but never entirely cured. When I first saw him: on everting his upper eyelids I found the conjunctiva bluish and congested in patches with white lines of cicatrices, and no granulations. In the fornices were rolls of wavy semi-translucent looking conjunctiva; in the right eye there was a small faceted ulcer of the cornea with a clear surface, and some amount of pannus. I applied the acetic acid treatment to the wavy-looking conjunctiva, and followed it with applications of solution of nitrate of silver, 2 per cent., once every week. After several applications he appeared to be cured and I lost sight of him for a few months. He appeared again one day with acute inflammation of the right eye: on everting the eyelid I found a linear swelling extending along almost the whole length of the eyelid. Expecting to find pus I incised the swelling, and uncovered four lymphoid bodies about the size of hemp seeds, which I removed.

I saw this man several times afterwards at long intervals, and found that his eyes gave him no more trouble except a little irritation on windy dusty days which might be expected from the dry cicatricial condition of his conjunctiva.

BARRAQUER'S OPERATION

BY

J. RUSSELL SMITH, M.R.C.S.

LONDON

"I do not believe in violence—especially if it is not likely to be successful."

I AM indebted for this quotation to my father, Lt.-Col. H. Smith, C.I.E., I.M.S.(ret.), whose experience of some 50,000 cataract operations performed during his time as Civil Surgeon of Jallandar and Amritsar, Central Punjab, has been of the greatest assistance to me in writing this article. The quotation is taken from the first edition of the "Collected Public Addresses of Gandhi," whose policy was to "spiritualize" Indian politics in order to bring them into harmony with the Holy Writ of Hinduism.

Professor Barraquer's article in Dr. W. A. Fisher's book on "Senile Cataract," in the edition published in 1923, by the Chicago Eye, Ear, Nose, and Throat College (obtainable from Messrs. H. K. Lewis & Co.), is a mine of information which well repays careful study. He seems to have evolved a method of dislocating and extracting the cataractous lens in its capsule, which, if the claims he makes for it are correct, constitutes a revolution of the very greatest importance. For to quote from page 38: "Facoerisis

consists in drawing the crystalline lens by its anterior surface, separating it mechanically without either traction or violence of the zonula (suspensory ligament) and extracting it completely out of the eyeball, without having produced ectopias or traumatism to the intraocular structures. The instrument employed, called the Erisifaco, is nothing more than a pneumatic forceps and a zonulatome. Fig. 39 represents a longitudinal section of the Erisifaco and of the intermittent or vibratory pump which is employed to work it." A critical examination of these claims should be of interest to the profession.

The first thing to examine is this vibratory pump on which a very large part of the claims for the method are based. A year

FIG. 1.

Fig. 39 from Barraquer. Section of pump and handpiece (vertical section).

or so ago Professor Barraquer did my father the kindness of presenting him with a complete outfit for facoerisis. Messrs. Down Bros. took the apparatus to pieces for us and examined it minutely. It is an ingenious and exquisitely made piece of machinery. In my description of it the numbers in brackets refer to Professor Barraquer's diagram, Fig. 39, in his article, which I reproduce as Fig. 1.

The pump consists of an inner cylinder (29) which is solid except for a transverse tunnel (30) bored across its lower part at right angles to the vertical axis about which it revolves. In the bottom of this cylinder there is a fairly wide central circular hole which is bored from its under surface into the transverse tunnel. This hole is in line with the shaft attached to the inner revolving cylinder above, on which is fixed the armature of the electric motor which drives the machine. It engages with the pin (33) which projects upwards from the bottom of the case, and the two form part of the bearings of the machine. The outer part of the

pump consists of a cylindrical case, which above contains the magnets of the motor, below is accurately machined on the inside to fit the central revolving cylinder (29). In it are two holes (35 and 37). These are placed diametrically opposite one another in the horizontal plane in which lies the axis of the transverse piston tunnel bored in the inner revolving cylinder (29). Hole 35 is the air inlet to the pump; hole 37 the air outlet. The transverse piston tunnel contains a solid piston, not long enough to fill it, and machined accurately to fit its walls. In the middle of this piston,

FIG. 2.

Transverse section through pump at various stages in the cycle of operations.

on its under surface, is a transverse slot in which works a small eccentric projection (A) of the pin (33) fixed in the case.

The working of the pump is easily explained by the diagrams in Fig. 2, which represent horizontal sections through holes 35 and 37, and the piston tunnel at successive phases in one revolution of the central cylinder. The small eccentric pin attached to the case is set so that at the starting point (Fig. 2A) when the tunnel is in line with the two holes 25 and 37, the end of the piston which is opposite hole 37 is in contact with the walls of the case; the end opposite hole 35 is furthest away from them. The next three diagrams represent the intermediate stages, the fourth the completion of half a revolution, while in the last the track taken by the ends of the piston is dotted out. It will be seen how they gradually leave the wall of the case as they pass from hole 37 towards hole 35, so producing a space in the tunnel into which the oil cannot get to fill it up as fast as it is formed, for the parts are as accurately machined and fitted together as the engine of a Rolls-Royce motor car. When the tunnel reaches hole 35 air rushes

from the latter into the space to fill up the vacuum which has been formed in it. In the second half of the cycle the piston again approaches the walls of the case, so compressing the air in the tunnel, and expelling it finally through hole 37.

It is thus clear that once in each half revolution air is sucked in from the tubing attached to hole 35, and a sudden alteration is produced in the pressure of that which remains behind—the variation in the intensity of the vacuum, termed by Professor Barraquer its interruption or vibration. The rate at which these variations succeed one another is 5,000 per minute, according to his account

FIG. 3.

Diagram of variable air leak.

on page 98, which involves the pump running at 2,500 r.p.m. The degree to which it is capable of exhausting the air in a closed chamber attached to it is dependent on several factors, the vapour pressure of the oil used being the ultimate theoretical limit. In practice the speed at which it works has some bearing, and varies with the viscosity of the oil used and the voltage of the current applied to the motor. Professor Barraquer supplies oil of relatively high viscosity, but Weiss told me that they found it to be most efficient with the thinnest oil available.

