THE RUPTURE OF THE ZONULE IN INTRA-CAPSULAR CATARACT EXTRACTION—A NEW METHOD*†

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THE rupture of the zonule (zonula Zinnii) of the crystalline lens is the *sine qua non* of intracapsular cataract extraction. It is the purpose of this paper to record some personal observations and experiences and to add them to existing knowledge of the best means of rupturing the zonule in various types of eyes with their different cataracts and zonules. The finding of a fairly large percentage of resistant zonules in the author's surgical experience is accounted for by the fact that the greater proportion of the cataracts operated upon are in the immature stage. In this period, both the capsule and the zonule are more nearly normal and resistant than in mature or hypermature cataracts when both capsule and zonule may be quite fragile. The author's system of intracapsular cataract surgery will be further explained and his new method for direct rupture of the zonule in difficult cases by stripping it from its attachment to the lens capsule will be elaborated upon.

Applied surgical anatomy. The zonule.—The zonule may be defined as the suspensory ligament of the crystalline lens. It consists of homogeneous glass-like fibres covered by a delicate lamella on their anterior surface, taking their origins from the ciliary body, and from the ora serrata where their arrangement undoubtedly accounts for its serrated appearance. The principal fibres run in the ciliary valley and by their early presence and strong formation account for the alternation of ciliary processes and valleys. Termination and insertion is made by the fibres splitting and diverging to fuse with the zonular or most superficial portion of the anterior lens capsule and with the capsule itself in its equatorial portion. In the living, normal eye with the zonule surrounded by aqueous, the lamella being of the same index of refraction as the aqueous, is invisible even with the magnifications possible with the slit-lamp microscope. Only when the eye is opened as in surgery or in the dissection of the fresh specimen is the lamella visible when exposed to the air, and then only when properly illuminated, best with parallel rays of incident light and

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viewed with magnification of two or more times. The descriptions of the older anatomists who examined fresh specimens and others who have recently done likewise, rather than those who come to depend upon fixed material, correspond with my clinical surgical observations. The processes of fixation, dehydration, imbedding, sectioning and staining cause the disappearance of the delicate zonular lamella.

The ligamentum hyaloidea capsulare.—Clinically, in intracapsular surgery the ligamentum hyaloidea capsulare does not seem to be more than a coaptation of the hyaloid to the posterior lens capsule, the easiest manoeuvres releasing it. Only in the rare or exceptional case are the hyaloid and the vitreous apparently really adherent to the posterior lens capsule being drawn up in cone shape when the lens is lifted vertically. In the average case, the ligamentum hyaloidea capsulare is easily separated by the manoeuvres directed at the rupture of the zonule and no particular attention need be directed to the former.

Embryology.—The origin of the zonular fibres, at least in the chick embryo, I believe, is in the prolongation of the protoplasmic adhesions which develop when the primary optic vesicle touches the surface ectoderm to stimulate the formation of the lens. After the development of the secondary optic vesicle, the fibres suspend the lens vesicle from the rim of the optic cup. As the ciliary body and iris grow forward from the rim, the fibres are further stretched out and finally in the adult reach between the ora serrata, the ciliary body and the equatorial portion of the lens capsule. The zonular lamella is most probably laid on at the time of the formation of the tertiary vitreous. It is a fallacy that the lens primordium is cast loose into optic vesicle and cup, the zonule being formed later at the time of development of the tertiary vitreous. My observations of the protoplasmic adhesions and the presence of primordial zonular fibres even at the time of the earliest lens formation were made in the course of microdissection of living chick embryos at various ages for the determination of the best age at which the lens might be removed in capsule for pure cultures of lens epithelium *in vitro*.¹ Prior to the time of five days incubation there is not enough space between the pigmented tissues and the lens for separation without leaving pigment cells still attached to the capsule and after five days the zonular fibres become too strong for separation without tearing away pigmented cells or lens capsule. Observations on living embryonic specimens gave me a clearer idea of the origin of the zonule than the study of fixed, stained and cut embryonic material.

