the field of Refractive Keratoplasty.

1949:

1. The possibility of modifying the refractive power of the eyeball through plastic surgery on the cornea: Introduction to the term *Refractive Keratoplasty* (1).

2. The possibility of modifying the refractive power by means of interlamellar inclusions (1).

1958:

3. The preservation of transparency in corneal tissue in anterior lamellar grafts in which there has been modification of the parallel cell structure of the corneal layers (2, 3).

4. The recuperation of the transparency of the corneal tissue after freezing (2, 3).

5. The cutting of grafts with specific dioptric value, by modifying or distorting the shape of the cornea to the desired curvature and then by performing a horizontal section to derive a corneal tissue lens of a desired power (2, 3).

6. The possibility of turning the frozen corneal graft on a lathe and the resulting tissue lens of predetermined refractive value (2, 3, 32).

7. The conservation of transparency in lamellar grafts that have been frozen at minus 79 grades centigrades and turned on the lathe. (2, 3).

8. The possibility of obtaining the desired modification in the eye refraction error by means of refractive grafts (2, 3).

9. The development of the technique for anterior lamellar grafts and auto grafts with dioptric value (2, 3).

10. The possibility of modifying refraction by including lenses of corneal tissue in the interlamellar layers (2, 3).

1963:

11. The preservation of the transparency of corneal tissue in the interlamellar inclusions of corneal tissue lens (4).

12. Survival (without reabsorption) of corneal tissue lens inclusions with change of the parallel cell structure of the cornea (4).

13. The complete cellular replacement of the inclusions of dead corneal tissue lenses (4).

14. Keratophakia. First clinical results (4).

1964:

15. The relationship between the curvature and thickness of the cornea (5).

16. Keratomileusis. First clinical results (6).

17. Keratomileusis is the first intervention, performed successfuly, in which a portion of a noble organ (cornea) is separated from the body and after an extracorporaly modification of a main function (the refraction) is replaced in situ (25).

II

INTRODUCTION TO REFRACTIVE SURGERY

The refractive characteristics of the eye depends upon the following factors:

1. The radius of curvature of the optical surface areas.

2. Their interrelationship.

3. Index of refraction of the transparent media.

4. The longitudinal length of the ocular globe.

Since both the human and the animal eye normally modify their dioptric power under certain circumstances, before beginning our discussion of the artificial means of altering the refractive power of the eye, let us look briefly at the mechanisms which nature has provided to accomplish the same end (8).

In some fish (Teleost) the process of focussing the eye for near objects is carried out by displacing the lens forward until it touches the cornea (Fig. 1).

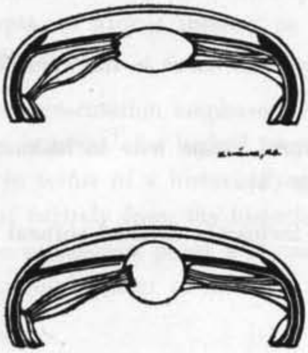


Fig. 1. Teleost eye.
a) Non - accommodate eye.
b) Accommodate eye.

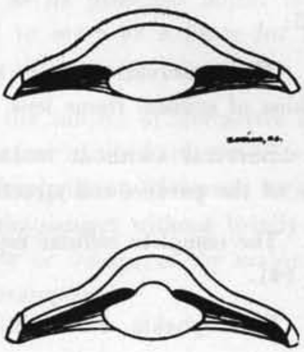


Fig. 2. Bird eye.
a) Non . accomodate eye.
b) Accommodate: increase in the curve of the cornea. Increase in the refractive power of the lens by displacement and compression by the iris.

In certain species of birds (Fig. 2) accommodation is realized by the constriction of the cilliary muscle, which results in:

a) The forward displacement of the lens,

b) The compression by the iris of the lens, which has the effect of diminishing the radius of curvature of its anterior face.

c) Increase in the curvature of the cornea.

In contradistinction, in some water fowl (Fig. 3), there exists a transparent membrane which corresponds to a third eyelid. When this transparent membrane covers the cornea, it flattens and compresses it. This has the result of diminishing the refractive power of the eye during periods of subaquatic vision, that is, vision in a medium of greater refractive index than the air.

Fig. 3 Water fowl eye.
a) Aerial vision.
b) Sub-aquatic vision: The cornea is flattened by compression of a transparent membrane.

In the majority of the higher mammals, among them man, accommodation is carried out by the modification of the shape of the lens by the cilliary muscle (Fig. 4). In others, such as the horse, the retina is situated at varying distances

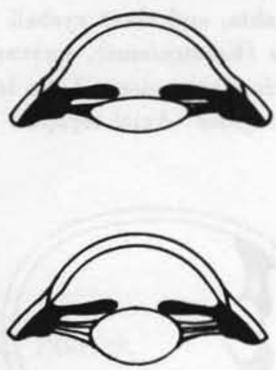


Fig. 4. Mammal eye.

a) Non . accommodate eye.
b) Accommodate eye.

from the lens. This permits the horse to focus upon a nearer or more distant part of the retina, depending upon the distance of his object of view (Fig. 5).

In summary, the different species of animals use the following four particular mechanisms for modifying the refractive power of the eye:

a) Displacement of the lens,

b) The change of the dioptric power of the lens, by modifying its shape,

c) The modification of the curvature of the cornea,

d) Modification of the longitudinal focal distance.

From this brief survey, we may conclude that in the animal kingdom, nature has provided for the physiological modifications of the refractive power of the eyeball by modification of three of the four factors on which depend the refractive characteristics of the eye (7), the radius of curvature of the optical surfaces, their interrelationship, and the length of the ocular globe.

Let us see now what anatomical changes are produced in the human eye under conditions of severe ametropia.

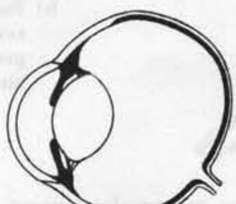


Fig. 5 Horse eye.

In human pathology, we find that hypermetropia is associated with one of the following conditions: flat cornea, flat lens, aphakia, and short eyeball (Fig. 6). Myopia is associated with a very curved cornea (Keratoconus), increased curvature of the lens (Spheroaphakia), increased refractive power of the lens (Cataract, Diabetis, etc.) and elongation of the ocular globe (Axial myopia) (Fig. 7).

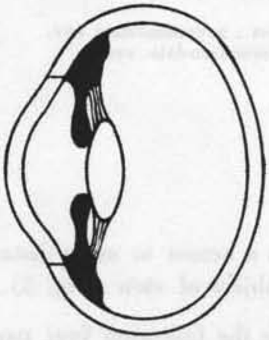


Fig. 6 Hyperopic factors:
a) Flat cornea.
b) Flat lens.
c) Short eyeball.

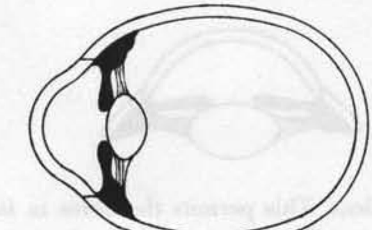


Fig. 7 Myopic factors:
a) Curved cornea.
b) Spheric lens.
c) Long eyeball.

We find various types of ametropiae resulting from the displacement of the lens, either by the modification of the depth of the anterior chamber, subluxation, colobomas, etc., or from deforming diseases of the cornea.

We see then, that in human pathology modification of any one of the various factors which contribute to the refractive power of the eye will have the result of changing the refractive characteristics of the eye.

At the present time it is difficult to conceive, from a surgical point of view, of being able to modify at will the refractive index of those refractive media which constitute the dioptric system of the eye; neither does the displacement of the lens or the modification of its shape appear to be surgically practicable. If we eliminate these two possible methods as impracticable, there remains as surgical procedures only the following three: the modification of the curvature of the cornea, the removal of the lens, or the varying of the longitudinal length of the eyeball.

Fukala (9) noticed that following the extraction of cataracts in cases of high myopia, the myopia was diminished. It then occurred to him to remove the lens as a cure for severe myopia, even in those patients without cataracts. This operation, which is still practised in special cases, has the inconvenience of being effective only in those cases in which the refractive defect is approximately equal in diopters to the dioptrical value of the lens; not to mention the inconvenience caused to the patient by the loss of his accommodation, the risk of severe accidents and later complications.

Later, in 1903, Muller (10) devised the method of scleral resection for the purpose of shortening the anterior-posterior diameter of the eyeball in cases of high myopia, and thus was able not only to avoid the progression of myopic sclero-coroidal lesions, resulting from the distention, but, at the same time, was also able to reduce the refractive error. However, this intervention is not very effective in the last sense, since the correction in the refractive error to be gained, even with several operations, is almost insignificant.

Along the same lines, Malbran (11) and Barraquer (12) proposed the reinforcement of the eyeball by means of a strip of fascia lata or sclera, applied in the manner of a belt, for the purpose of diminishing the anterior-posterior dimension of the eyeball and at the same time reinforcing the sclera in the region of the

Fig. 8 Scleral reinforcement of the macular area, to avoid distension.

macula, to avoid further distention (Fig. 8). Although this intervention produced some satisfactory short-range results, it had the effect of being excesively traumatic to the eye and and the ultimate results obtained still have not been well evaluated. Recently, William E. Borley has published an evaluation of the results obtained with this technique.

Today we cannot conceive of the elongation of the anterior-posterior dimension of the eyeball, which would have been necessary for the correction of high hypermetropias, such as result from aphakia, because of the prohibitively delicate nature of the intraocular tissues, especially of the retina.

Here, at least brief mention must be made of the surgical interventions of Ridley, Strampelli and others, which aimed at the modification of the optical system of the eye by means of the inclusion of intraocular lenses. At the present time this procedure is no longer employed because of the high percentage of later complications.

Eliminating, for the reasons already mentioned, the sclera and the lens as possible areas for surgical intervention, there remains only the cornea. Because the cornea accounts for the major refractive power of the eye, we may conclude that merely by changing its curvature sufficiently, it is possible to correct the majority of the refractive defects of the eye.

Clinically, there are many cases of myopia and astigmatism in which the patient squints in order to obtain better vision, not only with the aim of utilizing the principle of the slit thus formed to obtain a clearer image but also utilizing the pressure exerted by the lids to flatten the cornea and thereby change its refractive power. Some patients in order to increase this flattening efect of the lids will go so far as to apply increased pressure with their finger, and thus augment their distance vision.

The observation of ametropia resulting from accidental or surgical corneal scarring and the refractive errors coming with the extreme values of corneal radius (hypermetropia is cases of flat cornea and myopia in the cases of curved cornea), confirms the possibility of correcting refractive defects of the eye through the modification of the radius curvature of the cornea.

Modification of the Curvature of the Cornea

In 1949, J. I. Barraquer (1) revealed the results that demonstrated the possibility of modifying ocular refraction by means of plastic surgery of the cornea.

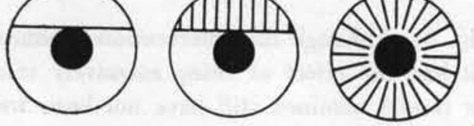


Fig. 9 Sato's corneal incisions to correct myopia and astigmatism.

