Changing Concepts in the Surgical Repair of Primary Retinal Detachment: The Odyssey of a Leaking Break (part 1)

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ABSTRACT

The evolution of current surgical approaches for reattaching a primary retinal detachment and issues that determine the various techniques are analyzed through a comprehensive literature review of retinal detachment surgery starting from 1929. Ongoing changes in treatment modalities during the past 35 years are discussed: a change from surgery on the entire retinal detachment to a surgery limited to the retinal break and a change from extraocular to intraocular surgery for achieving retinal reattachment.

Introduction

Treatment of primary rhegmatogenous retinal detachment is being discussed again. This time the issues are no longer whether to treat the retinal break with or without drainage of subretinal fluid or to limit extraocular retinal surgery to the area of the break, or extend the operation over the entire circumference of the retina. Today's question is: treating the retinal break by extraocular retinal surgery, or intraocular vitreoretinal surgery. Since this question is complex, a short review will be presented first of the various developments in retinal detachment surgery over the past 75 years including the present state-of-the-art. Then, one will realize, "It is an unending story of a leaking break in a retinal detachment which has to be closed once and for all". The odyssey of the leaking break is addressed in this literature review.

Review of Literature

A: Traditional Surgical Techniques for Repair of a Rhegmatogenous Retinal Detachment

Prior to 1929 retinal detachment was a blinding disorder. The first conceptional progress for treatment was made by Gonin[1] who postulated that a leaking break is the cause of the detachment. This postulate is no longer in doubt; however, the discussion of how to close it best is still going on.[2] Therefore, the best procedure to repair a rhegmatogenous retinal detachment should be one with minimal trauma, maximum rate of primary reattachment, minimum rate of reoperations, minimum need for secondary operations in subsequent years (e.g. cataract, glaucoma), the best long-term visual results and performed under local anesthesia on a small budget.
Treatment limited to the area of the leaking break was performed first by Gonin in 1929.[1] (Fig.1) He surrounded the break by Ignipuncture-coagulations after drainage of subretinal fluid. The reattachment rate abruptly increased from practically 0% to 57%. This procedure was quickly

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modified by extending the coagulations within the entire quadrant of the leaking break (Fig. 2). In 1931 Guist and Lindner circumvented the need for precise localization of the break even more by performing multiple scleral trephinations posterior to the estimated position of the break and cauterizing the choroid at each trephine opening with KOH (potassium hydroxide). The intent was to create a "barrier" of inflammation and retinal adhesions posterior to the break. This barrier would confine redetachment to preserve the posterior retina.[3,4] In the same year Safar[5] placed short perforating pins (on a bar or single) in a semicircle posterior to the break and connected them to a diathermy electrode to create a barrier of coagulations (Fig. 3). Drainage was accomplished when the pins were removed. With this barrier operation, reattachment rates increased to 70%. But redetachment occurred, because the retinal break was not closed off and started to leak again. This caused first an anterior redetachment which subsequently crossed the barrier of coagulations and redetached the posterior retina.

A second conceptional progress in the treatment of retinal detachment evolved with Rosengren[6] in 1938. He recognized that the leaking break was the basic problem and therefore, he again limited, now for the second time, the coagulations to the edges of the break. In addition for the first time he added an intraocular tamponade of air. After drainage of subretinal fluid air was injected into the vitreous. The air bubble was positioned into the area of the break to provide an additional tamponade ab interno during retinal scarring (Fig. 4). The rate of reattachment further increased to 77%, but many redetachments developed, because the duration of tamponade by the air bubble was sometimes too short for sufficient adhesions to develop around the break. In addition, as experienced before, it was difficult to precisely localize the break and place coagulations around it. Therefore, the Rosengren technique did not become popular and instead, attention was drawn away from this type of limited surgery to procedures consisting of extensive coagulations.

Now for the second time the barrier concept was integrated into treatment. This resulted in coagulations placed posterior to the break, but the barrier of coagulations was reinforced by an additional scleral resection (Fig. 5). Subsequently an additional plombe was embedded into the scleral resection for the first time creating a high scleral wall with the intention to seal off the break more effectively against future leakage (Fig. 6). Several lines of coagulation were added between the buckle and the ora serrata as additional barriers to stop a redetachment from progressing. But this did not work either, since the break, positioned at the anterior edge of the buckle, was not sufficiently tamponaded. It started to leak again and caused an anterior redetachment, which crossed the barriers of coagulations and descended behind the buckle. Finally it would cross the buckle inferiorly and progress towards the posterior retina.