The device, which is used to regulate the intensity of the vacuum and the amplitude of the variations in it, is most ingenious. It is attached in different machines to different parts of the apparatus, and has been altered in detail in successive models, but in all it is in principle the same. It is a variable air leak, Fig. 3, which can be set to let air into the apparatus at any desired rate. In its latest form it consists of two parts, an inner and an outer metal tube whose adjacent surfaces are machined to a conical shape and fit one another accurately. There is a hole drilled through the

inner part which is the only communication between the exterior and the interior of the apparatus except that at the cup of the Erisifaco. This latter is normally sealed by the lens when it is in action or shut off by the valve in the handpiece. On the outer conical surface of the inner tube is a V-shaped groove which starts from the hole and passes round in a circle almost but not quite to the hole again. It gets gradually shallower until it finally fades away into a short piece of smooth surface lying between its own end and the hole. The outer part has also a hole through it, which, when the two are fitted together, overlies the hole in the inner part or some point on the circle in which the groove in it is cut. The two parts are not secured to one another mechanically, but can be twisted round freely to occupy any desired relation and fixed in position by simply pressing them together. It is clear that when the two holes overlie one another, air can get into the apparatus as fast as the pump can take it out. As the outer hole is turned round over the groove the channel through which air can enter gets smaller and smaller. Finally, when it lies over the small piece of smooth surface on the inner portion between the end of the groove and the hole in the latter, there is complete obstruction to the passage of air if the two parts of the regulator are pressed firmly together.

When the air leak is set fully open there can be no vacuum produced in the tubing; there is merely a discontinuous flow of air through it. As the regulator is turned round an obstruction is set up to the entry of air and becomes gradually greater, since the size of the hole through which it must enter becomes smaller and smaller. The intensity of the vacuum produced in the interior of the apparatus is determined by equilibrium being reached between the rate at which air enters it through the air leak and that at which air is extracted by the pump from it. The same factors are responsible for the difference in the amplitude of the periodic variations in its intensity (the vibrations or interruptions of Barraquer) when the vacuum is high and low in degree. But before proceeding to elucidate these points I wish for the sake of convenience to make one change in Barraquer's terminology. On page 58 he says that the intensity of the vacuum required varies between 50 and 70 cm. Hg. These figures clearly refer to the difference between the pressure of the atmosphere, 76 cm. Hg, and the mean pressure of the air inside the apparatus. But the intensity of the vacuum is more correctly measured in terms of the latter—that is the custom in most physical experiments on expansion of gases. That is to say, Barraquer's vacua of 50 and 70 cm. Hg would be better described as being of 26 and 6 cm. Hg. It is a small point, but helps to simplify the explanation of the diagrams in Figs. 4 and 5.

We must first make sure of our definitions. What exactly is meant by the phrase "rate of air flow" through a hole or channel?

FIG. 4.

FIG. 5.

How can we compare one rate with another? The simplest method is to compare units of *weight* of air passing a given point in a unit of time. If we compare units of volume per unit of time we must measure those volumes at the same pressure, for by Boyle's Law

of the expansion of gases the volume of a given weight of a gas is inversely proportional to its pressure.

The graphs in Figs. 4 and 5 are frankly diagrammatic and are based on a deduction of what ought to happen from theoretical consideration only. The first, Fig. 4A, shows how the rate of air flow through the air leak is affected by variations in the intensity of the vacuum. The former is plotted vertically against the pressure difference between the outside and the inside of the air leak. It is directly proportional to the latter, the size of the air leak remaining constant and the ensuing graph is a straight line. The different lines are the graphs with different sizes of air leak, being horizontal when there is no leak at all, increasing in slope to nearly vertical as the air leak is opened to its full size. Fig. 4B shows how the rate at which the pump can extract air from the apparatus varies with the intensity of the vacuum in the latter. It is nil when the intensity is highest, *i.e.*, the air pressure in the apparatus is lowest and rises steadily in correspondence with increase in that pressure. It is directly proportional to the weight of air extracted by the pump at each half revolution if we assume for a moment that the speed of the latter remains constant. The volume of this weight of air is constant, since the size of the empty space which it fills in the piston tunnel cannot alter. Since the weight of a given volume of gas varies directly as its pressure, we see that the rate at which air is passed through the pump must be directly proportional to the pressure of the air inside the tubing. This gives us the straight line graph shown in Fig. 4B.

In Fig. 4C the two diagrams are superimposed on one another by taking the mirror image of Fig. 4A and placing its zero at the point corresponding to a pressure of 76 cm. Hg on Fig. 4B. The points at which the graphs of Fig. 4A intersect with that of Fig. 4B give us the mean intensity of the vacuum produced with air leaks of different sizes, for at those pressures equilibrium is reached between the rates of entry of air through the air leak into, and of its extraction from the apparatus by the pump.

Now the volume of the tubing may be assumed for practical purposes to be constant. Hence the amplitude of the periodic variations of the pressure of the air within it must be proportional to the weight of air extracted from it by the pump at each stroke. For it is the fact that this extraction occurs during a short part only of the time occupied by a half revolution which is responsible for the presence of the variations. We have already seen that this weight is directly proportional to the mean intensity of the vacuum, measured in terms of the actual pressure of the air in the tubing. This gives us Fig. 4D in which the amplitude of the variations is plotted vertically, the pressure of the air in the tubing horizontally, and the resulting graph is a straight line.

In Fig. 5 the same thing is represented in a form which better strikes the eye, the pressure of the air inside the tubing at any instant being plotted vertically, the time horizontally. The resulting curves show the periodic rise and fall of the former, and how this is greatest when the vacuum is on the point of collapsing, is practically nil when it is most intense. Compare this with the tracings in Fig. 6 (Fig. 58 of Barraquer's article) quoted from Gallemaerts and we see that they represent the same thing, only that in the latter the intensity of the vacuum is not measured in absolute terms, but in terms of the difference between the air-pressure inside and outside the apparatus, *i.e.*, in Barraquer's original notation. Hence the two tracings are inversions of one

FIG. 6.