He proposed the term Refractive Keratoplasty which embraces all plastic procedures on the cornea which are aimed at modifying the refraction of the eyeball.

In 1953, T. Sato (13) modified the shape of the cornea by means of tangencial and radial, anterior and posterior incisions (Fig. 9) for the correction of myopic and hyperopic astigmatism, and myopia.

The method of Barraquer aims at a precise optical correction by means of exactly mathematical surgical interventions. Sato, on the other hand, depends upon the approximate correction to be gained from the cicatricial retraction resulting from the healing of hopefully well-placed incisions. In the method of Sato the degree of correction obtained depends upon the amount of retraction of the wound in healing. Because this process differs in intensity from one individual to another, the result obtained must be variable, inconstant, and fundamentally regressive in nature.

Later on, Malbran (14) published his observations and techniques. Some of these were a mixture of the basic methods of Barraquer (1) and Sato (13).

It is easy to see that a procedure designed to modify the shape of the cornea, with the aim of correcting the refractive defect of the eye, cannot be based on the cicatricial retraction of the wound. What is demanded is a process that permits a predetermined result of the greatest possible accuracy on an organ in permanent regeneration.

Of the two types of surgical intervention, that of Barraquer and of Sato, we shall only concern ourselves with the former in the following pages, that is, "*the surgical plastic procedures carried out on the cornea with the aim of modifying its refractive power*", those that constitute, by definition, the subject of the chapter entitled "*Refractive Keratoplasty*".

III

GENERALIZATIONS ABOUT THE CORNEA

1. *The Cornea as a Dioptric System*

The cornea, which accounts for the major dioptric power of the eye, consists of a group of transparent structures which have an index of refraction of 1.376 and a variable dioptric power. The dioptric power of the cornea is determined by the radius of curvature of its anterior and posterior faces, and the distance between them.

The anterior face of the cornea is bathed by the air, with a refractive index of 1.000, and the posterior face is bathed by the aqueous humour, with a refractive index of 1.336.

The refractive power of the cornea is dependent upon certain variables and constants.

The constant factors are:

Index of refraction of the air	n = 1.000
Index of refraction of the aqueous humour	n' = 1.336
Index of refraction of the cornea	n' = 1.376

The variable factors are:

Radius of the anterior surface of the cornea	= r
Radius of the posterior surface of the cornea ...	= r'
Thickness of the cornea	= d

In man these factors vary with the individual, during growth, as a result of pathological processes, and in certain species of animals as a function of accommodation.

These factors which for various reasons show significative modifications, can be influenced surgically, at will, with the end of modifying the dioptric power of the cornea, and consequently the total dioptric power of the eye.

According to Gullstrand, the cornea accounts for more than two-thirds of the dioptric power of the eye. This fact permits us to believe that refractive variations induced in this organ can be sufficient to correct cases of severe ametropia.

The power in dioptries of the refractive surfaces of the eye is given by the general formula,

$$D = \frac{n' - n}{r} \cdot 1.000 \qquad (1)$$

and according to Littmann (15), the total power in diopters of the cornea is given by the following formula,

$$D = \frac{1.000}{n'' \cdot n' \cdot r \cdot r'} \left[n' \left((n' - n)\, r' - (n' - n'') \cdot r \right) + d \cdot (n' - n'') \cdot (n' - n) \right]$$

and is equal to 32,229 diopters as refringent corneal power on the image side.

The refringent power on the object side is obtained by multiplying the anterior data by n" / n. and is equal to 43.05.

The values proposed by Gullstrand are:

Radius of the anterior face	r = 7.700 mm
Radius of the posterior face	r' = 6.800 mm
Thickness of the cornea in the center	d = 0.500 mm

If we substitute Gullstrand's value for the anterior face in formula (1), we arrive at the result,

$$D = \frac{376}{7.700} = 48.83 \text{ diopters}$$

Likewise, if we substitute his value for the posterior face in the same expression, we arrive at the result,

$$D' = \frac{40}{6.8} = 5.882 \text{ diopters}$$

Now subtract, D — D' = 42.95 diopters.

The difference between this result of 42.95 diopters and the total refractive power of the eye, as given by Littmann, of 43.05 diopters corresponds to the thickness of the cornea.

Therefore, we can consider that the dioptric power of the cornea is a result of a combination of the following three factors:

Anterior face	= 48.83 diopters
Posterior face	= 5.88 diopters
Corneal tissue	= 0.10 diopters

A simple analysis of these figures clearly demonstraates that the greatet corrections may be obtained by modifying the curvature of the anterior face and that only small modifications can result from the modification of the posterior face.

These values should be considered only as a referral since the real refractive corneal value is subject to the consideration of the cornea as a whole.

The variations in thickness have in themselves very little value from a refractive point of view, but as we shall see later on, they have a very great corrective value surgically, owing to the modifications that they indirectly induce in the radius of the optical surfaces (5).

In surgical procedures on the cornea, we can aim at:

A. *Modification of the radius of the anterior surface.*

B. *Modification of the radius of the posterior surface.*

C. *Modification of both radii in the same sense.*

D. *Modification of both radii in a contrary sense.*

The thickness of the normal adult cornea is not uniform because the posterior and the anterior surfaces are not parallel. The cornea is thinner at the center than at its periphery.

Also the radius of curvature of the anterior surface of the cornea is not completely uniform. It is uniform only in a small central portion (optical zone) and increases towards the periphery in varying degrees, according to the direction from the center, i. e. to the nasal side, the temporal side, superiorly of inferiorly. The radius varies widely, and it is difficult to establish where the pathological region begins. In general, except in extreme cases, variations in the radius are governed more by the regularity of the corneal surface than by its curvature.

In the foetus, the cornea is most curved (6.264 mm to 5.928 mm according to age) and thicker in the center than in the periphery. In the infant the cornea becomes flatter, and the faces become parallel. Thus, the greater dioptric power of the infant cornea compensates in part for the physiological hypermetropia that is present in the short ocular globe in childhood. (Approximately 18 mm).

During its development, the cornea becomes flatter and thinner in the center until it has gained its adult characteristics.

In axial myopia and buphthalmos, the distention of the ocular globe also affects the cornea which sometimes becomes as much as two or three diopters flatter as a refractive compensation.

In those cases of cornea plana, it is common to observe that contrary to the normal rule the cornea is thicker in the center than in the periphery. As a result, the posterior face assumes an optical area of lesser negative value to compensate in part for the strong hypermetropia.

Also in sclerokeratitis, with fibrosis and thinning of the periphery, one may observe the inward curving of the anterior face of the cornea, accompanied by myopia, generally with astigmatism, which results in the irregularity of the localization of the pathological process.

One may make similar observations in all diseases of the cornea which affect its thickness. The variation in curvature will affect the anterior or the posterior face, or both, according to the localization of the change in thickness.

From an architectural point of view, the shape of the cornea appears to depend upon the shape of the denser and more rigid anterior layers, while its biological functions depend on its laxer and more elastic posterior layers.

Thus far we have considered the optical zone of the cornea as if it were a part of a sphere of uniform radius and shall continue to do so for purposes of simplifying the discussion. According to the classic concept the central segment, or optical zone of the cornea, which has a diameter varying between four and seven milimeters, is a toric refracting surface, i. e. one that is generated by the revolution of the arc of a circle about an axis that lies in any plane of the circle other than the center. Once beyond the optical zone, the corneal radius increases toward the periphery, creating those zones referred to by Norman Bier as "Negative" and "Positive".

Other authors consider the cornea parabolic and others as a cathenary arc.

2. *The Curvature of the Corneal Surfaces and Changes in Thickness. "The Law of Thickness"*

Experimental modifications in the thickness of the cornea (5) clearly demonstrate the relationship between variations in corneal thickness and the radius of curvature of the optical surfaces. Our understanding of this relationship permits us to explain the origin of various clinically observed ametropia which are either a consequence of various pathological processes or of surgical intervention. The conveniently effected alteration of the normal relationship allows us to modify at will the curvature of the corneal faces, with the purpose of modifying refraction. *The norms that govern this relationship between thickness and curvature may be explained by a general law, "The Law of Thickness".* Which has been demonstrated either experimental and clinically.

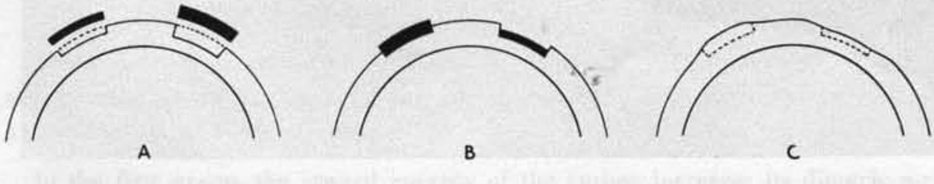


Fig. 10 Transposition Autokeratoplasty. a) Resections. b) Resection's Transpositions c) Result.

A) If two exentric corneal resections of equal width but unequal depth are performed, in order to realize an Autokeratoplasty by transposition, when the resected corneal discs are exchanged, we obtain one area of thicker cornea, and another of thinner cornea (Fig. 10). Once, the cicatricial process is complete,

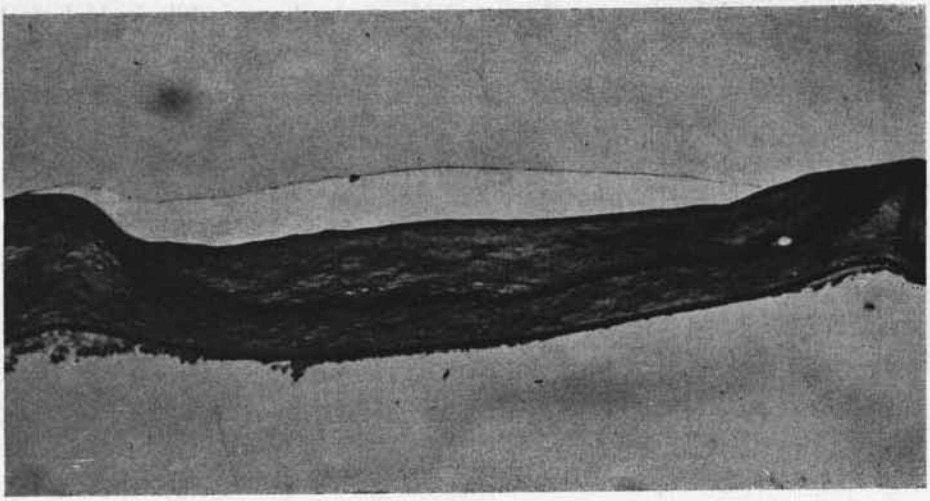


Fig. 11 Histologic section of a graft with tissue substraction. (Graft thinner that the receiving bed.). Result: flattening of the cornea.