The place of the rupture of the zonule.—Observations of cataracts removed in capsule demonstrate that the break in the

zonule is at its union or fusion with the lens capsule. The fibres are the strongest and most important part of the zonule and apparently do not break in twain but separate with a portion of the zonular lamella at the capsule leaving the equatorial portion of the cataract smooth and free from any and all evidence of broken fibre remnants. These findings are contrary to the report of Goldsmith² and others, but have been described separately and confirmed by Berliner³, and others. The clinical observation has also been made that in cases of traumatic subluxation of the lens, there are no microscopic bits or stubs of fibres of the zonule attached to the equator of the lens whereas in congenital subluxation, the defect or coloboma of the zonule is in the region of the ora serrata, the zonular fibres being visible in the area bared by the subluxation of the lens. The separation of the zonule at the capsule accounts for the lack of untoward reaction to surgery of eyes from which the lens has been properly removed in capsule. It also bears out my observation made previously that any pressure used to rupture the zonule should be point pressure or made in the narrow zone of attachment of the zonule to the capsule. Trauma, other than that of traction upon the ciliary body by the lesser zonular fibres, accounts for the development of cyclitis when it does occur after cataract surgery. The relatively low index of the complication of detachment or disinsertion of the retina after intracapsular surgery should calm the fears of those who believe that traction on fibres which took their origin at the zonule might produce separation of the retina.

Various manoeuvres for rupture of the zonule

The manoeuvres designed by various surgeons for rupture of the zonule in intra-capsular surgery are : I. Indirect Rupture by (a) Pressure from without, (b) Traction on the lens or its capsule and transmitted to the zonule, (c) Rotation of the lens in its capsule, (d) Various combinations of the above manoeuvres. II. Direct rupture of the zonule used alone or in combination with others of the various manoeuvres described above for indirect rupture to effect delivery by extraction or expression.

The rupture of the zonule is nearly always partial at first and is extended gradually through various forces until it is complete. The most important step in the rupture is the initial one. Some surgeons have one manoeuvre which they try to use in every case, making the eye adapt itself to the manoeuvre. For some eyes almost any manoeuvre is good and sufficient because the zonule is fragile. In case of failure either through inability to rupture the zonule or through rupture of the capsule or untoward immediate or later

effects in the eye itself, the blame is put upon the eye because of lack of adaptability. Rather should the surgeon have all of the above manoeuvres in his surgical armamentarium as his system for rupture of the zonule, and apply the one which is suitable to the particular case. All are valuable alone and in combination. Once started, a rupture may be extended by further procedure, the tear or dehiscence widening and enlarging from the starting point until the lens is freed.

Definitions.—By *indirect rupture of the zonule* is meant rupture by means of manoeuvres applied through an intermediary tissue, such as the cornea, sclera, lens capsule or vitreous, whereas *direct rupture of the zonule* refers to application of a manoeuvre directly to the zonule by a new method which has proved to be feasible and can be used safely and in a conservative manner under direct visual control when other manoeuvres fail.

The discussion of the various manoeuvres.—It will be well to consider each of the manoeuvres in order to evaluate them, to learn the limits of each in their application, to decide how to apply each to achieve the desired result with the least trauma to the eye, so that prompt graceful healing will supervene and long lasting excellent visual results obtained.

INDIRECT RUPTURE OF THE ZONULE

We will first consider the various manoeuvres producing *indirect rupture of the zonule* separately and together.

PRESSURE

Pressure may be applied directly to the lens or upon the outside of the eye. The ancient surgeons who couched lenses used pressure from within the eye after having pierced the cornea or more frequently the sclera. With a sharp instrument they impaled the lens or with a dull instrument they pressed against the lens forcing it back with the capsule broken or intact in the operation of depression or reclinatation. Apparently they found then as many resistant zonules as we do now, for when the latter were unyielding they often had to resort to the operation of opening the lens capsule and comminuting the cortex and nucleus, hoping for solution and absorption.

Smith⁴ was the greatest exponent of pressure as a means of rupturing the zonule for intracapsular delivery. I believe much can be learned from Smith's work, even though we do not agree that pressure alone is good. Because of anatomical relations, I believe that pressure should be applied by a relatively pointed instrument, as for example the tip of a fine lens expressor hook on

the outside of the cornea. Smith was probably the first to use a strabismus hook for the purpose. I found the tip of the Smith hook too large to be insinuated between the equator of the lens and the ring of the corneal limbus. I have the same objection to other blunt or rounded expressors. I have adapted the hook of Jamison⁵ for the purpose, and for ease of manipulation have put a 5 mm. cylindrical handle on it (Fig. 1). After making a superior limbus incision, I selected equidistant points below at 6, 8 and 4 o'clock on the corneal dial, just inside the ring of the limbus of the cornea, for the application of pressure. This semi-circular area is directly over the zonule where it joins the lower equator of the lens.