Fig. 53. From Barraquer showing tracings of vibrations by Prof. E. Gallemaerts. The lines A, B, C, D, A', B', C', D' and EE' have been added for purposes of comparison with Fig. 5. The position of EE' has been calculated from the equation $AB/AE = CD/CE$ and since $AB = 8$ mm., $BC = 12$ mm., $CD = 15$ mm., therefore $DE = 3$ mm. approximately.

another, with but one slight difference. In my diagram the frequency with which the "vibrations" occur is represented as the same whatever the intensity of the vacuum on the assumption that the pump maintains a constant speed throughout. Now this is not quite a reasonable assumption, for one might expect that there would be some difference in the load on the motor with a difference in the intensity of the vacuum against which it had to work—hence the speed at which it would drive the pump would vary too. This view is confirmed from Professor Gallemaerts' tracings, for the ratio of the frequency of the "vibrations" at a high and a low vacuum is as 34.5 to 38, and is substantiated in the text, for on page 100 it is stated that: "In an Erisifaco that low voltage will operate because it has been constructed and arranged in accordance with the density and viscosity adequate for it. The number of the interruptions increases as the intensity of the vacuum is diminished by the regulator."

It is clear then that the "vibrations" or "interruptions" of the vacuum in the Erisifaco are present all right, though I have heard men deny that they exist. I think my explanation of how they are produced and of the way in which they vary is sound.

Now we must consider the claims made for these vibrations. In Figs. 7 and 8, I reproduce diagrams from Barraquer's article to illustrate what is said to occur, and quote chapter and verse from the text in support of these diagrams. On page 90 the Figs. 99 and 100 represent two cataracts; the first extracted by an Erisifaco poorly regulated with insufficient altitude of vibration; the second shows a "correct" extraction. We note with the aid of a binocular immersion (?microscope) the different lengths of

Fig. 7.

Figs. 92, 99, and 100 from Barraquer.

Fig. 8.

Figs. 38 and 28 from Barraquer.

its fibres and compare both with those of a lens removed with a forceps (Fig. 92). Opposite these diagrams I have placed some others in Fig. 8 which represent the reverse side of the medal, the state of the eye, as represented by Barraquer, after facioerisis, after Daviel's operation, and during expression of the lens by brute force applied from without. After the first there is a horrid mess, after the second all looks clean and tidy, the intact zonule hanging in a neat fringe from the ciliary body. But in the last of the three the artist seems to have made a slip of the pen. The lens capsule seems perfectly smooth and the whole of the zonule is depicted as remaining attached to the ciliary body just as after facioerisis. I have no doubt that Barraquer will correct this in the next edition of Dr. Fisher's book, for surely, in this method the

zonule is torn out by its roots leaving the ciliary body in a sorry state, torn, harrowed, and bleeding?

We now have to deal with the instructions given for the regulation of the Erisifaco in practice. On page 58 we find: "The intensity to be used in each case varies between 50 and 70 cm. Hg according to the elasticity of the lens or the state of maturity of the cataract. These figures hold a certain relation to the age of the subject; the only thing that indicates the degree of vacuum to employ in each case is the practice of making preliminary and careful examination of the cataract—Fig. 110." Figs. 108 and 109 of Barraquer's article might equally well be referred to here, for the three represent respectively (a) a slit-lamp and corneal microscope (b), a way of using them, and (c) what is seen with them. Then on page 104 we find—"The Erisifaco is a pneumatic forceps and zonulotome and ought to be kept perfectly regulated in accordance with the physical condition of the eye to be operated." It is clear that before we can begin to think about regulating the Erisifaco we must understand the variations to be met with in the physical condition of the eye.

On page 82 Barraquer states: "With the cataractous process zonular fragility is increased; in myopic subjects the zonula is also more fragile than in emmetropes and hypermetropes. In zonulas of individuals more than 40 years' old the linear stretching amounts to only one millimetre which these fibres can stand, whereas in young individuals its elasticity is so great that the elasticity may be twice as much. A weight of 30 grams suffices to break the zonula in an emmetropic eye, more than 40 years old, whilst in the cataractous this weight diminishes in proportion to the maturity of the cataract." This statement is not in accordance with Colonel Smith's experience, which is that the strength of the zonule decreases progressively from childhood to old age, myopes being no exception, and is in general unaffected by onset of the cataractous process. The exception is that if the cataract takes the Morgagnian line of development the strength of the zonule is reduced below the normal for the age of the particular patient. The type of cataract which he has called "hypermature ab-initio," and is also known as disciform, develops at a comparatively early age, 30 to 40 years, and therefore has a strong zonule, while its capsule is incidentally very tough. But this summary is based solely on his interpretation of the sensations of his finger tips, while Barraquer's statement is supported by diagrams and illustrations of exact scientific laboratory experiments. I have, however, come across one difficulty in repeating his experiments for the purpose of confirming his results. He recommends the eye of the cadaver for the performance of these experiments. I have searched England in vain for an institution which will

provide me with human eyes containing mature cataractous lenses. Perhaps Barraquer will help me out of my difficulty by informing me of the source from which he obtains his material? He might also explain how he correlates the physical conditions of cataract in life and after death for practical purposes. In practice every structure in the eye becomes more and more

FIG. 9.

Types and lines of development of senile cataract. Diagrammatic.

fragile every hour that passes after death. What inference can be drawn from experiments on such eyes?

On pages 99, 100, and 101, we find Barraquer employing a terminology which agrees better with that employed by Colonel Smith (Fig. 9). He makes clear the distinction between the Morgagnian or soft, and the hard cataract, though he does not allude specifically to the disciform type. He evidently agrees that the zonule becomes progressively stronger as we pass up this ladder, for he says (page 101): "The surgeon ought to try to regulate the intensity of the vacuum in proportion to the hardness of the cataract, which may be determined with great accuracy by the examination of the patient with a dilated pupil, measuring the depth of the anterior chamber and the distance between the two capsules, determining if there are any transparent portions in the lens, by means of the focal illumination of Gullstrand and the

corneal microscope of Zeiss with the graduated drum." It would be interesting to know how Barraquer manages to see the posterior lens capsule when the lens is entirely opaque; for I was not aware that Professor Vogt himself claimed such powers for the slit-lamp. And I fail to see what information he would gain by it, for the Morgagnian cataract has just as weak a zonule and nearly as delicate a capsule in the shrunken stage, when all the soft matter has been absorbed, as in the stage of intumescence or greatest swelling.