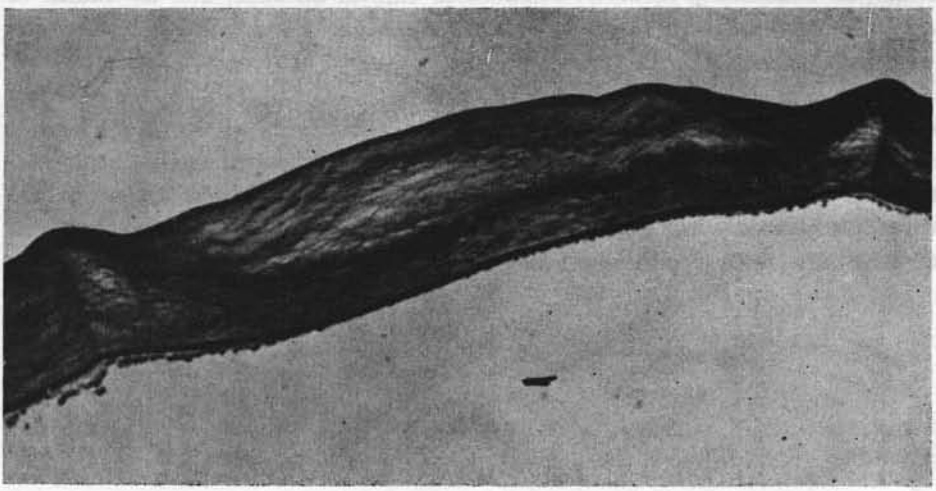


Fig. 12 Histologic section of a graft with tissue addition. (Graft thicker than receiving bed.). Result: Steepening of the cornea.

the result in the anterior surface of the cornea, in the region of the deep bed and shallow disc (thinner cornea), is a flattening of the corneal area. A steeper area is produced in the region of the shallow bed and thick disc (thicker cornea).

In the thinner zone, the curvature of the anterior face is diminished, which is to say, its radius has been increased and the cornea has been flattened (Fig. 11).

In the thicker zone, the curvature of the anterior face is increased; the radius has been diminished and the cornea is now steeper (Fig. 12).

B) In anterior lamellar keratoplasties of six milimeters in diameter or less, exclusively envolving the anterior half of the corneal parenchyma, for the purpose of avoiding errors due to ectasia, the same behaviour is observed with this advantage: the graft's greater dimension and its corneally central localization permits ophthalmometrical readings and retinoscopical checkings of the refractive variation obtained.

When we transplant a graft of lesser thickness than the corresponding depth of the receiving bed, the anterior face of the cornea becomes flat (Fig. 13). In

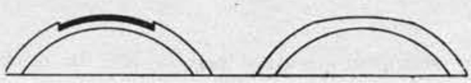


Fig. 13 Anterior lamellar keratoplasty with graft thinner than the receiving bed. (Tissue substraction).
a) Anterior lamellar graft, thinner than the receiving bed.
b) Result: flattening of the cornea.

the reverse process, in which the graft is thicker than the depth of the receiving bed, the cornea becomes more curved (Fig. 14).

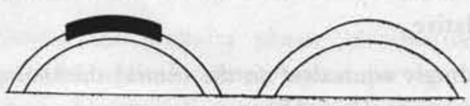


Fig. 14 Anterior lamellar keratoplasty with tissue addition.
a) Anterior lamellar graft, thicker than the receiving bed. (Tissue addition).
b) Result Steepening of the cornea.

These variations of the curvature of the cornea, through the modifications of its thickness, are greater when the diameter of the graft is smaller, and not so evident when its dimensions is greater.

If we analyze this behavior, it becomes self apparent:

a) The reason of the highest postoperative ametropias in lamellar grafts of small dimension than in larger ones.

b) The degree of modification is in relation to the sagitta of the corresponding arcs.

Which is to say,

$$\text{The modification obtained } D - D' = \frac{(n' - n)\ 1.000\ .}{R} - \frac{(n' - n)\ .\ 1.000}{R'}$$

$$\text{When}\quad R = \frac{F^2 - 0^2}{2F}$$

$$R' = \frac{F'^2 - 0^2}{2F'}$$

Substituting for R and R', we arrive at the following relation,

$$D - D' = \frac{(n' - n)\ .\ 1.000}{\dfrac{F^2 - 0^2}{2F}} - \frac{(n' - n)\ .\ 1.000}{\dfrac{F'^2 - 0^2}{2F'}}$$

Then, the difference between the pre and postoperative refractions, in other words, the refractive modification obtained, is a function of the (thickness), since the index of refraction n and n', and the chord "0" (the diameter of the resection) are constants. In the transplants of different thickness to the receptacle bed, and parallel faces, the regenerative power affects only the coaptative edge and neighbouring area without reaching the center.

The modifications of curvature determined by modifications in corneal thickness, are not only absolute but also relative.

The peripheral thinning is correspondingly equivalent to the central thickening and governs the steeping of the inscribed zone (Fig. 15).

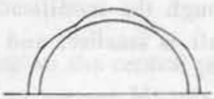


Fig. 15. Annular resection of the cornea, followed by steepening of the central corneal area. (Relative addition).

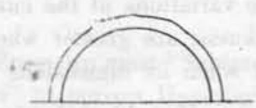


Fig. 16. Annular addition followed by flattening of the central corneal area. (Relative substraction).

Likewise, the peripheral thickening is correspondingly to the central thinning and produces the flattening of the inscribed zone (Fig. 16).

The study of healing in histological sections of grafts which are of a thickness different from the corresponding depth of the receptor bed, demonstrates the process that leads to the above exposed results.

First, the corneal layers curve inward the towards center of the eye in those grafts which are thicker (Fig. 17) and towards the epithelium in those grafts which are thinner (Fig. 18).

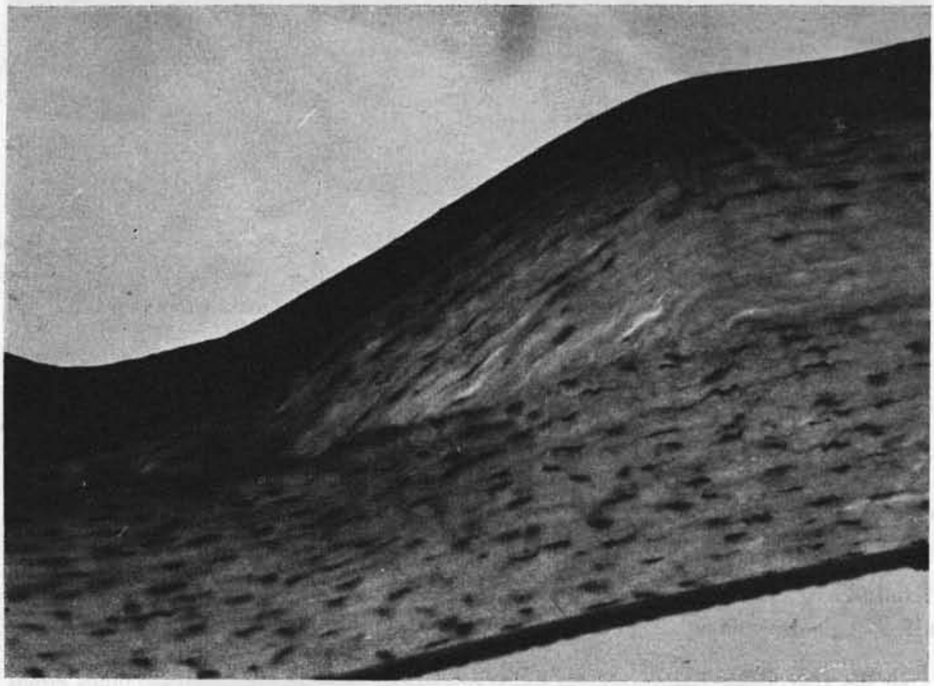


Fig. 17 Inward curve of the corneal layers, toward the center of the eye, in a graft thicker than the receiving bed.

Then, the thicker adge becomes thinner and the thinner edge becomes thicker, until they are equal. Contrary to what has been generally accepted to be the case, parallelism of the corneal layers can be modified, within certain limits, without loss of transparency (Biomicroscopy).

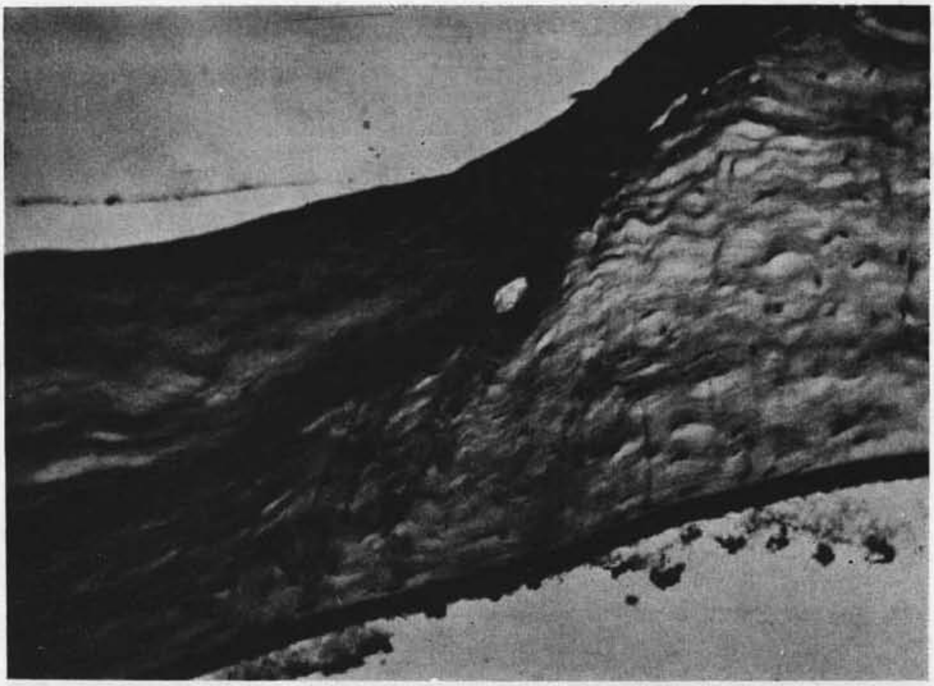


Fig. 18 Inward curve of the corneal layers, toward the epithelium of the eye, in a graft thinner than the receiving bed. (Substraction).

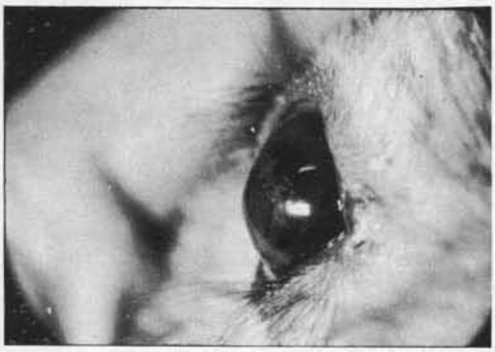
Finally, keratoblasts, proceeding from the recipient cornea penetrate the graft, completing the cicatricial process.

At this point the acquired or modified curvature may be considered permanently fixed. The change in thickness resulting from the regenerative process can never affect the entire extent of the graft (Observations of eight years) (Fig. 19).