FIG. 1.

Half-size photograph of:—1. Kirby double-ended lens expressor hook. 2. Kirby lens expressor hook with lens loop at opposite end. 3. Kirby lens expressor hook with iris spatula at other end.

The point pressure I have used as an initial procedure before traction or rotation and have applied it in a fairly sudden and sharp fashion, indenting the cornea at the three points 2 to 3 mm., and causing the incision to gape diametrically opposite. Unless contraindicated, these points may be pressed upon a second time. In some cases, it is evident that a fragile zonule has ruptured below. In such a case, if such pressure were continued, the lens could easily be delivered by expression alone, tumbling out, the hook being insinuated through the cornea back of the lens, following it up in its tumbling manoeuvre and, as it makes its exit, sweeping away the cataract by stripping off the remaining upper zonule in all effects the same as Smith described years ago. I have seen a good many cataracts subluxate below in the manner described following the initial pressure, but have had no desire to tumble

them out by pressure alone because it is so easy to pick them up with a suitable forceps⁶ and lift them out because of the fragility of the zonules in such cases; and the principle of pressure alone for rupture of the lens in all cases is not a good one. I believe that pressure outside the limbus ring of the cornea is contra-indicated and ill-advised, unnecessary and inefficient, unduly traumatizing, and productive of complications both immediate and late. The use of blunt instruments for pressure is not good because they cover too wide an area, and do not reach the zonule and cause more trauma than necessary.

Point pressure.—The procedure of point pressure, as used by me⁷, does not affect rupture of the zonule below in over 15 per cent. of the cases operated upon. It does not rupture the zonule in the average case or in those with resistant zonules. However, if not contra-indicated it gives valuable information, even though rupture of the zonule below is not effected. It reveals the thickness and resistance of the cornea and sclera, the intra-ocular tension or pressure after the incision has been made, the condition of the vitreous, the size and shape and consistency of the cataract and thus permits me, as the surgeon, to judge how best to proceed with the extraction of the cataract.

TRACTION

Traction may be applied prior to the manoeuvre of pressure as Knapp⁸ first did with forceps, or it may be applied after or simultaneously within the pressure. I believe the latter most efficient⁹. The manoeuvre of traction may be applied (1) with a loop placed behind the lens, (2) with a pointed hook impaling the lens, (3) with the electro-coagulation electrode of La Carrère¹⁰, (4) with the suction cup either of Dimitry¹¹ or Bell¹² or the erisphake of Barraquer¹³, (5) with the aid of forceps grasping the anterior capsule of the lens.

Traction alone is not a good manoeuvre for rupturing the zonule unless it is applied to certain sections of the zonule at a time. The zonule as a whole is relatively strong and it stands to reason that the zonule as a whole is more resistant than any of its continuous parts. Non-traumatic cataract surgery must be based on a system of a small initial rupture of the zonule being made, this being extended until the whole zonule is ruptured and the lens made free for delivery.

1. *The loop.*—The use of traction by the loop may be indicated when the zonule is partially ruptured, when the loop may be passed through the area of the rupture. It does not seem advisable to use it routinely or to create the initial rupture in the zonule above the loop being passed through it according to the old technique of

Pagenstecher¹⁴ even though he said he could pass it between the posterior capsule and the hyaloid without disturbing the vitreous. Once in place the loop behind the lens, in cases of subluxation, is a good instrument to support the lens and to withdraw it, provided the zonule is fragile, but not so when the zonule is resistant, then it is better judgment to use other manoeuvres as indicated. I have used the loop to bring the subluxated lens into position for use of forceps on the lens capsule and then have used the loop to strip off the portion of the zonule which is still adherent so that the lens may be freed for delivery. If viscid vitreous is anterior to the lens, then the loop is apparently the only safe instrument to use to get the lens into position for extraction. There is hardly any need for a barbed hook or vectis, based on the principle of the points engaging the lens for greater traction.

2. *The pointed hook.*—The pointed hook has been used by some to impale the lens and to draw it from the eye. Those who have done much capsulotomy surgery and have used the cystotome have undoubtedly all had the experience of the lens nucleus being fixed by the point and the zonule when fragile being ruptured and the cataract being withdrawn from the eye. The puncturing of the capsule in this manner will only give a small percentage of deliveries in capsule in the average case even though purposefully applied and it cannot be recommended.