Now for the influence of the type and stage of development of the cataract on the strength of the lens capsule. Barraquer states on pages 99 and 100: "A very hard cataract causes more deformity than a white one on account of the great necessity of a very intense vacuum, whereas a white soft cataract is deformed with more facility, and like that in the stage of intumescence the capsule is distended and drawn; a less intense vacuum causes an exaggerated deformity and may produce its rupture." Some hard thinking is needed to interpret this passage. To my mind the only construction it will bear is that the more nearly a cataract approaches the soft Morgagnian type the weaker is its capsule, which is in agreement with Colonel Smith's experience in as far as senile cataract is concerned. And I think that in connection with the strength of the zonule we can bring order out of chaos by assuming that Barraquer is confusing maturity with softness and in reality agrees with Colonel Smith that in a patient of any given age the softer the cataract the weaker is the zonule. In short that age in any given type determines the firmness of the anchorage of the lens.

Let us apply to these facts the basic principle which is claimed to underlie facoerisis, that the greater the "altitude" of the vibrations the nearer to the suction cup of the pneumatic forceps is the point at which the zonule is ruptured. It would be logical to extend the application of this principle and to include the lens capsule in its range, assuming that with excessive "altitude" of the vibrations the latter and not the zonule would be ruptured. On page 59 Barraquer states: "As the intensity corresponds to the height of the wave, with insufficient intensity the fibres of the zonule do not rupture, with an excessive intensity we may break the capsule." To my mind the first sentence of this paragraph can only be taken to bear out my previous presumption—that with excessive "altitude" of the vibrations there is danger of bursting the lens capsule and not the zonule. Otherwise why was it included in the paragraph at all?

Now the plain commonsense view would be that a high vacuum is more likely to burst a weak capsule than a low one. Barraquer subscribes to this view frequently, both in the remainder of the paragraph—just quoted, in the paragraph quoted previously from

pages 99 and 100 in which he gives his views of the physical condition of the different types of cataract and again on page 72, where he states that: "Rupture of the zonule may occur at the moment the cataract is drawn upon, indicating that we have made a mistake by employing a vacuum of excessive intensity." But it is puzzling when one tries to reconcile this commonsense view with the vibratory theory. For I have previously shown that the correspondence of the intensity is, measured in Barraquer's notation, a correspondence in inverse proportion. The two aspects seem irreconcilable.

Finally, we must consider the adjustment of the intensity of the vacuum and the "altitude" of the vibrations to the strength of the zonule. We are agreed that in a patient of a given age the strength of the zonule decreases *pari passu* with the softness of the cataract. It would again be only plain commonsense to agree that with a strong zonule, in a hard cataract, the suction cup of the pneumatic forceps ought to have a firmer grip than with a weak zonule, for it would be more liable to come off when we pulled. Barraquer again subscribes to this view frequently, to requote from pages 99 and 100: "A hard cataract causes more deformity than a white one on account of the great necessity of a very intense vacuum," from page 101: "The surgeon ought to try to regulate the intensity of the vacuum in proportion to the hardness of the cataract." But again there comes a difficulty in fitting this in with the vibratory theory. For, with a very intense vacuum the "altitude" of the vibrations is nil, with a low degree of intensity they are at their greatest. How does it come about that the stronger the zonule the weaker, on this view, are the vibrations suited to its rupture, the weaker it is the greater must be their amplitude? One seems to catch a glimpse of Barraquer himself being a little perplexed about the matter, for in the second paragraph on page 100 he seems to contradict his instructions which immediately precede and follow. He states: "When the cataractous process is less advanced as a rule the zonule is less friable, which necessitates the employment of a greater number of interruptions of the vacuum. In an Erisifaco the number of interruptions increases as the intensity of the vacuum is diminished by the regulator," *i.e.*, the machine moves faster as the load is diminished. In fact within the space of twenty lines of print he first recommends a vacuum of high intensity for the extraction of a cataract whose zonule is tough, and in consequence low "altitude" of vibrations, then the reverse, and finally returns to the original instructions. But I am sure Professor Barraquer will be able to explain these apparent inconsistencies to my satisfaction. I have been unable to study his writings in the original Spanish text, and the explanation must lie in errors which have crept in during its translation into English.

So much for the theoretical aspect of facoerisis. I was fortunate enough to have been able to study its practical aspect during the last winter, when I had the opportunity of visiting and working at

FIG. 10.

Down's mercury vacuum apparatus.

a number of clinics in Northern and Western India, where intra-capsular extraction of cataract is performed on an extensive scale. I have seen in action most of the methods which are before the profession at the present time, including the "pneumatic forceps" with both Down's mercury vacuum apparatus (Fig. 10) behind it and Barraquer's latest type of outfit. The men whom I saw at

work were very highly skilled in the technique of expressing the lens in its capsule by pressure from without, and had the experience of some thousands of cases to their credit. They had acquired by long practice a lightness of touch and a dexterity in the manipulation of their tools which is to be gained in no other way. Yet at the time at which I saw them at work with the pneumatic forceps they were having one disastrous accident after another.

With Down's mercury vacuum apparatus there was such a violent rush of air through the anterior chamber, if the suction cup was misapplied to the lens when the vacuum was transmitted to it, or if the zonule was so strong that it lost its hold and came off when they pulled, that the lens was blown straight back into the vitreous, to be recovered with difficulty if at all. The control of the vacuum was in the hands of an assistant who pressed a spring clip on the rubber tubing to transmit it to the suction cup when the word was given. He had instructions to shut it off at once if he heard the hiss of air entering the suction cup. But before he could possibly have time to do so a quantity of vitreous had been sucked into the apparatus, and could be seen in the watery fluid which gradually accumulated on top of the mercury in the vacuum chamber. I suggested to the surgeon concerned that, if his assistant released the spring clip at once when he had pressed it and transmitted the vacuum to the suction cup, the latter would keep its grip on the lens just as well as if it was still in communication with the vacuum chamber. If it came off during the subsequent manipulations air would only enter in small amount to fill up the tubing as far as the clip, not in the great rush which was inevitable with the way in which he was handling the apparatus at the time. When he tried this he found it to be the case. When the zonule was too strong for the grip of the suction cup no disasters ensued when it was pulled off the lens. But this initial stage is not the only one at which its grip can fail. I saw it do so more than once even after the lens had been dislocated. When it did so the vitreous, which was sucked into it, was now held up at the clip, and instead of passing over into the vacuum chamber streamed out from the handpiece on its withdrawal, like a thin watery jelly, in full view of the audience.