The logical consequence of these events could have been the search for more sufficient means for tamponade of the leaking break, but instead, a more effective barrier of the redetachment was created. Thus, the former segmental buckle barrier was expanded to a circular plombe in 1953 by Schepens[7] and in 1958 by Arruga[8]; the cerclage operation with drainage of subretinal fluid evolved. This circular buckle operation represented a maximum barrier for the leaking break. The cerclage was intended to seal off detected breaks and to tamponade non-detected breaks in the so-called "porous" peripheral retina. The aim was to create a new ora serrata. Extensive coagulations were placed on the circular buckle to secure the anterior retina. More retinas were reattached now, over 80%, but redetachments occurred again due to the leaking break (Fig. 7). For reoperations, the cerclage was either made higher, by greater constriction of the globe, or positioned more posteriorly. However, if the break was not tamponaded sufficiently, it started to leak again leading to the same outcome: development of anterior redetachment crossing the barriers of coagulations and cerclage finally redetaching the posterior retina.

In subsequent years Schepens and Pruett further refined the cerclage technique with drainage of subretinal fluid. The leaking breaks were now placed on the circular buckle and tamponaded by an additional plombe or wedge if necessary.[9] However, the drainage with this technique represented a dangerous and vision-threatening complication; the procedure was accompanied by serious complications such as intraocular hemorrhage which occurred in 15.6% in our series in 1971,[10] in 16% as published by Blagojevic in 1975,[11] or in 6.9% as reported by Huebner and Boeke.[12] Additional complications consisted of suprachoroidal hemorrhage in 8.6%, as reported by Toernquist and Toernquist in 1988,[13] and intraocular infection and vitreous or retina incarceration as described by Lincoff and Kreissig.[14]

A procedure without drainage to reattach the retina would eliminate two major hazards associated with drainage: (1) perforation of the choroid with its serious complications, and (2) the subsequent intravitreal injection to restore lost volume which adds to the risk of intraocular infection.

The needed change was already “ante portas” in 1953 when Custodis[15] introduced a different approach to repair retinal detachment, this was a third conceptional progress in detachment surgery. He limited treatment (now for the third time) to the area of the leaking break, but in addition, for the first time omitted subretinal fluid drainage. This was in complete contrast to the cerclage operation with drainage. Nondrainage was made feasible by the use of an elastic explant, the polyviol plombe consisting of polyvinyl alcohol, gum arabic and congored, which was compressed by an intrascleral mattress suture over the detached retinal break. However, the sclera was treated by full-thickness diathermy, which subsequently proved detrimental to this exceptional technique. Due to subsequent expansion of the compressed elastic plombe, the retinal break would be closed and subretinal fluid would resorb spontaneously. Thus, drainage was eliminated and the intraoperative complications were reduced to a minimum. The simplicity and genius of the Custodis method was the concept that after closing off the leaking break the pigment epithelium will pump out subretinal fluid and reattach the retina. Despite all these advantages, this exceptional technique was nearly abandoned, not because it did not work, but because of serious unexpected postoperative complications caused by the polyviol plombe compressed over full-thickness and diathermized sclera. The diathermized sclera became necrotic, and if bacteria were present under the compressed explant, a scleral abscess and perforation could result. In 1960 the Boston group[16] reported serious postoperative complications after the Custodis procedure, i.e., scleral abscess and endophthalmitis even requiring enucleation. As a result, this procedure was abandoned in the United States and in Europe.

However, this was not the case for everybody in the United States, not for Lincoff in New York. He had observed complications as well, but did not give up the Custodis method. Instead, he was convinced of the logical approach and simplicity of this procedure. Therefore, in the subsequent years he and his colleagues replaced diathermy with cryopexy[17,18] and the polyviol plombe with an inert silicone plombe, the Lincoff sponge.[19] This operation was called the modified Custodis procedure and was subsequently named the cryosurgical detachment operation.