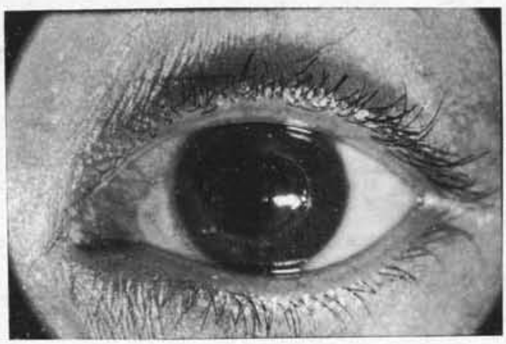
In the regenerative process, the thickness of the edge of the graft becomes equal to the thickness of the edge of the bed but this process of equalisation does not extend to the central portion. The resul is a corneal tissue lens of positive or negative value, according to whichever the case may be.

If instead of transplanting neutral grafts, in which the faces are parallel, we use corneal tissue lenses in which a dioptric value has been incorporated into the graft (Fig. 20) the regenerative process permits us to conserve the shape of the graft as long as the edge of the graft is equal in thickness to the depth of the edge

Fig. 19 a) Hypermetropizing keratoplasty in rabbits.



b) Myopizing keratoplasty.



c) Refractive keratoplasty, with lamellar graft, with incorporated dioptric power.

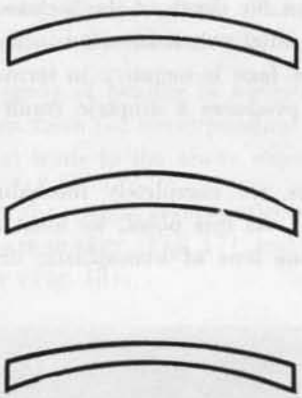


Fig. 20 Lamellar grafts with dioptric power.
a) Plano.
b) Positive.
c) Negative.

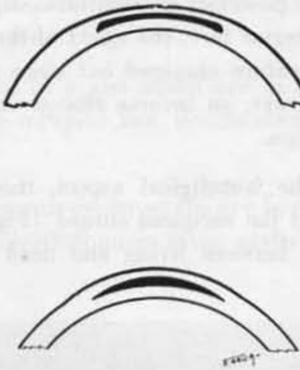


Fig. 21 Interlamellar inclusion.
a) Negative corneal tissue lens.
b) Positive corneal tissue lens.

of the receptor bed. If not, the refractive value of the graft will be modified by the regenerative process according to the "Law of Thickness" (5).

The interlamellar inclusions of corneal tissue discs (Fig. 21) modifies the curvature of the surfaces of the cornea according to the "Law of Thickness". The effect on the interlamellar inclusions is distributed between the anterior and posterior surfaces of the cornea, predominating the change in curvature either in the

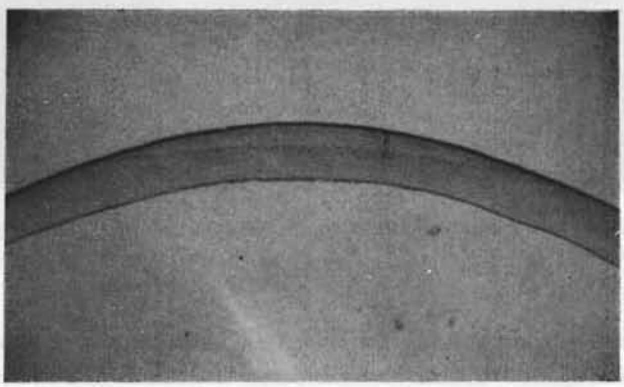


Fig. 22 Intracorneal inclusion (addition) of a positive corneal tissue lens, one year old (rabbit). General view.

anterior or posterior corneal face, depending upon the depth of the inclusion (4). In the posterior face, the effect of the changes in thickness is inverted in the sense of the curvature obtained but since the posterior face is negative in terms of its dioptric power, an inverse change in curvature produces a dioptric result of the opposite sign.

From the histoligical aspect, these inclusions are completely reinhabited by the cells of the recipient cornea (Figs. 22|23|24). At this point, we must make a distinction between living and dead corneal-tissue lens of homoplastic origin.

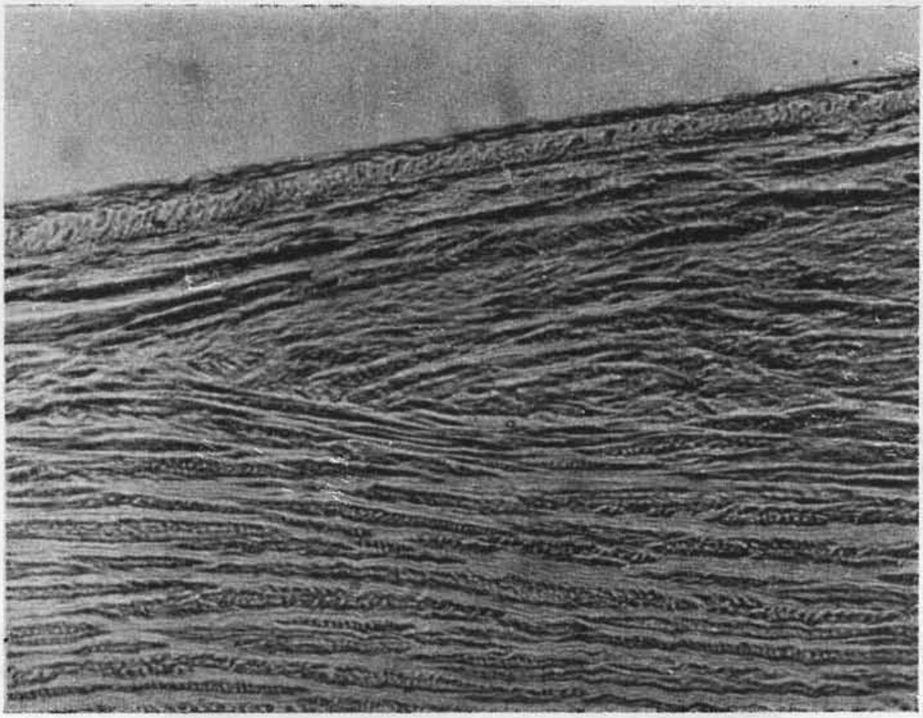


Fig. 23 One end of the corneal tissue lens of Fig. 22, seen at the higher magnification and phase contrast microscope.

In living corneal tissue lenses, the cellular substitution takes place gradually, so that at no time is the structure of the tissue acellular. Corneal tissue lenses which have been through the process of freezing or desiccation go through two phases: 1) the stromal cells disappear, leaving only the collagen structure; 2)

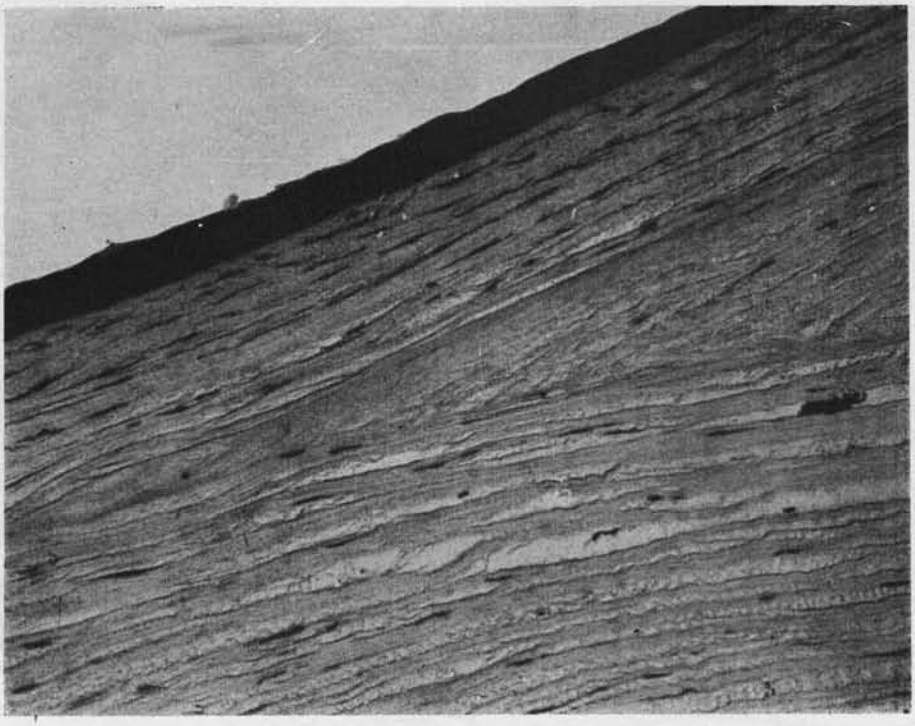


Fig. 24. Same. Fig. 23 dyed with Hematoxilin-Eosin.

the empty collagen structure is later reinhabited by the stromal cells of the recipient's cornea (Fig. 25).

During the acellular phase, examination with biomicroscope and slit lamp reveals an optically empty space corresponding to the zone of inclusion. This method of examination permits us to control in vivo the progress of keratoblastic migration into the interfibrillar spaces of the connective meshwork.

The changes in curvature of the corneal surfaces, induced by modification of the thickness, whether by subtraction or addition of corneal tissue, naturally imply a change in the parallel cell structure of the cornea. This alteration in the parallel cell structure of the corneal layers does not, as was classically believed, result in the loss of tissue transparency. Corneal transparency is conserved as long as the magnitude of the change is not so great as to cause hypotrophic disturbances.

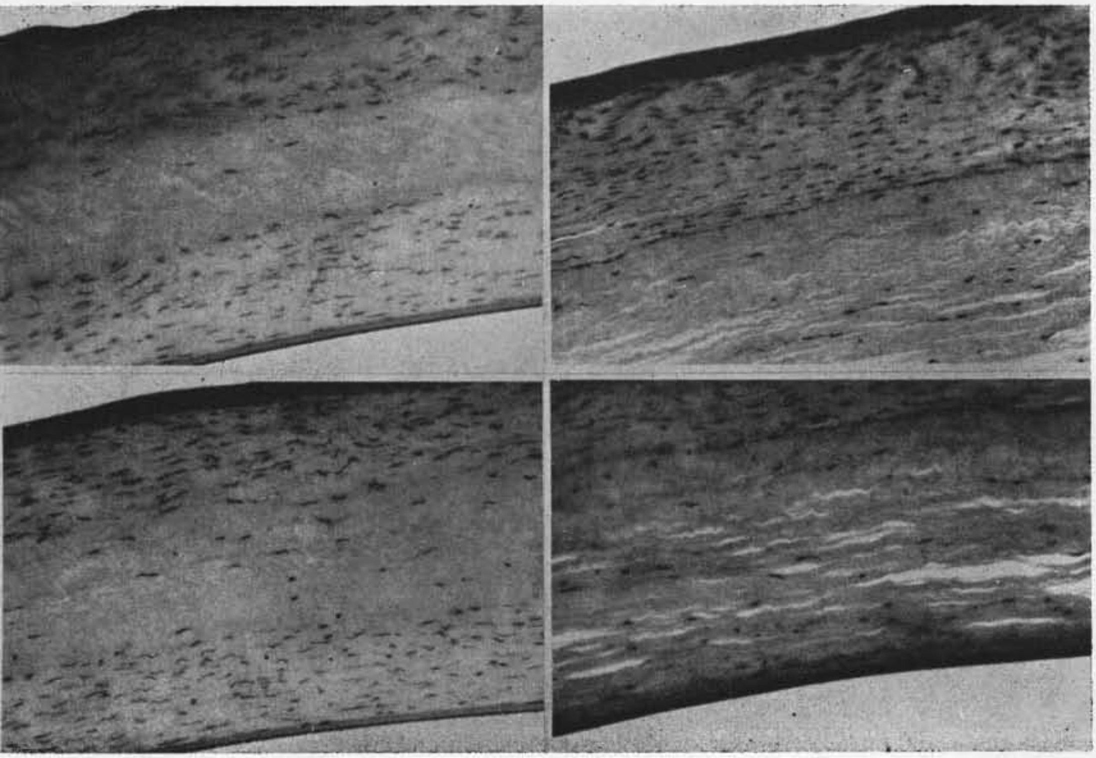


Fig. 25 Steps in the cellular repopulation of the interlamellar inclusions of dead corneal tissue lenses.

a) Corneal tissue lens without histolo gical estructure.

b) Some nucleus appear.

c) Some nucleus appear.

d) Near normal histologic appearance.