Barraquer's pump does not suck air in through the open spoon as fast as does the mercury vacuum apparatus. With it there is in consequence less danger of the lens being blown back into the vitreous if things go wrong. The accidents I saw with it were a little less frequent and a little less violent. But despite the addition of the vibrations the log book still showed a sorry tale of woe. Burst capsules I exclude from consideration, for they were clearly due to faulty diagnosis and regulation of the apparatus, not to lack of manipulative skill. But there was to my mind a prohibitive

proportion of cases in which the lens had to be dug up out of the vitreous with a spoon, or was lost not to be seen again.

The situation puzzled me. For though a man might publish that he had failed a thousand times with the Erisifaco, he would still have to face the fact that Barraquer himself can do the job with it perfectly. Everyone who has seen him at work, either in Barcelona or elsewhere is agreed that in his hands all goes like clockwork. What one man can do another should be able to do. Yet here were men making a complete hash of the job, over whose skill and experience I will not grant Barraquer the right to claim any superiority. I tried my hand on a few cases with Barraquer's apparatus and had no more success than the others. The mystery deepened, though once I thought I saw the glimmer of a solution in that ancient maxim: "The diagnosis first and the treatment afterwards." It might be that the diagnostic armament was at fault. We had to rely on the unaided powers of observation of the naked eye, for there was no slit-lamp at hand to help us.

I had had for long suspicions about the accuracy of some of the statements made in Barraquer's article and had failed to confirm certain of his findings, and a chance remark coupled with statements in an article by Capt. Cruickshank, I.M.S. (*Brit. Jl. of Ophthalm.*, July, 1925) gave me the clue to what seemed the solution of the problem.

Are the vibrations, such as they are, responsible for the zonule being ruptured close to the periphery of the lens when it is extracted by facoerisis, and is it dragged out by the roots from the ciliary body, as is implied to be the case, in other methods of extraction? The whole of the claims for facoerisis have been built on the hypothesis that both these things occur. It is not sufficient for Barraquer to demonstrate the truth of the former alone, he must also demonstrate that of the latter. Now since the earliest days in which Colonel Smith began to express cataract in its capsule by "brute force" this question of where the zonule gives way has interested him. He always showed visitors to his clinic that no trace even of tags of the zonule were visible on the capsule, however examined; much less, the veritable halo which Barraquer would have us believe should have surrounded the lens. Early in 1921, on a visit to Barcelona, both Barraquer and he extracted a lens by their respective methods. The elder Professor Fuchs (late of Vienna) who was present, examined and said: "In the hands of the two experts I see nothing to choose." I have yet to meet anyone who can demonstrate any difference, in the matter of the presence of tags of zonule, between senile cataractous lenses, extracted in their capsules from the living human eye, which is in any way dependent on the method by which they were extracted.

The inconsistencies present in Barraquer's own account of how to "regulate" the vibrations in accordance with the physical conditions in the eye to be operated on should be obvious. He is convicted out of his own mouth. For on page 96 he says that when he operated with a constant vacuum he "ruptured the fibres of the zonule to extract the lens which then appears with a crown of zonule fibres like the representation in Fig. 92." This diagram

FIG. 11. FIG. 98 from Barraquer.

Experiment by Prof. T. Escriche explained in the text of pp. 87 and 89. "A physical experiment explains clearly the different ways to make a force continuous or instantaneous; we suspend a thread from the ceiling; at its extremity a weight (A); at the inferior extremity of the weight another thread of the same resistance as the upper one with another weight (B) on its end; if the sum of the two weights represent a force greater than the resistance of the thread when it yielded by suspending slowly the weight (B), the thread is broken by the weight (A) if the force is represented by the sum of the two weights in the act above, all along the length of the thread; if we raise the inferior weight and drop it suddenly, the force has not time to transmit itself as far as the upper weight and the thread escapes at some centimetres from the inferior weight, notwithstanding a lesser weight was used."

(reproduced in Fig. 7) shows the lens with what clearly is intended to portray the whole zonule attached to it. Yet in the very next sentence he tells us that "by examining those patients with the corneal microscope it was noticed that, in some, remains of zonule fibres are incarcerated in the lips of the wound." I need say no more. The vibrations, such as they are (for as a matter of fact they hardly exist at all), have absolutely no influence on the place at which the zonule ruptures.

There is one other aspect of the action of the vacuum in dislocating the lens which deserves attention. Reproduced in Fig. 12 is a diagram which figures repeatedly in Barraquer's article. It purports to show how the lens is dislocated immediately by the application to it of the vacuum and vibrations. One point about

it at once strikes the eye as queer—for though the lens capsule is intact, the nucleus is portrayed as being displaced through the soft cortical matter towards the suction cup and gripped by it. In the text (page 57), the representation is confirmed: "By the rarefaction of the air in the suction cup, it adheres to lens . . . deforms it

FIG 12. FIG. 57 from Barraquer.

Barraquer's representation of effect of applying vacuum, *i.e.*, immediate dislocation of the lens in *all* cases, and the nucleus being gripped by the suction cup *through an intact capsule*.

FIG. 13.

Representation of actual sequence of events when vacuum is applied.

by shortening its greatest diameter *and displaces the nucleus.*" A simple experiment with fresh human cataractous lenses will serve to convince us that this unlikely happening does not in fact take place. The capsule and as much soft fluid cortex as it will hold is sucked into the suction cup. If the nucleus is large and the cortical matter small in amount the capsule is drawn tightly round the former. If the cataract is of the Morgagnian type, the

FIG. 14.

Natural planes of cleavage in the structures which anchor the lens to the fibrous coats of the eye.

small nucleus sinks to the bottom of the fluid in the bag in which it is contained. Applying these facts to consideration of the sequence of events inside the eye, we see that the only effect of the application of the vacuum is to take up a little of the slack in the anterior lens capsule. What happens then depends on the circumstances (Fig. 13) for this by itself will only effect dislocation if the zonular attachment is very weak. If it is strong the moorings of the lens will not part until the strain on them is increased by pulling or pushing, and when they do part they will do so at their weakest point, vibrations or no vibrations. On the other hand the capsule may burst, if it is weak in relation to the intensity

of vacuum employed, the suddenness with which the latter is let on, or the sharpness of the edges of the suction cup.