The technique represented an extraocular approach, since drainage was eliminated, and cryosurgery and the buckle were limited to the area of the leaking break. However, the acceptance of this modified procedure was delayed because there were major doubts regarding the strength of the cryosurgical adhesion which was eventually confirmed by extensive animal experiments by Kreissig and Lincoff.[20,21] It was proven that cryopexy induces a sufficiently strong adhesion within 5 days and reaches maximum strength after 12 days. Another area of uncertainty was whether the spontaneous, "magical" disappearance of subretinal fluid occurred by tamponading the leaking break ab externo with an elastic buckle, even if the break is still detached over the buckle at the end of surgery. This was the most difficult issue to accept. Why? Because in this situation the surgeon has to leave the operating table with the retina still detached in contrast to the situation after drainage or injection of a gas bubble after drainage, in which case the retina is already reattached at the table. Following such an operation the surgeon can feel relaxed and, as often said, "sleep better".

However, the secret of success with nondrainage is that the surgeon should be convinced that all breaks have been found and tamponaded sufficiently (spontaneous reattachment on the next day will confirm this issue). However, this will be the case only in retrospect. But by performing drainage, often questioned as being done for the sake of the patient or the surgeon, the retina might be reattached at the table only temporarily, just due to the drainage itself. Other questions were: Will a buckle effect that is unsupported by an encircling band persist? Is a cerclage needed for long-term retinal attachment?

With the essential prerequisites of spontaneous postoperative retinal reattachment in mind, the diagnostics for detection of retinal breaks were further improved by binocular indirect ophthalmoscopy, developed by Schepens, biomicroscopy, introduced by Goldmann, development of various direct and indirect contact lenses, the 4 rules to find the primary break,[22,23] and subsequently 4 additional rules to detect missed breaks in an eye requiring reoperation.[24,25] Today these 8 rules represent essential guidelines for the detection of leaking retinal breaks which is crucial for successful limited retinal detachment surgery.

By performing this type of minimal extraocular surgery, the time required for a retinal detachment operation was dramatically reduced, however, the time needed for preoperative evaluation increased. If, however, retinal reattachment did not result on the days following surgery, the logical questions had to be: (1) Has a break been overlooked? (2) Is the break that was buckled still leaking due to inadequate tamponade? Both of these causes of failure are iatrogenic. Thus, one can understand why a procedure that would provide (1) retinal reattachment on the table and (2) additional prophylaxis for overlooked breaks by an encircling element might be preferred by some surgeons.

Soon it was found that a leaking break is more sufficiently tamponaded by a radial than by a circumferential buckle (Fig. 8).[26] This refined detachment surgery evolved as "minimal segmental buckling without drainage" or "extraocular minimal surgery".[27]

B. More Recent Surgical Techniques for Repair of a Rhegmatogenous Retinal Detachment

1. Minimal Segmental Buckling without Drainage (Extraocular Minimal Surgery)

Minimal segmental buckling without drainage, which is still in use, consists of cryopexy and a sponge in the area of the break without drainage of subretinal fluid. The size of the buckle is not determined by the extent of the detachment, but only by the size of the break. A buckle of same size obtains retinal reattachment of the 2 detachments depicted in Fig. 9.

In a prospective study, 107 consecutive detachments were treated with minimal segmental buckling without drainage between 1979 and 1980 with over 15 years of follow-up for every patient.[28] Retinal reattachment rate was 93% after a single procedure and 97% after reoperation (Table 1). Proliferative vitreoretinopathy (PVR) was the cause of final failure in 3.7% after 15 years. Visual acuity increased from 0.3 preoperatively to 0.5 after 6 months and to 0.6 after 1 year. The slight decrease in visual acuity over 15 years of follow-up was not significantly different from the course of vision in the fellow eye (Fig. 10). This slight decrease is due to aging, as confirmed by an analysis on 17,379 individuals by Slataper.[29]

2. Balloon Operation

To further reduce the surgical trauma of minimal segmental buckling without drainage, the suture-fixated segmental scleral buckle was replaced for the first time in 1979, by a temporary balloon buckle, which was not fixated by sutures.[30] Subsequently the Lincoff-Kreissig balloon was developed (Fig. 11) and the balloon operation had evolved.[31] In contrast to the sponge buckle, application of balloon buckle is limited to detachments with a single break or a group of breaks within 1 clock hour (located superiorly and inferiorly), the balloon is not fixated by sutures and is withdrawn after 1 week. The rationale for removing the balloon after 1 week were the results of our earlier animal experiments on the strength of the cryosurgical adhesion and the time required to develop a sufficiently strong adhesion.[17,18] These experimental data on the strength of the cryosurgical retinal adhesion were confirmed clinically after 10 years by outcomes of the temporary balloon buckle procedure.