3. *Electro-coagulation electrode.*—The electro-coagulation electrode of La Carrère has been used for changing the protein of the lens cortex and nucleus, causing it to adhere to the electrode and thus permitting the withdrawal of the lens in its capsule. This may be feasible if the zonule is weak, but the procedure can hardly be said to change or weaken the zonule unless it is carried to an unsafe and traumatizing degree. I have had no experience with it.

4. *The suction cup—erisiphake.*—The suction cup of Dimitry or Bell or the erisiphake of Barraquer would be excellent instruments for traction alone, if it were desirable to take up a relatively large portion of the capsule. This would be true if the zonule were always fragile or if it broke as a whole, instead of starting at a small area and then tearing gradually from this beginning. The suction cup is usually applied near the central area of the anterior lens capsule tenting up the entire capsule and zonule if lifted directly up. It is appreciated that in practice the manoeuvres of drawing the cup toward the surgeon as well as of turning the instrument to one side or to the other are feasible, but still the area of capsule affected is too large for easy rupture of the zonule. The instruments are relatively clumsy in their application, take up too much room and do not permit of the application of point pressure, or of rotation or of direct rupture of the zonule by stripping it off

the capsule as adjuvants in the removal of cataracts with resistant zonules. It is true that the suction cup can be applied to the tense or taut and rubbery capsule in certain cases of intumescent cataract when attempts to take up the capsule with forceps fail, but unless the zonule in such cases is found to be fragile, it might be better to release the grasp of the suction cup and to remove some of the fluid from the lens by aspiration as done by Traquair¹⁵ or by point puncture as done by Riddell¹⁶ and then proceed with forceps extraction in capsule. I have not had experience in doing this, but I have opened the capsule and proceeded with the capsulotomy extraction. In some cases where it is evident in the pre-operative examination that the capsule is taut, it has seemed best judgment to permit the cataract to go on to maturity, when it could be handled more gracefully. I appreciate the fact that Barraquer has had success that is admirable, but still the objections as detailed above have been learned in a practical way by others who have tried the use of the suction cup.

The technique of Barraquer includes the principle of traction through the medium of a relatively strong suction effect, which permits considerable direct traction effect with the application of the pressure below and at the side as well as torsional effect combined with pressure through the cornea on the zonule which is under tension, tumbling the lens from one side to the other. The lesser degrees of traction obtainable with the suction syringe of Dimitry or the pipette suction tip of Bell do not afford enough negative pressure to tumble the lens on its vertical axis. Fortunately, it is true that with lesser degrees of suction, the cup will come loose before too much traction is made upon a resistant zonule.

5. *Forceps*.—All surgeons who did capsulotomy extractions, including von Graefe, have most probably had the experience of having the lens coming away in capsule when using toothed capsule forceps designed to remove a segment of the anterior capsule. The teeth have penetrated the relatively thin capsule and have taken a sufficiently firm hold on the hard nucleus to effect with traction the rupture of a fragile zonule.

This happened frequently to Kalt¹⁷, who used his relatively smooth bladed forceps for removal of a section of the capsule, so he purposefully tried to remove the average cataract in its capsule, succeeding in 25 per cent. of the cases. Knapp found no reason to change the model of the Kalt forceps for his intra-capsular cataract surgery and succeeded because he found an efficient method of using them. Various surgeons have devised special forceps. The concave curve of Kalt's forceps¹⁸ adjusts itself to the convexity of the anterior face of the lens and seems best adapted

to get down to grasp the lowermost portion of the capsule. The Elschnig forceps modified by Arruga¹⁹ have been most popular and useful. The Sinclair forceps modified by Castroviejo²⁰ are of the cross-action type which, when relaxed and closed, hold the grasp of the capsule with a certain pressure, regulated by spring tension which may be adjusted to the desired degree. Arruga forceps blades are well adapted to grasping the area of the capsule just anterior to the superior equator of the lens as Verhoeff²¹ has done, and it was for this reason that I adopted them.