SUMMARY

Acting on the central part of the cornea, Optical Zone, we must "Subtract (—) tissue" to correct Myopia, and "To add (+) tissue" to correct Hyperopia. Acting over the perifery of the Optical Zone, we must act inversally, addition of tissue to correct Myopia (relative central substraction), and substraction to correct Hyperopia (relative central addition).

Acting this way we have:

Substracting a positive lens = Myopia correction. (Fig. 26).

Substracting a negative lens = Hypermetropia correction. (Fig. 27).

Adding a positive lens = Hypermetropia (Fig. 21).

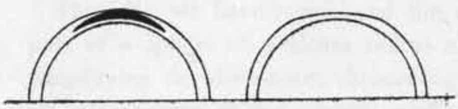


Fig. 26 a) Substraction of a positive lens.
b) Result: Flattening of the cornea.

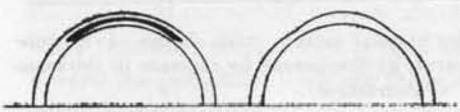


Fig. 27 a) Substraction of a negative lens.
b) Result: Steepening of the cornea.

I V

"REFRACTIVE KERATOPLASTY"

The term "Refractive Keratoplasty" (1) applies to a wide range of plastic corneal surgery which has as its aim the direct or indirect modification of ocular refraction.

These surgical procedures may be classified according to its action:

1) *Modification of the curvature of the cornea while maintaining the original relationship between the anterior and posterior faces.*

2) *Modification of the curvature of one or both corneal surfaces by altering the original anterior-posterior relationship.*

Those changes of refraction, observed in human pathology, resulting from a modification of the curvature of the corneal surfaces, also depend upon one or a combination of these processes.

In the first group, the inward curving of the cornea increases its dioptric power while applanation diminishes it (Fig. 28). In the second group, the increase

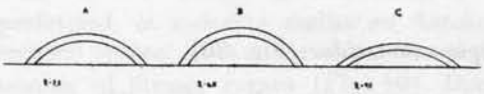


Fig. 28 Modification of the corneal refraction, by change of the corneal curve, while maintaining the normal relationship between its faces. a) Normal curve. b) Increased curve c) Diminished curve.

in thickness in the zone of the optical vertex increases the dioptric power, while the diminishing of the thickness of the center of the cornea decreases the dioptric power (Fig 29).

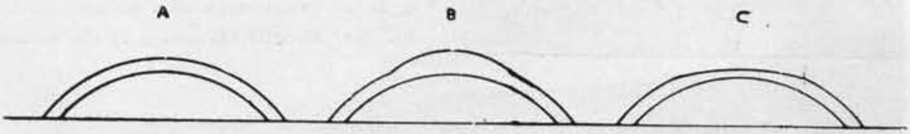


Fig. 29. Modification of the curve of the anterior corneal surface, with change of the anterior-posterior relationship. a) Normal curve. b) Steepening by increase in thickness (Addition). c) Flattening by thinning (Substraction).

Fundamentally, there are three different surgical ways that may be employed to modify refraction, either of the first group or the second group:

A) *Resection*
B) *Grafting*
C) *Inclusion*

Each one of these ways may be classified according to location, shape and the source of the donor material when it is required.

1) *Modification of the curvature of the cornea while maintaining the original relationship between the anterior and posterior faces.*

A) *RESECTION*

The resection, as the name implies, consists in the extirpation of a portion of corneal tissue. The resection may be classified, according to the shape of the exeresis:

a) Anular
b) Crescent.
c) Fusiform.

a) The anular resection is always anterior, lamellar, and axially concentric.

Whether or not it is associated whit an interlamellar disection of the inscribed zone, the anular resection has as its object the flattening of the cornea (Fig. 39).

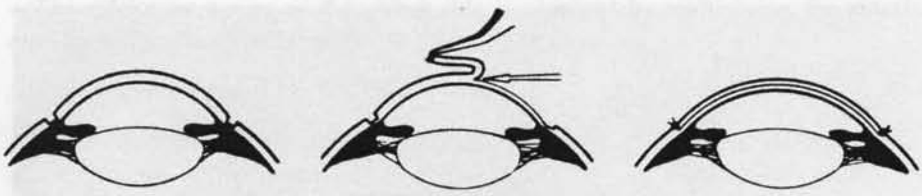


Fig. 30 Annular keratectomy (1949). a) Annular resection. b) Interlamellar disection. c) Flattening after stitching.

This type of resection was the first one practised by us in cases of myopic anisometropia. The immediate results were good but impermanent.

The degree of correction obtained is in proportion to the width of the resected ring. The resection may be contiguous with the limbus, in which case it will be 11 mm in diameter, or it may be situated nearer to the corneal vertex, in which case the diameter will be smaller.

b) The crescent resection may be performed in any corneal sector of the limbus, whether or not it is associated with an interlamellar disection of the cornea. The crescent resection aims at increasing the corneal radius in the meridian perpendicular to the resection (Fig. 31).

c) There are two types of fusiform resections: lamellar and penetrating. This type of resection is radially oriented and is localized in the corneal scleral limbus. It aims at decreasing the length of the corneal perimeter (Keratomiosis) for the purpose of increasing corneal dioptric power. The resection many be single or multiple, according to the degree of correction desired (Fig. 32 and 33).

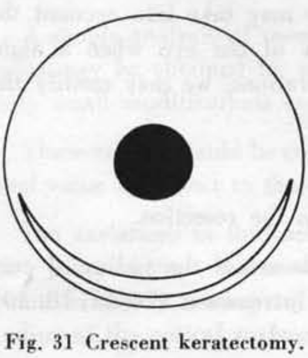


Fig. 31 Crescent keratectomy.

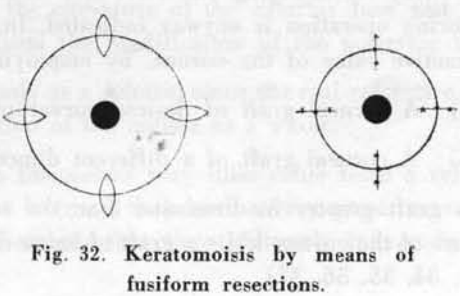


Fig. 32. Keratomoisis by means of fusiform resections.

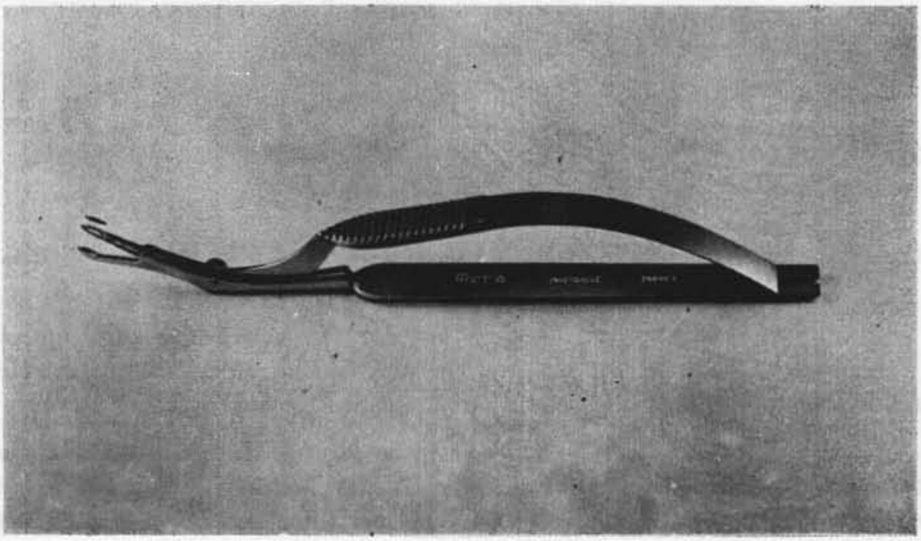


Fig. 33 Punch for fusiform resections.

B) *GRAFTING*

Grafting implies the substitution of a part of a donor cornea for one part of the recipient cornea, having a different shape or dimension. The graft may be autoplastic or homoplastic, depending upon the source of the donor cornea.

The graft may be penetrating or lamellar; in shape, it may be cylindrical, conical, or step. From the present state of our knowledge, we cannot consider surgical penetrating grafting which has as its only purpose the modification of refraction, because of the high surgical risk. However, we may take into account the possibility of changing the refractive characteristics of the eye when a sight restoring operation is anyway indicated. In such operations, we may modify the refractive value of the cornea, by employing:

a) A corneal graft of desired curvature.

b) A corneal graft of a different dimension from the resection.

A graft greater in dimension than the resection decreases the radius of curvature of the cornea while a graft of lesser dimension increases it (16, 17, 18, 19) Fig. 34, 35, 36, 37).

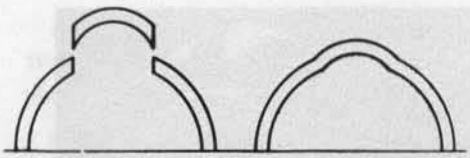


Fig. 34 Full thickness graft steeper than the receiving cornea.

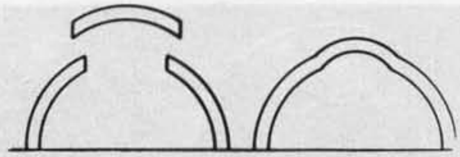


Fig. 35 Full thickness graft bigger than the receiving bed.

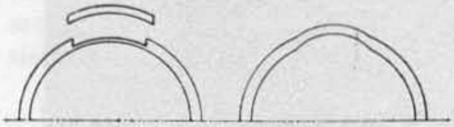


Fig. 36 Deep lamellar graft, bigger than the receiving bed.

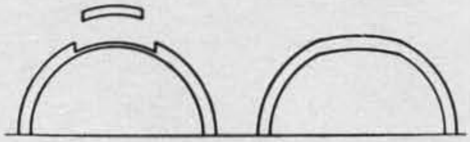


Fig. 37 Deep lamellaer graft, smaller than the receiving bed.