The balloon operation is performed under topical or subconjunctival anesthesia. No sutures have to be placed to fixate the balloon buckle, and the small conjunctival wound of 1-2 mm, needed to insert the balloon catheter will close by itself after withdrawal of the balloon. Thereafter, sustained reattachment will depend exclusively on the strength of the retinal adhesion, induced by transconjunctival cryopexy prior to insertion of the balloon, or by laser, applied postoperatively after reattachment of the break on the balloon buckle.

The balloon operation represents the ultimate refinement of closing a leaking break ab externo without leaving a buckle on the eye. The break is sealed off by surrounding retinal adhesions. This type of surgery represents a procedure with minimal surgical trauma. The balloon operation follows the postulate of Gonin[1], to find the break and to limit treatment to the area of the leaking break and the principle of Custodis[15], i.e. no drainage of subretinal fluid. With the balloon procedure, the last complications of segmental buckling, namely infection, extrusion of the sponge buckle (< 0.5%) and diplopia (≈ 1%), are eliminated.

The results of 500 detachments treated with temporary balloon buckle with two and half years of follow-up demonstrated reattachment rate of 93% after a single operation and 91% after balloon removal. Reoperation was required in 0.8% (4 eyes) and reattachment was obtained in 99% (Table 2). Postoperative PVR was reduced to 0.2%. This low rate of PVR reflects the further reduced surgical trauma with the balloon operation.[31]

3. SF_6 Gas Injection and Drainage

Parallel to the refinements in segmental buckling, it was found that giant tears were not suitable for buckling. The required long circumferential plombes caused constriction of the globe and radial retinal folds resulting in leakage through the posterior edge of the giant tear. Therefore, the gas operation of Rosengren was introduced again, now for the 2nd time, by Norton[32] and Lincoff[33] at the beginning of the 70's, for detachments with problematic tears. For these eyes the intraocular gas operation proved to be a more suitable approach. After drainage of subretinal fluid the new gas, SF6, was injected into the vitreous cavity to unfold and to tamponade the giant tear. After reattachment, adhesion at the edges of the tear was accomplished by cryopexy or with photocoagulation, introduced by Meyer-Schwickerath[34], and replaced by laser coagulation in subsequent years.

The reattachment rate of retinal detachments caused by giant tears increased with the gas operation, which was limited to the area of the tear, but combined with prior drainage of subretinal fluid. However, the Custodis principle, i.e. to omit drainage, was left behind again.

4. Expanding-Gas Operation without Drainage

Since 1974 Kreissig[35] began to look for the possibility to sustain the nondrainage principle when treating detachments with problematic tears with an intraocular gas bubble. After ocular compression injection of SF6 gas was done without prior drainage. As a result, a larger gas bubble could be injected which subsequently increased in volume due to its expansion coefficient. Now for the first time the nondrainage principle was transferred to an intraocular gas operation. This was used for problematic detachments with giant tears and posterior breaks. However, in contrast to the good results experienced with extraocular minimal surgery, postoperative PVR increased significantly after intraocular gas procedures. Therefore this nondrainage gas operation without drainage, called "expanding-gas operation",[35] was reserved for these selected problematic detachments; it was not used for detachments with uncomplicated leaking breaks, because since 1979 the balloon operation was available for these eyes.[30,31] The balloon operation was also a nondrainage procedure with temporary tamponade of the leaking break during scarring, but it represented an extraocular approach.

5. Perfluorocarbon Gases

The operation with the expanding gas SF6 for complicated retinal tears was further improved with the introduction of the 4 perfluorocarbon gases (CF_4; C_2F_6; C_3F_8; C_4F_{10}) by Lincoff and his group.[36-39] The expansion of CF4 is 1.9x and practically the same as SF6, but the 3 other perfluorocarbons expand 3.3, 4 and 5 times their original volumes respectively (Fig. 12). As the chain of the perfluorocarbon gas increases in length, the insolubility of the gas increases. Thus, the half-life (representing the therapeutical volume of a gas) of these 4 gases ranges between 6 and 45 days (Fig. 13). As a result, more complicated tears could be treated with the "expanding-gas operation without drainage". On the other hand, greater gas expansion was combined with longer duration in the eye, resulting in a higher rate of PVR and complications.