New intra-capsular forceps.—In developing a new intra-capsular forceps, I combined different features—the length from Kalt, the angle and blades from Arruga, the stops from Verhoeff²² and have added my own useful cylindrical handle (Figs. 2 and 3). The angle enables one to bring in the instrument from the side and not obscure the field with the hand as in using a straight shafted instrument. I have modified this forceps by using the Kalt concave curve of the shank for special use when I desire to take hold below and tumble the lens. Both of these forceps provide shafts long enough to fit easily into the hand, with cylindrical handles for graceful manipulations. They have the Verhoeff stops, one controlling the opening so that the 4 mm. opening can be adjusted without tension and placed ever so lightly on the lens capsule without pressure and the other controlling the closure so that the blades will not bite out a portion of the capsule unnecessarily. Various cups have been tried and

FIG. 2.

Two-third size photograph of:—1. Intracapsular forceps. 2. Iris forceps. 3. Corneo-scleral suture forceps. Front view.

FIG. 3.

Two-third size photograph of:—1. Intracapsular forceps. 2. Iris forceps. 3. Corneo-scleral suture forceps. Side view.

that of Arruga has been selected and incorporated, but it has been offset by 1 mm. from the tip of the curved shank so that it will pick up the capsule only in the relatively small area of the blades and not have the shank behind the blades engage anything else. Such forceps permit the greatest ease of application, manoeuvrability and safety in handling the capsule and affecting various tensions that are purposefully transmitted to small areas of the zonules for simultaneous application and combination with the manoeuvres of pressure, rotation and direct zonulotomy by stripping the zonule from its attachment to the capsule.

Traction as it has been described by various surgeons includes pull tensions made by drawing the capsule vertically, horizontally both forward and transversely, tangentially and diagonally. Forceps are well adapted for the manoeuvres of traction and rotation (Verhoeff described a manoeuvre of "the upper part of the lens swing to and fro laterally with the forceps").

ROTATION

The manoeuvre is a variation of traction, but is important enough to be considered separately. It causes the lens to turn in the circle of its circumference by traction on the capsule preferably from a point of advantage of grasp just anterior to the true equator of the lens. It is valuable because it puts a tension on the zonule directly surrounding the lens, emphasizing with traction the formation of a tense fold or plica of zonule opposite the point of traction and rotation which may be pressed upon through the

cornea for the greatest rupturing effect with the least effort. The same use of traction and rotation may be made in aiding the manoeuvre of direct rupture of the zonule by stripping it from its attachment to the capsule. There are two other uses for rotation which are valuable. The first is achieved when with the upper half of the zonule ruptured, the application of a second pair of forceps to the lens capsule makes possible further rotation. The zonule below may then be ruptured or torn by wheeling the lens around in the circle of its circumference. The second is the wheel rotation type of delivery rather than the flat sliding delivery, the former offering quite an advantage, there apparently being easier separation of the ligamentum hyaloidea capsulare and less drag on the bared hyaloid or face of the vitreous.

THE APPLICATION OF FORCEPS

Forceps may be applied, except when pressure is inadvisable, simultaneously with pressure from below, causing the lens to tilt, present and be supported by the instrument. Forceps may be (1) applied radially to the capsule below, as far below as can be reached conveniently; (2) to the central area of the capsule; (3) horizontally or vertically to the equatorial region directly above; and (4) to an area just to the right of centre above when the forceps are held in the left hand and *vice versa* when held in the right hand. For a right-handed surgeon it seems easier and more efficient to use the forceps in the left hand and the expressor instrument in the right hand.

1. When the forceps are applied below, the application is radial. It is possible to lift the lens vertically about 2 mm. toward the cornea, horizontally, transversely or cephaled to either side about 3 mm. and about the same diagonally or in rotation. Evidently these movements from the grasp below cause sufficient rupturing action on the zonule, for by the Knapp method with traction alone or by the Knapp²³, Lancaster²⁴, Torok²⁵, Stanculeanu²⁶, Elschnig²⁷, Arruga¹⁹ and other methods of simultaneous traction and pressure, a large percentage of zonules may be ruptured and the cataracts delivered well and safely by tumbling them out in the capsule. 2. When the capsule is grasped at or near the centre it is apt to cause equal although insufficient tension on the zonule all around the equator. This will result in a lesser percentage of safe deliveries in capsule. 3. The grasp of the capsule tangentially just anterior to the true equator above according to Verhoeff, offers several advantages. (a) The surgeon can see better what he is doing, particularly when the corneal flap is lifted. (b) He can make localized traction directly away from the nearby zonule. (c) He can produce greater tension and direct it to