The relative irregulary of the resection, the intensity of the cicatricial process, the ectasia and the immunological reactions tend to invalidate, in large part, the predicted results.

C) *INCLUSION*

The term inclusion implies introducing into the corneal layers an implant, of adequate shape, for the modification of the corneal curvature.

Acrylic implants have been employed experimentally but without result because of: 1) the intolerance of the eye for a foreign body, and 2) the pressure exerted by such a foreign body (21, 21) (Fig 38).

Recently Choice (35) has reported good results with this technique by placing the implant near the Descemet's.

2) *Modification of one or both corneal surfaces with change of the original anterior-posterior relationship.*

These methods, based upon the Law of Thickness (5) require additions or substractions in the thickness of the optical vertex of the cornea, in order to increase or decrease the dioptric power (Fig 39). These additions and substractions may be absolute or relative and may be carried out by resection, grafting and inclusion.

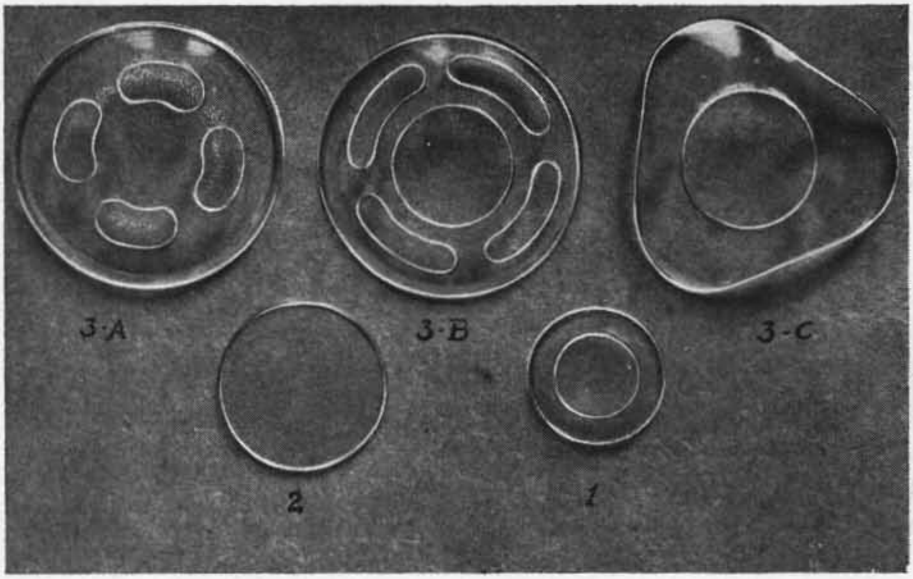


Fig. 38 Acrilic inlays, for interlamellar inclusion, with different curve than the receiving cornea.

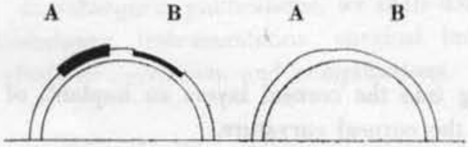


Fig. 39 Transposition autokeratoplasty. 1) Immediate post-operative result: a) Thickered area (Tissue addition). b) Thinnered area (Tissue substraction). 2) Late result: a) Steepening of the cornea, b) Flattening of the cornea.

A) *RESECTION*

The resection exclusively affects the corneal tissue (parenchyma) and consists in the extirpation of one portion of the corneal tissue of precise shape (Meniscus or Torus) which determines the required degree of modification of the curvature of one or both faces of the cornea.

By this method we can correct spherical and cylindrical refractive defects, within those limits permitted by the structure of the cornea.

At the present time, the interlamellar resection constitutes the principal basis for refractive surgery (6).

An interlamellar resection of the corneal parenchyma of exact and predeter mined shape, may be accomplished by three procedures:

a) Resection of the anterior layers of the cornea, their optical reshaping and subsequent replacement. (6) (Fig. 40).

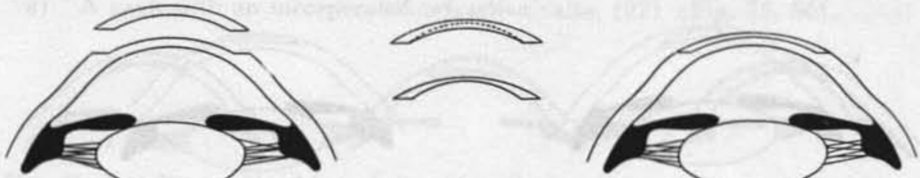


Fig. 40 Keratomileusis: a) Resection of the corneal anterior layers. b) Optical carving in the posterior face of the resected corneal disc. c) Replacement of the corneal tissue lens.

b) Resecting the anterior corneal layers, then the middle parenchymal layers, in which once away from the body, the optic shaping is performed and once replaced in situ already modified, will be covered by the superficial layers.

This varation has the purpose of avoiding trauma to the most delicate anterior corneal layers, such as epithelium and Bowman's layers.

c) Resecting, or simply raising, by means of a flap, the anterior layers of the cornea, then optically reshaping the sub-layers of the parenchyma and finally replacing the corneal flap or corneal resection, whichever the case may be. (Fig. 41).

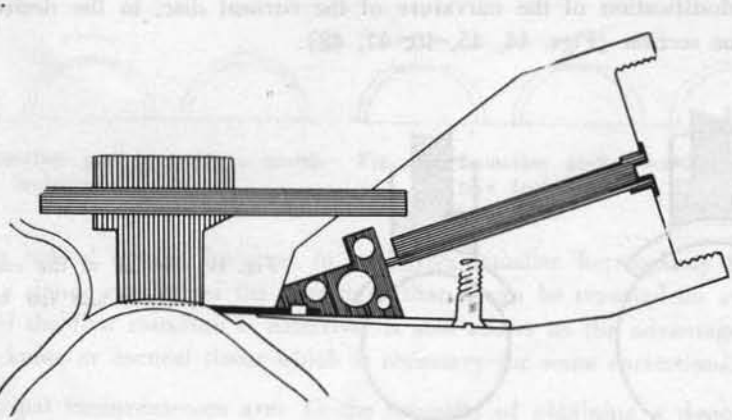


Fig. 41 Razing a thinner corneal flap resection in the bed, under molding.

In the first group, the resection is performed extra corporally: "Optical cutting of corneal tissue lenses". (Fig. 42).

In the second group, the resection is performed in the corneal bed: "Optically cutting in the corneal bed". (Fig. 43)

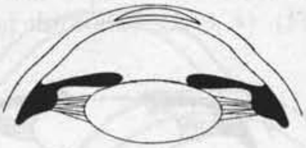


Fig. 42 Extracorporeal cutting.

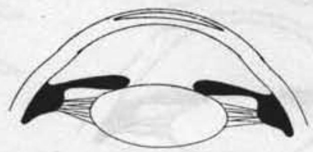


Fig. 43 Corporeal cutting.

Optical Cutting of the Corneal Tissue Lenses

For the purposes of avoiding repetition, we shall consider the optical cutting of corneal discs in those cases in wich the patien's own cornea supplies the corneal disc i. e. resection, and in those cases in which the corneal disc supplied by a donor, i. e. homoplastic graft, jointly. We must also consider a third case, very infrequent but nevertheless possible: an autoplastic graft, in which the patient furnishes the corneal graft from his other eye, which although blind, has a healthy cornea.

Technically there are three basic procedures (2, 3) which we may employ:

1) Modification of the curvature of the corneal disc. in the desired grade, and plane section (Figs. 44, 45, 46, 47, 48).

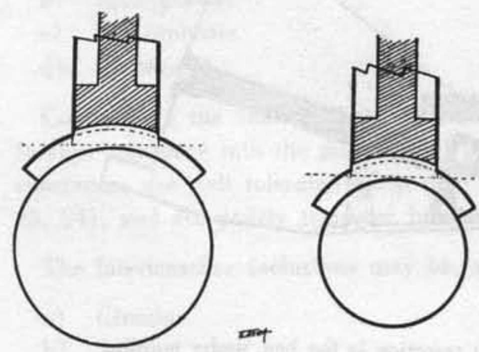


Fig. 44 Change of the curve of the cornea and flat section.

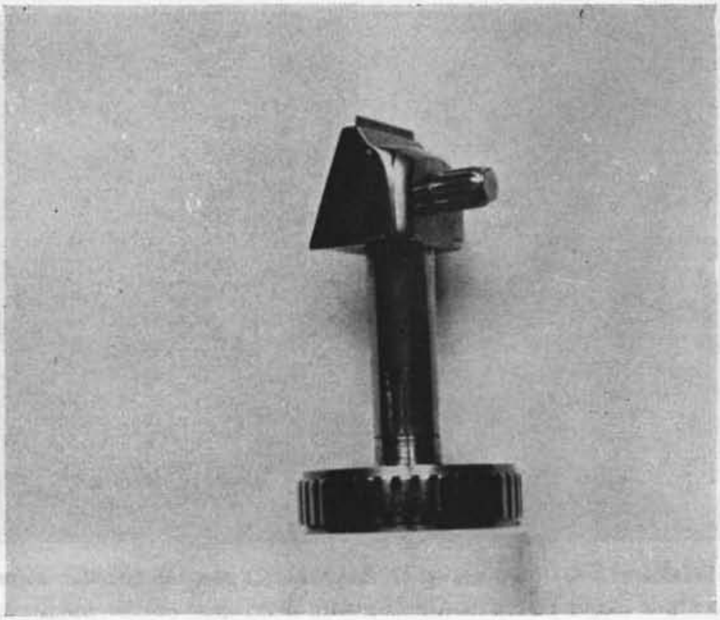


Fig. 45 Microkeratome for flat section (no parallel faces.)

Fig. 46 Holder to obtain refractive grafts, from a total cornea

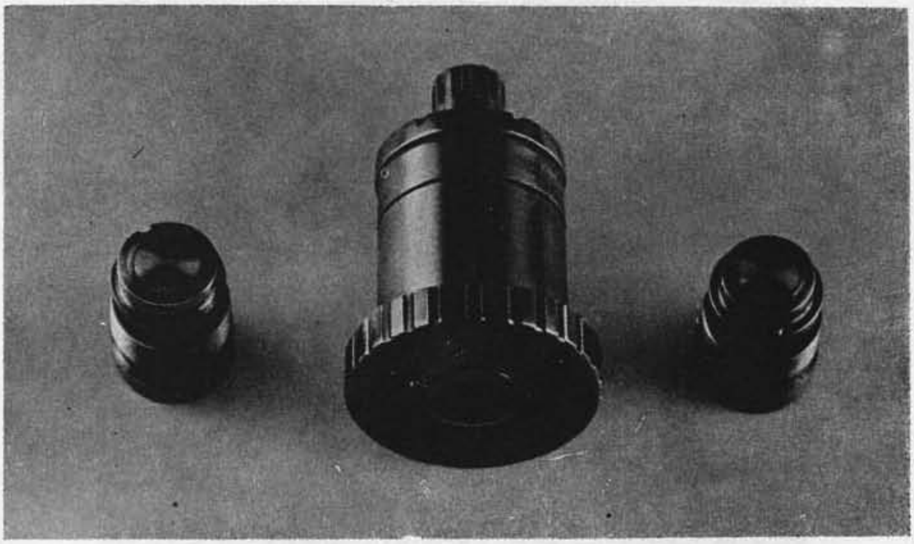


Fig. 47 Holder for optical cutting of the posterior face of lamellar corneal discs.