6. Balloon-Gas-Procedure

To reduce this higher rate of PVR, Kreissig began to look for a way to reduce the intraocular duration of the gas and in 1984 started to use a combination of balloon and gas, the so-called "balloon-gas-procedure" (Fig. 14) for problematic detachments.[40] Under topical anesthesia, a balloon was inserted into the parabulbar space and due to compression of the eye, internal drainage of subretinal fluid was induced. Two hours later, again under topical anesthesia, a larger volume of gas could be injected into the eye without closing off the central retinal artery. Why? Because the moment the patient reported disappearance of light, fluid from the pre-placed balloon was withdrawn to restore retinal circulation. This was repeated until the balloon volume was completely withdrawn and replaced by the volume of the intraocular gas bubble. Thus, a larger volume of gas could be injected in the first place and as a result, a less expandable gas could be selected which was combined with a shorter intraocular duration. As a result, even for larger volumes of intraocular gas, nondrainage with fewer complications could be sustained. Thus, for giant tears up to 90° or even 150° and for posterior holes this balloon-expanding gas operation represents a minimal intraocular procedure with relatively good results, but a substantial rate of PVR.

7. Pneumatic Retinopexy

Despite the observed complications after intraocular gas, the expanding-gas operation without drainage, published in the German literature in 1979,[35] was not known to Hilton[41] and Dominguez,[42] when they re-introduced this gas technique without drainage in 1986 and 1987, respectively, now for the second time, but this time for uncomplicated detachments. This procedure was named "pneumatic retinopexy". It is still in use today due to its simplicity and despite the fact that it harbours greater morbidity in closing the leaking break in comparison with minimal segmental buckling or the balloon operation.

In a study of 500 uncomplicated detachments[41-50] the retina was reattached after one gas injection in 91%; after disappearance of the gas redetachment occurred in 11%. Yet after several reoperations, up to 3 operations in originally uncomplicated detachments and reoperations needed in every 5th detachment, reattachment was obtained in 99%. New breaks and PVR developed in 15% and 4%, respectively (Table 3).

8. Primary Vitrectomy

Perhaps due to the increased rate of PVR and reoperations after pneumatic retinopexy, in the mid 80's it was assumed that with additional vitrectomy performed prior to gas injection, the rate of PVR could be reduced or even eliminated completely. This modified gas operation, consisting of vitrectomy and gas injection, was now used for the first time for primary retinal detachments with uncomplicated breaks; the procedure was called "primary vitrectomy". The reason behind using vitrectomy for primary detachments was, as Lincoff once stated "If vitrectomy is good for complicated detachments, why should it not be as good or even better for uncomplicated detachments and the same thing goes for applying expanding gases for uncomplicated detachments".

Vitrectomy was available since 1972. It was employed by Machemer[51] for retinal detachments complicated by vitreous traction and vitreoretinal proliferation. The first instrument for vitrectomy, the "VISC", was still somehow bulky and subsequently refined by O'Malley to the "Ocutome". In the beginning of the 70's Kreissig returned to Bonn, Germany after her 3-year training with Lincoff in New York, but continued to be involved, now on a transatlantic basis, in joint clinical studies on retinal detachment surgery. As a result, she received the first Ocutome which was shipped to Europe. Yet just at that time large numbers of retinal detachments were sent to Bonn for repair with this new minimal segmental buckling without drainage, which was introduced after her return from New York. Due to this new buckle operation without drainage very few failures due to PVR resulted, and only these eyes required a vitrectomy for reoperation. But there was Neubauer in Cologne, 12 miles North of Bonn, who had just developed a new technique to localize and remove nonmagnetic intraocular foreign bodies.[52] As a result, many perforating injuries were concentrated in Cologne. Therefore, Kreissig offered Neubauer and his senior Klaus Heimann to try her new Ocutome for their surgery on traumatized eyes. As a result, in the subsequent years Heimann became deeply involved in vitrectomy and Kreissig in minimal segmental buckling without drainage.