An experiment on the eyes of young animals fresh from the slaughter house (pigs' eyes are very suitable) gives us interesting information as to the situation of these weak links in the chain which moors the lens to the fibrous tunic of the eye (Fig. 14). The age of the pig may be estimated roughly by the size of the eye. Make a section which admits of an easy passage for the exit of the lens. Punch it out boldly by pressure applied from the outside so as to bring it out upside down. In the eyes of the older animals the zonule can be seen to strip off the capsule of the lens and leave the latter quite smooth and bare. In younger animals the zonule comes with the lens, but brings with it a narrow black pigmented fringe consisting of that part of the epithelial covering of the ciliary body (the *pars ciliaris retinae*) which overlies it and to which it is attached. In the youngest animals the continuation of the zonule back into that thickened portion of the hyaloid membrane which is termed the "zonula ciliaris" is so strong that the whole hyaloid and vitreous come with the lens. With them is brought the whole of the *pars ciliaris retinae*, which encircles the lens, as it sits on the vitreous, like a broad black halo. It is simple to cut through this halo into the canal of Petit and to extend the cut right round the circle. The lens peels off the vitreous and the hyaloid membrane which lines the patellar fossa is clearly displayed.

I should warn the reader that the pig's eyes must be fairly fresh, for in the process of decomposition the attachment of the zonule to the lens capsule is the first place to be weakened.

Now though Colonel Smith has more than once been successful in expressing cataract in its capsule in children, yet, in them the zonule is as a rule so firmly attached to the capsule that he has long since given up doing it as routine. It is not because he is afraid that the pressure required, which is considerable, would be injurious to the structures inside the eye. Nothing of the sort is the case. Nor is it because he has seen the lens bring with it a black halo of epithelium off the ciliary body as in the case of the young pig's eye. It is because in most cases the pressure required is such that it is difficult to prevent the instrument from plunging, when the zonule loses its hold, and so expressing a quantity of vitreous with the lens. In very rare cases of cataract in childhood the lightest touch will suffice for dislocation, but they are so rare as to be a curiosity, impossible to diagnose before operation.

Knowledge of these facts led me to think more than once over a chance remark by an American surgeon who had just visited Barcelona. He had seen Barraquer take out a congenital cataract in a child "perfectly." The whole tone of his remark gave me the

impression that Barraquer had laid his hand to that child's cataract without the quiver of an eyelash, absolutely sanguine of success, and had regarded it as just an ordinary everyday-routine event. Now, what I had seen of the "pneumatic forceps" in action had convinced me that, even with the machinery behind it in perfect working order, its grip was inadequate for the removal of any but the most *lightly* anchored senile cataract by pulling. For I had frequently seen it lose its hold and come off when the zonule was but a little over the normal in strength. Yet here was Barraquer achieving success with a cataract whose anchorage was ten times as strong as that of any on which I had seen his instrument fail. It became clear to me that his success in that case could not have been achieved by pulling. He must have dislocated the lens by pushing it boldly back into the vitreous, a course which would impose no strain on the grip of the instrument which it was not fit to stand. The vitreous would press well forward round the periphery of the lens to fill the space vacated by the latter. But there is no reason why it should do more than this, why it should come forward in front of the iris, or come out of the eye. For Barraquer applies no pressure to the outside of the walls of the globe to deform them, and so to reduce the capacity of the vessel in which the vitreous is contained (Fig. 16).

I then recalled to my mind the article before mentioned, by Capt. M. M. Cruickshank, I.M.S., who has, I believe, been up to the present the most successful exponent of the art of facoerisis in the Indian Empire. He himself seems to believe firmly that he is getting the lens out by pulling. But his instructions as to how to avoid disaster display plainly, when read between the lines, that he is actually doing nothing of the sort. Labouring under the misconception, whose fallacy I have already pointed out, that the suction cup actually *grasps* the *nucleus* through the capsule, he goes into an elaborate explanation of why the surgeon must not attempt to turn the lens over on its back inside the eye before extracting it, by simply rolling the handle of the pneumatic forceps between the thumb and fingers. In it, however, he seems to have missed the real reason, which is that while the lens must be rotated about a transverse axis which lies in the plane of the suction cup, the shaft and handle of the instrument are set at an angle of about 45° with that plane. This at one and the same time gives the surgeon a leverage which enables him to apply immense force to the lens without realizing it, and compels him in using the instrument to swing the handle about that axis by movements of pronation or supination of the wrist and forearm. When one sees superadded to this, movements of the elbow and shoulder joints, with perhaps the hand not even steadied on the patient's head, one realizes that under these conditions the sensations of the finger

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FIG. 15. FIG. 102 from Barraquer. Compare with FIG. 14 D.

I must compliment Barraquer on the skill with which he has dissected the ciliary epithelium off the zonula ciliaris of the hyaloid membrane, a feat which I have not been successful in repeating myself.

FIG. 16.

In A the suction cup has gripped the lens, but the zonule is too firmly attached for dislocation to be effected by pulling. In B, the lens is shown pushed back quite a short way into the vitreous, which has burst its way forwards, through the hyaloid membrane and the zonule, but does not come in front of the plane of the iris, as there is no pressure on the outside of the globe to make it do so. Note two things. First the extra space given by this manoeuvre both from side to side (*cb*), and from front to back behind the cornea, second the way in which the shaft of the pneumatic forceps is set at an angle of 45° to the transverse axis, lying in the plane of the suction cap, about which the lens must be rotated.

tips will by themselves be a poor guide as to what is happening at the business end of the pneumatic forceps. And even they are blunted by the fact that it is necessary to grip the instrument the whole time in order to keep the valve pressed which transmits the vacuum to the suction cup. I was told by one man, who previously had been very successful, that there was some trick in the use of the instrument which his hand would take a little time to re-acquire, but which he could not explain in words. The reason for this difficulty in explanation was simple enough. He was under the impression that his fingers had been pulling on the lens while in reality they had been pushing.

Let us re-examine Barraquer's diagrams and his instructions for manipulating the pneumatic forceps in the light of the hypothesis that the secret of safety and success with it lies in using it to remove the lens as much as possible by pushing, as little as possible by pulling, because its grip is inadequate for the latter course. We shall find that it gives us a rational explanation of how he has arrived at his present method of "tumbling" the lens so as to deliver it lower edge foremost (page 63—"My Usual Method").