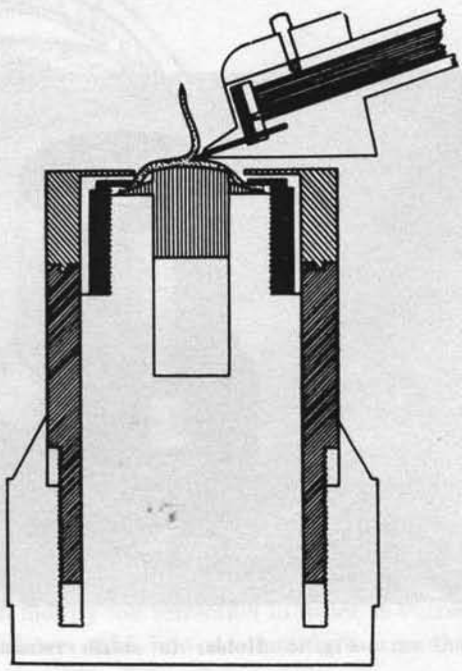


Fig. 48 This drawing shows the use of the Microkeratome of Fig. 45 with holder Fig. 46, to obtain a corneal tissue lens by modification of the corneal shape and flat section.

2) Without modification to the shape of the corneal disc, a curved resection is performed (Figs. 49, 50, 51, 52).

3) Modification to the curvature of the corneal disc, in the desired grade, and curved resection.

1) Modification to the curvature of the corneal disc and Plane section.

Owing to its great simplicity, this was the first method tried.

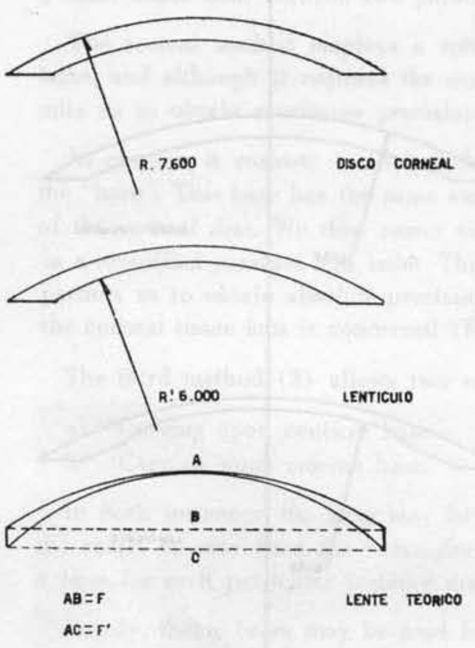


Fig. 49 Negative corneal tissue lens.

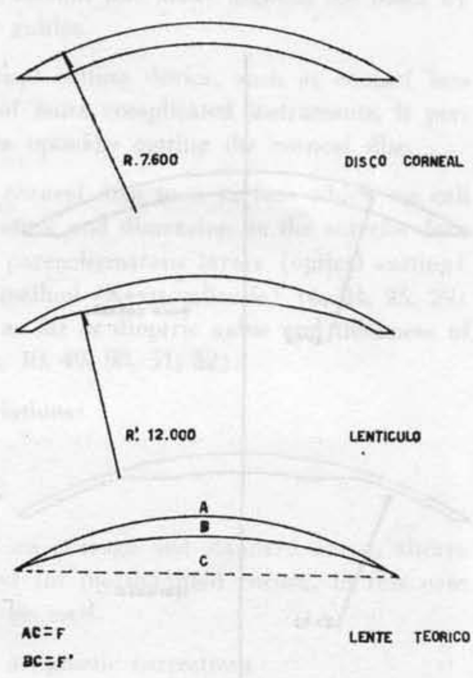


Fig. 50 Positive corneal tissue lens.

The corneal disc is set over an area with a curvature equivalent to the desired dioptric value and the corneal tissue is sectioned in plano to the required thickness, either manually or mechanically (Fig. 48).

If possitive corneal tissue lenses are required, the endothelial side must be adapted to the mold. On the other hand, if negative corneal tissue lenses are required, the epithelial side must be adapted to the mold.

Our first experiences in optical cutting were carried out in donor corneas, manually adapted to spheres of the required diameter. A plane section was performed with a razor blade (3) (Fig. 44).

Later, we adapted the corneal disc to a surface of desired curvature and then placed the corneal disc. plus-adaptor surface, on the congelation plate of the microtome. Finally, once freezed, we resected the desired thickness of surplus tissue by using the microtome's own cutting blade (2).

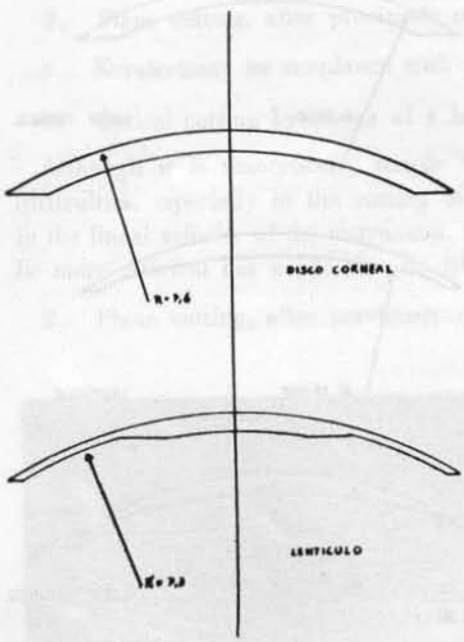


Fig. 51 Positive corneal tissue lens by peripheric substraction (Law of thickness).

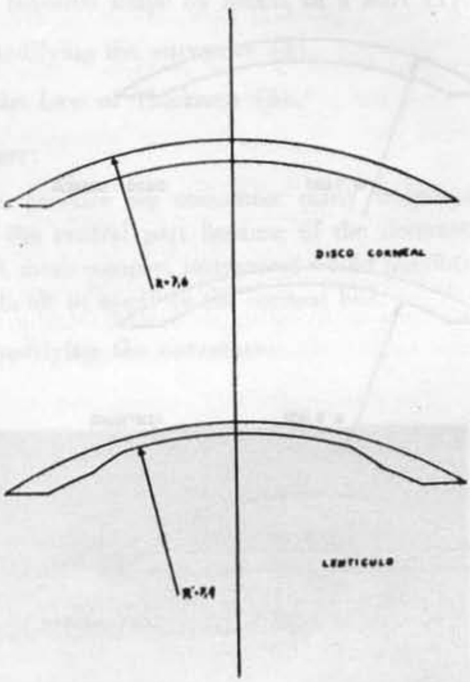


Fig. 52 Negative corneal tissue lens by central substraction (Law of thickness).

Later we constructed two apparatus, similar to Ranvier's microtome, with arrangements for fixing the corneal disc and with a flat surface to serve as a guide for the electrokeratome designed to carry out the resection.

This method had the advantage of being simple and of permitting us to cut the corneal tissue without previously hardening it. An examination of the illustrations will prove more enlightening than any verbal explanation. (Figs. 45, 46, 47, 48).

Martínez and Katzin (26) have followed the same principles as regards the design of their device for obtaining refractive grafts. In their procedure they have introduced a new element: they made a sandwich consisting of upper and lower optical bases of microporous or sticky acrylic material of complementary curvatures with the disc of corneal tissue in between. The desired pressure was applied by means of a spring-gauge and a plane section was made between the bases by a razor blade held between two parallel guides.

The second method employs a spherical cutting device, such as contact lens lathe, and although it requires the use of more complicated instruments, it permits us to obtain maximum precision in optically cutting the corneal disc.

In essence, it consists in flixing the corneal disc to a surface which we call the "base". This base has the same curvature and dimension as the anterior face of the corneal disc. We then resect the parenchymatous layers (optical cutting) in a modiffied conetact lens lathe. This method (Keratomileusis) (6, 24, 25, 29) permits us to obtain absolute precision as far as dioptric value and thickness of the corneal tissue lens is concerned (Fig. 40, 49, 50, 51, 52).

The third method (3) allows two variations:

a) Carving upon concave base.
b) Carving upon convex base.

In both instances, the base may have an average and standard curve, always the same, or may have the curve desired for the modified cornea, in this case a base for each particular instance may be used.

Finally, thoric bases may be used for astigmatic corrections.

The anterior procedures are useful both for corneal discs, formed by parenchyma only as for those composed of Epithelia, Browman's and parechyma.

In order to perform the resection in the last two cases, the corneal tissue must be previously hardened. The tissue may be hardened in three ways:

A. Freezing
B. Desiccation
C. Increase in the lineal velocity of cutting.

Freezing of the corneal tissue lens has been the first technique which has enabled us to obtain satisfactory clinical results (3, 4, 6, 22, 32).

The corneal tissue lenses can be of optical power (Fig. 49, 50) or else of neutral optical power, which operate, according to the Law of Thickness (Fig. 51, 52).

Optically Cutting in the Corneal Bed

It is technically more difficult to obtain the necessarily precise shape and thickness of the corneal parenchyma when the resection is performed in the corneal bed. The three basic methods are:

1. Optical cutting of the bed in the required shape by means of a burr (1).
2. Plane cutting, after previously modifying the curvature (3).
3. Keratectomy in acordance with the Law of Thickness (5).

1. Optical cutting by means of a burr:

Although it is theoretically simple in practice we encounter many technical difficulties, especially in the cutting of the central part because of the decrease in the lineal velocity of the instrument. A more complex instrument would possibly be more efficient but would also be difficult to apply to the corneal bed.

2. Plane cutting, after previously modifying the curvature:

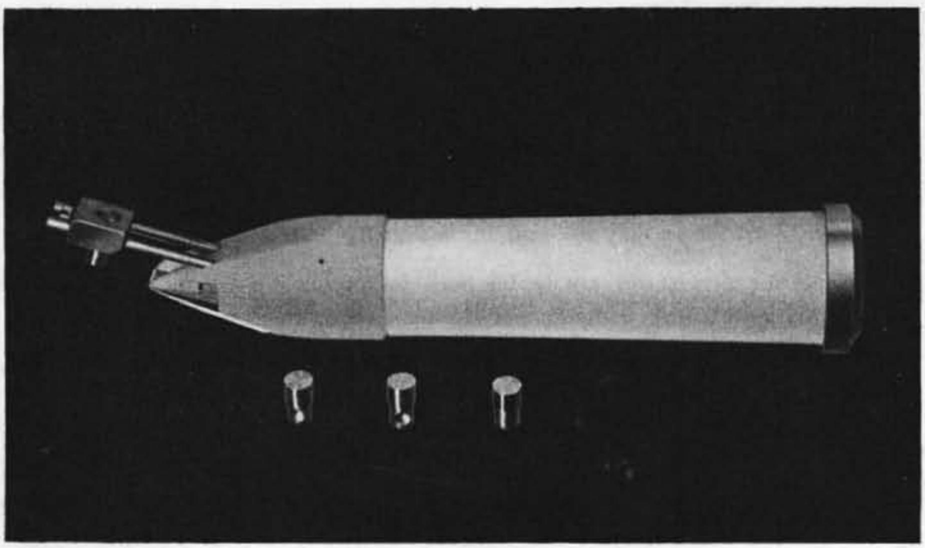


Fig. 53 Electrokeratome for flat section, with modification of the anterior curve of the cornea.