particular localized areas on the zonule as desired as he elevates the area of capsule vertically, makes traction to one side or the other and obtains greater rotational effect. (d) He can lift the lens away from the hyaloid and the vitreous. With the direct visual knowledge of what is happening, he can direct his pressure to the point where it will accomplish the most good with the least effort, to the narrow fold of zonule which is under tension, rupturing it more easily than if he applied much more pressure to a relaxed area of zonule or to a greater area in the same eye. When he wishes to produce direct rupture of the zonule by stripping it from its attachment to the capsule at the equator of the lens, he can by traction and rotation produce tension on the exact or certain area of the zonule which is to be touched for direct rupture. The traction superiorly also lifts the equator of the lens and zonule free from the relaxed vitreous to at least 3 mm. so that such manoeuvres are safe. Verhoeff said that the grasp of the capsule above could only be made if a complete coloboma of the iris has been made. I have demonstrated on numerous occasions that with the pupil dilated, the forceps can be made to grasp the lens tangentially, offering all of the advantages of the sliding delivery of Verhoeff. Certainly in difficult cases it is necessary to have as peripheral a grasp as possible so that the equator of the lens and the zonule may be lifted most easily and efficiently. In the grasp above, the horizontal tangential application of forceps above is better than a radial grasp because rotation to either side may be made without twisting the pedicle of the capsule by following the curve of the circle of the equator of the lens. Another advantage is that the surgeon may observe the behaviour of the capsule in the grasp of the forceps and, being aware of the imminence of a tear, change his tactics and avert it. He may shift to different portions of the capsule. A final advantage is that if a small tear in the capsule does develop, he can shift to another untouched portion of capsule above, and manoeuvring around the tear deliver the lens in capsule, or he may even go below to pick up the capsule and tumble the lens out. It might seem well when the manoeuvre of initial pressure alone has ruptured the zonule below that one would apply forceps below and tumble the lens out, but the application superiorly offers no difficulty, the zonule is fragile in such cases, the lens is lifted out easily and I believe the sliding delivery or rotational delivery is less disturbing to the vitreous than the tumbling delivery.

THE USE OF TWO PAIRS OF FORCEPS

It occasionally happens that with the technique of the application of forceps above, rotation to each side has effectively torn and released the zonule to the extent of the corneo-scleral incision and

there remains adherent the lower zonule still holding the lens. Pressure and traction may release this easily, but if not, I have found that a second pair of intra-capsular forceps applied judiciously behind the first pair may be used for further rotation and cause the further tearing of the zonule necessary for the delivery of the cataract.

THE REMOVAL OF THE RUPTURED CAPSULE

A method of removal of the remains of the capsule when it is ruptured in the extraction of cataract is called for in this discussion of rupture of the zonule. If a portion of capsule is visible in the incision or if with safe, relaxed patients the capsule can be identified when the corneal flap is elevated, then it can be picked up with a pair of intra-capsular forceps and judicious traction made upon it. No effort is made to draw out the entire capsule with one pair of forceps, but after a little has been withdrawn a second pair may be used nearer the incision, and so hand over hand the two forceps may effectively, easily and safely rupture the remaining zonule and remove the broken capsule completely or sufficiently.

Direct rupture of the zonule

(a) *Direct partial zonulotomy* by means of sharp instruments specially designed for the purpose as applied by Gradenigo²⁸ and others may, if properly used, accurately sever in part the zonular connections with the capsule, facilitating the complete rupture and permitting the delivery of the lens by extraction or expression, but the manoeuvre seems fraught with danger, particularly because with the collapse of the anterior and posterior chambers there is little space or margin of safety in which to work without disturbing the hyaloid and the vitreous.

(b) *Direct rupture of the zonule* by separating or stripping it from its attachment to the capsule superiorly under direct view is the new procedure which I have devised and used when the zonule proved resistant and resilient, difficult to rupture and not yielding to a safe degree of pressure, traction and rotation. I have stated previously that traction vertically with forceps lifted the lens and zonule at least 3 mm. safely away from the relaxed hyaloid and vitreous, furnishing adequate space for the manoeuvre of touching the zonule made tense by the vertical elevation or by rotation to one side or the other with a blunt instrument. A light touch under these conditions may cause the zonule to rupture in part, producing at first a small hole or dehiscence at the equator then, by further application of the instrument, a larger hole. Then by rotation, the zonule may be seen to tear further or it may be

FIG. 4.