In Cruickshank's article it is said that during the final stage of delivering the lens in this way it must not be pressed against the posterior surface of the cornea under the impression that by doing so any tendency for the lens to slip, or be dragged off the suction cup, as it engages the incision, can be prevented. The natural inference would be that such an accident, among others, would thereby be made more, not less, likely to happen. If the smooth posterior surface of the cornea can form such a serious impediment in the way of safe delivery, how much more serious an obstacle must be presented by that sharp scleral lip of the wound when the lens is brought out head first. Accidental pressure with the lens against it is a thing which is not unlikely to happen in that method of delivery. For in it the suction cup remains in front, the lens behind against the scleral lip, during the actual passage through the wound.

This is not the only way in which the scleral lip is an awkward corner to negotiate during the upright delivery with the pneumatic forceps. The cohesion between the posterior surface of the lens and the vitreous, two smooth moist surfaces perfectly adapted to one another, is such that, if an attempt is made to separate them by pulling the lens straight forward, the vitreous will tend to stick to it and hold it back. The grip of the suction cup may be inadequate to the task of pulling them apart in this way. It may lose its hold if asked to do so. Then as we have seen trouble begins. The lens must be disengaged from the vitreous by swinging it round on a transverse axis so as to slide apart the two

surfaces in contact. (See Fig. 17, A and B, that is Fig. 33 from Barraquer in which he himself recognizes this fact.) In upright delivery the nose of the lens may strike against the inner surface of that scleral lip of the wound. It will stay behind unless it is lifted over the stile by pulling it forward, and pulling is gambling with fate. (See Fig. 18.)

Finally, we can see from Barraquer's own account, that even the intact iris presents an obstacle to upright delivery, which he

FIG. 17. FIG. 30 from Barraquer.

"In A, by making pressure in the direction of the arrows, adhesion prevents us from separating the convex lens from the concave, if the two have identical curvature. It is necessary to disarticulate them as in B, to accomplish a movement of rotation."

FIG. 18. FIG. 64 from Barraquer.

Showing upright delivery. Note how the lens is represented as being *pulled* forwards off the vitreous in order to clear the awkward projection of the scleral lip of the wound. Yet Barraquer himself in Fig. 17 demonstrates the difficulty of so doing.

may not be able to surmount. For in that method the instrument must be asked to pull the lens through the pupil and it is more than likely to jib at the task. This is the only reason which I can see for his statement under Fig. 31 of his article "In cases of hard cataract total extraction succeeds only and invariably with an iridectomy." The picture represents a cataract being delivered upright in its capsule, impaled on a needle. I have no experience of this particular method but in so far as simple straightforward expression from without is concerned Barraquer's statement is entirely untrue. With it there is no difficulty whatever in pushing the lens through a pupil contracted to a pin point with opium; it is only a matter of patience. Again on page 53 he says, "If it is

a question of a more voluminous cataract, very intumescent, an iridectomy is indicated."

The secrets of success are now plain. Any lens can be dislocated with perfect safety by pushing it boldly back into the vitreous. Once dislocated "version" can be done without fear of accidents, by working back in the vitreous where there is plenty of room. (See Fig. 16B and note on page 20 of Cruickshank's article, the warning against striking the lower edge of the lens against the sclero-cornea.) Once the suction cup is behind the lens it can be disengaged from the vitreous and got through an intact pupil by *pushing instead of pulling*. And, finally, when it has got into the anterior chamber it can be negotiated round that awkward corner formed by the scleral lip of the wound with the back of the suction cup against it instead of the back of the lens.

There is one point which requires emphasis, the matter of making sure that the lens is completely dislocated before beginning to do the version. When I re-examined, in the light of the hypothesis of pushing instead of pulling, the events in the very few cases on which I had used Barraquer's instrument myself, the reasons for my success and failure became apparent. I had been successful with the hard cataract and had failed with the soft (burst capsules are here expressly excluded from consideration, as they are a matter of faulty diagnosis rather than faulty manipulation).

I had started on a movement of pronation of the forearm as soon as I had got hold of the lens, so driving its upper border back into the vitreous. In the former type the pressure I was making unawares on a rigid body had dislocated it below as well as above and all went well thereafter. In the soft cataract the suction cup simply slid over the small nucleus, which was floating in fluid cortical matter, and the zonule remained attached below. Then when I tried to swing the lower edge of the lens up through the pupil I had to begin pulling. There was a tug-of-war between the zonule and the suction cup in which the former had the mastery. The cup came off and the lens dropped back into the depths of the vitreous from which it had to be dug up with a spoon.

Here is the point at which to draw attention to Barraquer's Instructions on page 71: "In case the iris gets between the lens and suction cup. It suffices after having given the lens the turn within the anterior chamber to interrupt the passage of the vacuum allowing entrance of the atmospheric pressure into the suction cup by which the cataract is loosened and to take hold again." Now while this course is quite feasible if the iris is caught up in the suction cup above or at one side, it is not possible if it is caught up below. For then the lower border of the lens cannot be swung up through the pupil; the cup comes off; and the lens is lost.

The moral to draw from this is that the surgeon who uses the pneumatic forceps should be particularly careful not to ensnare the iris below and should always commence by dislocating the lens below, pressing it backwards there by supinating the forearm, then turn his attention to the zonule above, detaching it there by pressing backwards with a movement of pronation. Only when he is certain that the lens is completely dislocated should he begin to do the version. While doing it, in the words of Capt. Cruickshank, he must not attempt to steady an unruly eye with the instrument. He must be in no hurry whatever, but must exercise his patience and go dead slow from start to finish. And above all his hand must not tremble. For if he does any of these things he may inadvertently strike the lens against one of the numerous obstacles which lie in its path, and drag it off the suction cup. If it slips off after it has been completely detached from the zonule, there is nothing to prevent it from dropping back into the depths of the vitreous, never to be seen again. For the hyaloid membrane, lining the patellar fossa, has been torn to shreds and can give it no support from the rear.