In practice this method is also dificult because of the necessity of using a 0-degree angle of attack for the cutting edge. However, we could overcome this difficulty in the cutting angle if we used a rigid wire instead of a blade.

Our instruments consist of a concave, interchangeable head for modifying the curvature of the cornea and of an electrokeratome for performing a straight section (24) (Fig. 53).

Strampelli has constructed a similar instrument in which the advance of the cutting blade is automatic (27).

3. The simple, central keratectomy:

The simple central keratectomy is based upon the "Law of Thickness".

It may be carried out either by resecting an interlamellar meniscus with parallel faces and precise dimension and thickness, or by resecting a positive corneal tissue lens of greater or lesser diameter in order to arrive at the desired thickness. The procedure may be accomplished by using a microkeratome or a burr under magnification. The intensity of the correction may be calculated in advance according to the sagitta of the respective arcs (5). In this technique, the resection of the tissue is always central and only serves to correct myopia (Fig. 54).

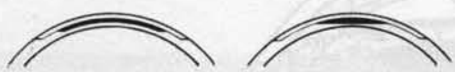


Fig. 54 Central Keratectomy:
a) With parallel faces.
b) Plano convex.

Krackwitz (28) has described an interlamellar resection which he carried out by means of a hollow punch after he had manually disected two successive layers of the cornea.

Anular resection for the correction of hypermetropia may be accomplished in four stages:

1. The resection of the anterior layers,
2. Delimitation of the central portion with a trephine,
3. The resection of the required thickness of the parenchyma, discarding the ring,
4. The replacement of the disc of the parenchyma and of the anterior layers.

B. *Grafting*

Grafting implies the substitution of one part of the recipient cornea, for a donor cornea of different thickness or size.

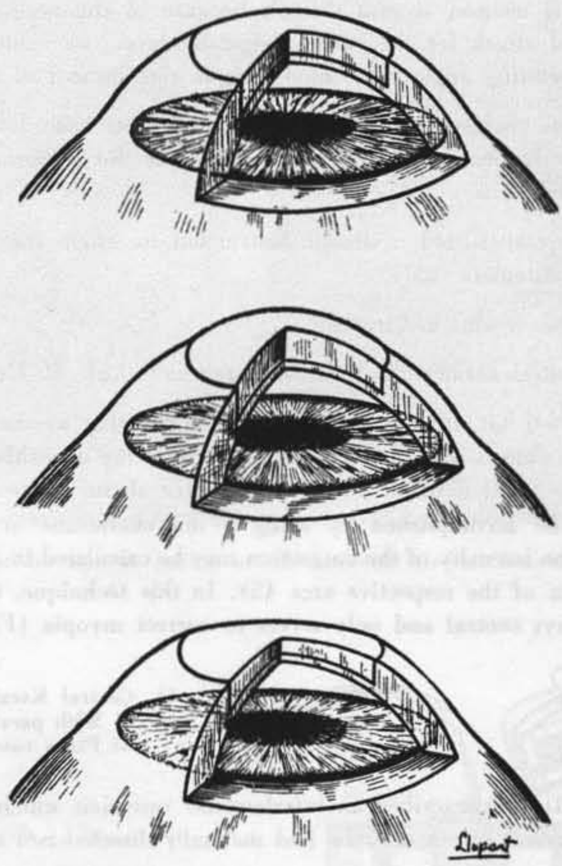


Fig. 55 Lamellar anterior keratoplasty with refractive grafts: a) Plano; b) Positive; c) Negative.

In this group, the keratoplasties are of the anterior lamellar type and may be autoplasties, homoplasties or heteroplasties, according to the source of the donor material (2, 3).

Anterior lamellar keratoplasties, using homografts with the exclusive end of modifying refraction, still are not performed although their low surgical risk and the small dimension of the cornea that is affected would seem to authorize them.

In optic lamellar keratoplasties, we can modify the refraction in order to correct a pre-existing ametropia, but we must always take into account the norms that

govern the curvature of the anterior face of the cornea in order to avoid the possible creation of secondary ametropia (22).

Three procedures may be employed to modify the anterior face of the cornea by means of lamellar keratoplasty:

a) A graft with an incorporated refractive value (22) (Fig. 55, 56).

Fig. 56 **Lamellar anterior keratoplasty with refractive grafts: a) Plano; b) Positive; c) Negative.**

b) A graft with parallel faces and thickness differing from the receiving bed (5) (Fig 13, 14).

c) We also may employ two mixed methods:

i) A lamellar graft covering a resection (1) (Fig. 57, 58).

ii) A lamellar graft covering an inclusion (1) (Fig. 59, 60).

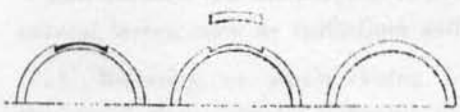


Fig. 57 **Lamellar graft covering a negative resection.**

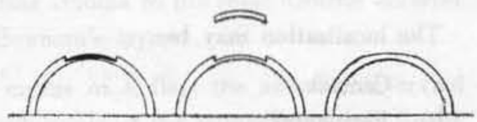


Fig. 58 **Lamellar graft covering a positive resection.**

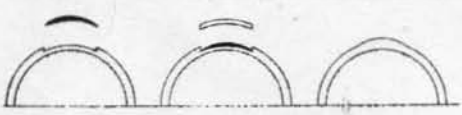


Fig. 59 **Lamellar graft covering a positive inclusion.**

Fig. 60 **Lamellar graft covering a negative inclusion.**

Since the optical cutting involved in refractive lamellar keratoplasty is performed on a donor eye, it has the advantage that it can be repeated on another donor eye if the first resection is defective. It also allows us the advantage of a greater thickness or corneal tissue which is necessary for some corrections.

The principal inconveniences are: 1) the necessity of obtaining a donor eye, and 2) the possibility of immunological reactions.

Autokeratoplasties in which the modification of the corneal tissue lenses is carried out extra corporally, are in reality resections and should be classified as such (33).

C. *Inclusion*

Inclusion implies the introduction of an implant of desired shape within the layers of the cornea (2, 3, 4) (Fig. 61).

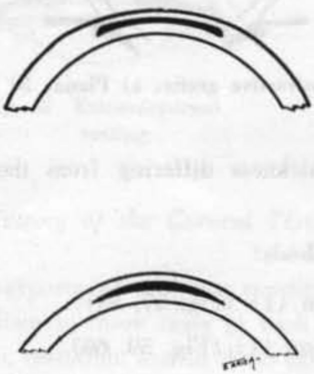


Fig. 61. Interlamellar inclusion. a) Negative corneal tissue lens; b) Positive corneal tissue lens.

The localization may be:

a) Central
b) Peripheral

and either, superficial or in depth.

According to the nature of the implant, the inclusion may be:

a) Autoplastic
b) Homoplastic
c) Heteroplastic
d) Aloplastic.

Contrary to the resection, the inclusion implies the introduction of tissue or foreign substance into the thickness of the corneal parenchyma. These introduced substances are well tolerated when they are autoplastic or homoplastic (Fig. 22, 23, 24), and are poorly tolerated in the other cases.

The interlamellar inclusions may be, according to shape:

a) Circular
b) Anular.

a) The circular inclusions of spherical or toric corneal tissue lenses, of positive or negative power, modify the curvature of the corneal surfaces (Keratophakia).

b) The inclusion of moderately-peripheral rings acts in the same way; however, it has the advantage that it does not surgically affect the central optical area of the cornea.

The principal inconvenience in corneal tissue lens inclusions is the double interface; the principal problems encountered in the inclusion of foreign materials are: late reaction to the foreign body, vascularization, opacification and expulsion (4).

We still have not been able to obtain sufficient regularity in the optical surface in those cases of anular inclusions.

However, we have been able to obtain good results both experimentally and clinically with interlamellar inclusions of corneal tissue lenses and corneal discs (4, 32, 33, 34). In both cases, we introduce into the corneal layers an implant of corneal tissue as near as possible to the anterior face. This implant may be a corneal tissue lens which has been optically cut according to the techniques already described, or it may simply be a corneal disc with parallel faces which acts, depending upon its dimensions, according to the "Law of Thickness" (Fig. 62).

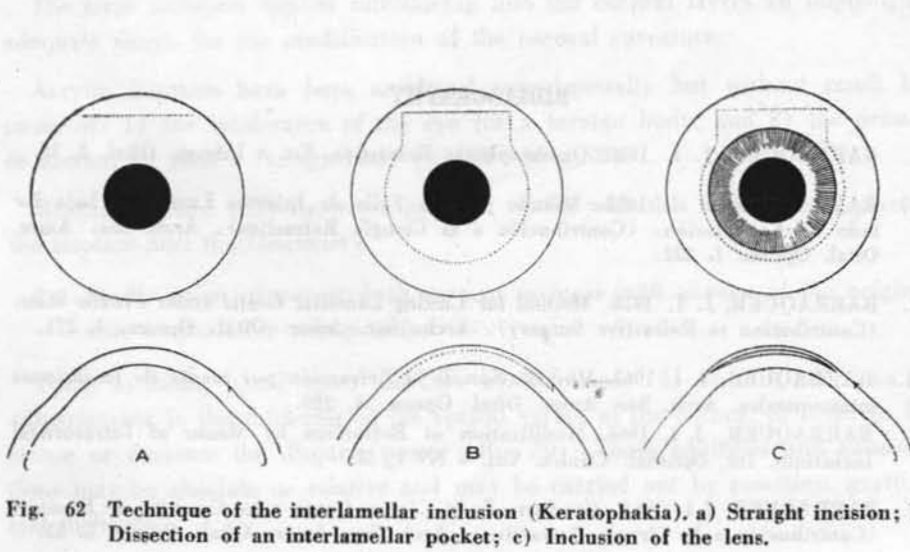


Fig. 62 Technique of the interlamellar inclusion (Keratophakia). a) Straight incision; b) Dissection of an interlamellar pocket; c) Inclusion of the lens.

COMMENTARY

Until the present time, the techniques that have proved most success have been interlamellar resections and inclusions. Physiologically we may divide these techniques into two large groups:

1. Techniques based on the regenerative process.
2. Techniques that do not depend upon the regenerative process.

In the first group, the surgical procedures construct the necessary conditions, pave the way, so to speak, for the cicatricial and regenerative process which produces its own optical result (lens).

In the second group, the corneal tissue lens is optically cut to the precise dioptric value required, and care is taken that the refractive result is not altered by the regenerative process.

The practical realization of these basic knowledges, is a question of technique and instrumentation, both in an unceasing striving for perfection.

In subsequent publications, we shall devote ourselves to a discussion of present techniques, instrumentation, surgical indications, methods for calculating the refractive correction, and complications.

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