Method of holding and rotating angulated iris spatula with Kirby cylindrical handle.

FIG. 5.

First point of preliminary pressure for palpation of the globe and test of fragility of zonule. Note the degree and position of the point of pressure and the effect of gaping of the incision directly opposite. Front view.

Fig. 6.

The corneal flap is retracted by the suture. Manoeuvre of rotation of the lens to the right, to the 120° meridian with pressure directly opposite at 300° meridian. The zonule is loose nasally. This is one of a series of three illustrations showing the point of pressure and the rotation of the lens. Front view.

FIG. 7.

Lens rotated to the left and elevated making zonule tense at the left. Application of blunt elbow of lens expressor hook to tensed zonule directly at junction with the capsule for direct separation of the zonule from the equator of the lens. The appearance of the zonule is considerably intensified by the artist. Surgeon's view.

stripped from its attachment to the lens capsule by further use of this manoeuvre. The natural tendency has been to extend the successful use of the procedure to cases in which the cataract does not come away very easily by traction, pressure and rotation. Only in one case which has been reported previously have I had occasion to regret the use of the manoeuvre²⁹. (Figs. 4, 5, 6, 7.)

The indications for direct rupture of the zonule

There is no way of determining before the operation that in a certain case a recommended or average degree of pressure or traction should be used, because the individual cases vary and often need more than simple pressure, traction or rotation either applied separately or simultaneously and in combination. The new manoeuvre of direct rupture of the zonule by stripping it from its attachment to the capsule under direct visual control is valuable and should be studied for use when pressure, traction and rotation are insufficient and if when applied to greater degree may be traumatizing. It may also be indicated in cases of subluxation with viscid or fluid vitreous which is in communication with the aqueous of the anterior chamber. The escape of fluid vitreous, directly after the section has been made, causes the intra-ocular tension to fall so low that pressure is of no value at all in the effort to rupture the zonule. The presence of a resistant zonule in congenital or traumatic subluxation requires more than traction with a loop alone for non-traumatic delivery of the lens.

Clinically, in intracapsular surgery the ligamentum hyaloidea capsulare does not seem to be more than a coaptation of the hyaloid to the posterior lens capsule, the easiest manoeuvres releasing it. Only in the rare or exceptional case are the hyaloid and the vitreous apparently really adherent to the posterior lens capsule being drawn up in cone shape when the lens is lifted vertically. In the average case, the ligamentum hyaloidea capsulare is easily separated by the manoeuvres directed at the rupture of the zonule and no particular attention need be directed to the former.

The conditions under which direct rupture of the zonule is safe and practical

These may be stated as (1) the finding of a resilient zonule which resists rupture by the application of pressure, traction and rotation applied simultaneously and in co-ordination. (2) The proper relaxation of surgeon and patient. (3) Proper illumination by parallel beam spot light, extraneous light and glare being excluded. (4) The observation that no undue tensions exist in the eye under operation, there being no gaping of the incision, no prolapse of the iris, no forward position of the lens, hyaloid or

vitreous. (5) The corneal flap should be elevated to afford a direct view of the lens equator which is exposed by retraction of the iris, by removal of blood clots, serum or other fluid, so that the zonule which extends from the equator backward is visible when exposed to the air and viewed with a binocular loupe which affords two power magnification. (6) There should be about 3 mm. distance between the lens equator and the relaxed vitreous and hyaloid. (7) The zonule must be made tense as described to make the manoeuvre easily effective. If all of these conditions are not met, then the manoeuvres should not be attempted. Manipulation, particularly under conditions of poor visibility, may lead to rupture of the hyaloid. In general, it may be said that any surgeon who is acute in observation and does intra-capsular surgery well, should be able to carry out this manoeuvre.

I personally prefer the grasp of the forceps above for the reasons given. If a surgeon has had good success with the radial application of the forceps below, as many have had, he should not be asked to give it up. Cases which are easy or give moderate difficulty with the lower grasp will not be different with the upper grasp, but, when one has a difficult case which resists rupture under these conditions, one may not wish to continue to do that which is ineffective, and one may decide to try the grasp above and to apply the manoeuvres which have been described. Those who use the grasp above need not think that the first grasp with the forceps is the only one which they may take in a particular case. If, for example, it is found that the first grasp is an inefficient one, it may be released and a second one taken, or if in a certain case the first grasp is not near enough to the equator above or below, another one may be taken. Verhoeff has shown that with properly adjusted forceps the grasp may be shifted. In the case of the grasp above, the first forceps may be used to assist in downward traction on the lens capsule for better exposure of the pre-equatorial portion of the capsule.