Having formulated this hypothesis I put it to the test of practice on embedded pigs' eyes. To my joy I found everything go smoothly. After a time I became wildly enthusiastic over the merits of the pneumatic forceps for it became clear to me that could I lay my hand with it to a congenital cataract in the eye of a foetus as yet unborn, there would be but one thing which would baulk me of my prey. Should the subject not have reached the stage of development at which the remains of the hyaloid artery have disappeared I would have to start pulling in order to rupture them, and that would be fatal to success. And I would be a little apprehensive that in the event of success the lens might emerge crowned with an artistic black halo of epithelium off the ciliary body. For the weakest link in the chain which moored it to the fibrous tunic of the eye would be the one which would give way, vibrations or no vibrations.

I think it is fairly clear that Barraquer's instructions are not likely to assist his would-be disciple in succeeding with his method. Turn to the "Advice to the Beginner," on page 103. Section 5 enjoins him: "Do not in your first operation try to change in the least possible way the details of the technique described, and be most exact in following them out." If the beginner wishes to succeed in his first operation he must depart radically in every particular from the technique described, from the very first step to the very last. On page 49 a section "including the superior 2/5 of the cornea" is recommended. It is next door to impossible to express cataract in its capsule by pressure from without through a routine incision of this size—the minimum safe standard is half

of the corneal circumference, or 180° . With the bulk of an instrument added to that of the lens 190° is the minimum, when that instrument has as light a hold as has the pneumatic forceps 200° would be better. This was the size of incision which was being made by the most successful of the men whom I saw at work with it. (In Capt. Cruickshank's article the same thing is emphasized though perhaps not so explicitly.) It is quite a safe size in so far as the vitality of the cornea is concerned.

Barraquer repeatedly utters a warning not to make any pressure with the instrument on the lens, not to compress the vitreous and

FIG. 19. FIGS. 73 and 74 from Barraquer.

Delivery as a Tumbler. Note how Barraquer represents the lens as being rubbed against the cornea from start to finish.

in his diagrams he represents the hyaloid membrane as remaining intact to the end, the vitreous as undisturbed. I do not need to deal with this again. In his illustrations of how he delivers the lens as a "tumbler" (see Fig. 19, that is Figs. 73 and 74 from Barraquer) he depicts it as being rubbed against the inside of the cornea from start to finish. I have already quoted Cruickshank's views on that issue but Barraquer himself sheds an interesting sidelight on it. For on page 59 we find a warning not to "produce friction on the posterior of the lens." It is interesting to note that in this passage it is the vitreous, not the lens, for which he is displaying great concern.

Finally, there comes the matter of escape of vitreous. He claims immunity from it on page 74 and both here and on page 74 ascribes this immunity to the use of novocaine to paralyze the orbicularis. Though elsewhere he does allude to the fact that the lids should be held away from the eye, yet he does not tell us whether his assistant who is looking after them is charged with the duty of retracting the eyebrow to guard against the very real danger of the novocaine failing to act.

Now for the benefit of those who may not be convinced that the secret of success with the pneumatic forceps depends on pushing instead of pulling, let me draw attention to the fallacy underlying a belief which has been prevalent in some

quarters:—that less violence is inflicted on the eye when the lens is dislocated by direct traction on the zonule with an instrument which grasps its capsule, than when pressure is applied to the eye from without. If we hark back to our geometry for a moment, we will remember the proposition which states that a given surface encloses the greatest volume when it is in the form of a sphere. Let us regard the sclerotic, the moorings of the lens-capsule to it, and the capsule itself as the walls of a sphere which contains an incompressible fluid, the vitreous. If we deform these walls the volume which they can contain will be diminished. Now whether we do it by pulling or by pushing on them, we will be constraining the vitreous to occupy a smaller space (*see* Fig. 20). Its refusal to do so will compress the structures lying between it and the walls which contain it, and will put the

FIG. 20.

To show how volume of a spherical container is diminished equally when its walls are deformed by pushing or by pulling.

latter on the stretch. If we go on deforming them the strain on them will increase until they burst at their weakest point. The compression to which choroid, retina, and vitreous must be subjected, in order to dislocate the lens in any particular eye, is determined by the tensile strength of the particular zonule, multiplied by the length of it which is ruptured in the first instance. The last factor is the only one which is within the power of the surgeon to vary. This compression is therefore least in the method which most nearly concentrates the strain on the zonule on a point—whether it involves pressure on the sclerotic, pressure on the zonule, pressure or traction on the lens capsule, is quite immaterial. The ideal would be achieved if we could use a sharp cutting instrument, but I need not discuss the use of such a weapon inside the eye. A blunt instrument applied directly to the zonule is the method next closest to the ideal, and has taken shape in the so-called zonulatomes to which different men have given their names. But it possesses certain theoretical dangers which are to my mind insurmountable. For at the worst it would be very easy when one is working with such an instrument in the dark behind the iris, to push it down the natural plane of cleavage which passes through

the ciliary body. At best, it would be difficult to be sure that one had not bruised the latter against the sclerotic with the hard metal instrument itself. When these two plans are dismissed, there is absolutely nothing to choose between an instrument which dislocates the lens by pressure on the eye from without, and one of the various types of capsule forceps used to do the same thing by direct internal manipulation. And whether the latter takes the form of pulling on the lens, or pushing, it is quite immaterial. The violence done to any particular eye would be exactly the same.

The pneumatic forceps was as far as I know first introduced into surgery by Stoewers. For an instrument bearing his name figured in Messrs. Down Bros. catalogue for 1906. The next man to take it up was Dr. Vard Hulen of San Francisco, who reported

Pneumatic forceps of Stoewers (1906).

six cases in 1910. Professor Barraquer deserves great credit for the thought and energy which he has brought to bear on the problem of how to use it. But I do not think we can allow his claim to pass, that his instrument is a "vibratory zonulatomer" possessed of magic powers, and that his operation consists "in drawing the crystalline lens by its anterior surface, separating it mechanically without either traction or violence of the zonule, and extracting it completely out of the eye without having produced ectopias or traumatism of the intraocular structures." I should like to rechristen the operation and call it "pushing the lens violently to the exterior."

ANNOTATIONS

Illumination and Efficiency

The Industrial Fatigue Research Board and the Illumination Research Committee have recently published a joint report by Messrs. H. C. Weston and A. K. Taylor on the relation between illumination and efficiency in fine work. As a type of the work