Results

The results of intra-capsular cataract surgery in my hands during the past fifteen years, in comparison with a previous period of ten years of extra-capsular surgery, justify the continuance of the methods and procedures of the intra-capsular surgery described in this paper. In addition, I may say that the direct rupture of the zonule has been used for ten years. I have had only one occasion to regret its use. It may well be said to be feasible, conservative and desirable where the zonule is found too resistant and difficult to rupture after trial by the other means described.

Summary and conclusions

The rupture of the zonule of the crystalline lens is the *sine qua non* of the intra-capsular cataract extraction. The author has recorded his personal observations and experiences, to add them to the existing knowledge of the best atraumatic means of rupturing the zonule in various types of eyes with their different types of cataracts and zonules. The findings of a fairly large percentage of resistant zonules, in the author's surgical experience, is accounted for by the fact that the greater proportion of the cataracts operated upon are in the immature stage. In this period, both the capsule and the zonule are more nearly normal and resistant to rupture than in mature or hypermature cataracts, when both capsule and zonule may be quite fragile.

In observations of the applied anatomy during clinical surgery the zonule is observed as a lamella covering the fibres. The zonule is visible when exposed to the air and viewed with two power magnification. Dissections of early chick embryos brought out the finding that the zonular fibres may well be formed through elongations of protoplasmic adhesions established at the time of contact of the optic vesicle with lens ectoderm. The lamella may be added at the time of the formation of the tertiary vitreous.

The zonule usually ruptures in a small area first and gradually the entire zonule is separated. The place of rupture of the zonule is always at its union with the lens capsule. The latter is smooth after intra-capsular extraction.

The various manoeuvres for rupture of the zonule may be found classed under I, *Indirect rupture* (a) pressure from outside the globe, (b) traction on the lens or its capsule and transmitted to the zonule. This includes rotation of the lens in its capsule, (c) various combinations of these manoeuvres. II, *Direct rupture* of the zonule used alone or in combination with the various manoeuvres which cause indirect rupture.

Each of these manoeuvres is considered alone and in combination with others. The principles underlying the classical and well known operations of various authors are explained. Pressure alone may be found to rupture fragile zonules, but traction is preferred for delivery even in such cases. A combination of pressure and traction is more efficient than either alone. Rotation of the lens in its capsule is used particularly to produce conditions whereby pressure and traction may be co-ordinated to produce the greatest effect with the least effort. The method of shifting the grasp of the forceps or the use of a second pair of forceps to provide greater rotation when necessary is given.

The reasons for the preference of the grasp of forceps over that of the suction cup or the use of the loop or spoon are given.

Rotational delivery is preferred to the direct sliding or the tumbling methods.

The new method of feasible and practical direct rupture of the zonule by separating or stripping it from its attachment to the equatorial lens capsule has been partially considered and reported before. To the present date, the author has not found any similar method in the literature. The indications for its use, the determination of the cases in which resistance of the zonule is found, and the conditions under which direct rupture of the zonule may be applied successfully without injury to the hyaloid, presentation or loss of vitreous are given.

The author prefers the grasp of the forceps above for various reasons. If many others have had success with the grasp below, there is no need for them to change. But, if a difficult case is encountered, the grasp of the forceps may be shifted above and the manoeuvres, as described, may be tried. Those who use the upper grasp may find that they may shift the grasp above to one nearer the superior equator if necessary. A second pair of forceps may assist in this in drawing down the pre-equatorial capsule. The author reports the further application of the procedure as desirable, feasible and practical in difficult cases of cataract with resistant zonules. A follow-up of the cases in which this manoeuvre has been applied in a period of five years has proved that there has been no undue reaction, inflammation or infection, that the eyes have done well and that there has been good healing with good visual results.

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STUDIES ON THE INTRA-OCULAR FLUIDS*

1.—The Reducing Substances in the Aqueous Humour and Vitreous Body

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In a recent paper to this Journal (Duke-Elder and Davson, 1948) a general review of the present position of our knowledge regarding the nature of the intra-ocular fluids was given; the present paper deals more particularly with our experimental work on the reducing substances (sugars, etc.) in the aqueous humour and the vitreous body. It has long been recognized that the concentration

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