By applying vitrectomy as a primary procedure for rhegmatogenous retinal detachments, traction on the leaking break or tear and as well the anterior and posterior vitreous were removed. With this new extensive intraocular surgery (no longer limited to the area of the break), one was hoping that the cause of postoperative PVR, new breaks, and redetachments would be completely eliminated. However, as will become apparent later in the comparison of primary vitrectomy versus pneumatic retinopexy or minimal segmental buckling without drainage, primary vitrectomy did not achieve this aim.

Conclusion

The present literature review on changing concepts in surgery for repair of a primary retinal detachment indicates that great progress has been made during the last 75 years. This has led to the introduction of two extraocular and two intraocular surgical procedures for repair of a leaking break in primary retinal detachments at the beginning of the 21st century. To succeed with any of these methods, the break has to be found and sealed off sufficiently; however, in each method this objective is achieved differently and emphasis on the retinal break varies significantly. Further study is recommended to compare existing conventional methods and explore the superiority of different techniques for repair of retinal detachments in terms of morbidity, complication rates and long-term visual results.

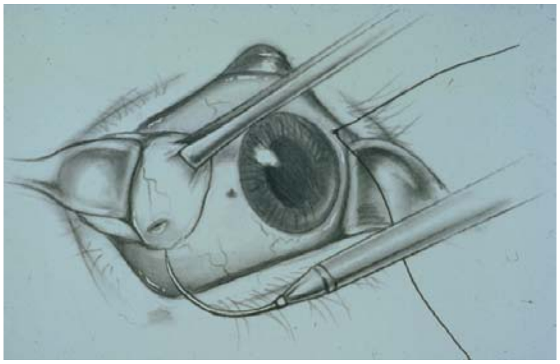

Fig.1 Ignipuncture coagulations after drainage of subretinal fluid by Gonin. Treatment is limited to area of the break.

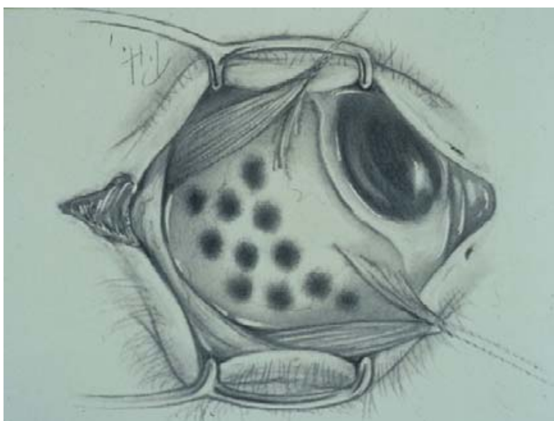

Fig. 2 Coagulations are spread over the entire quadrant of the break.

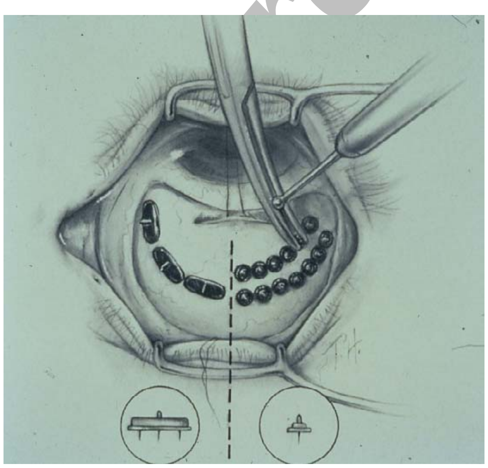

Fig. 3 Short perforating pins on a bar (**left**) or single (**right**) are placed in a single or double row posterior to the break and touched by a diathermy electrode to create a "barrier" of coagulations.

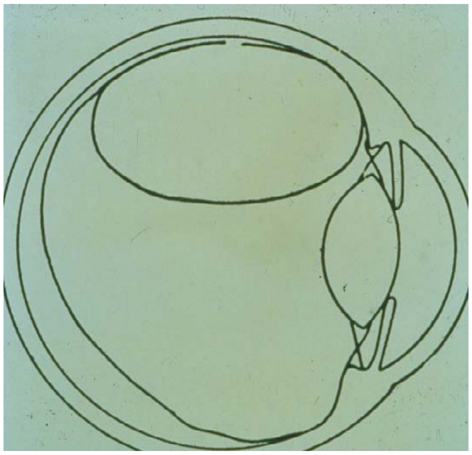

Fig. 4 Use of an intraocular air bubble to tamponade ab interno a break, performed by Rosengren in 1938.[5]

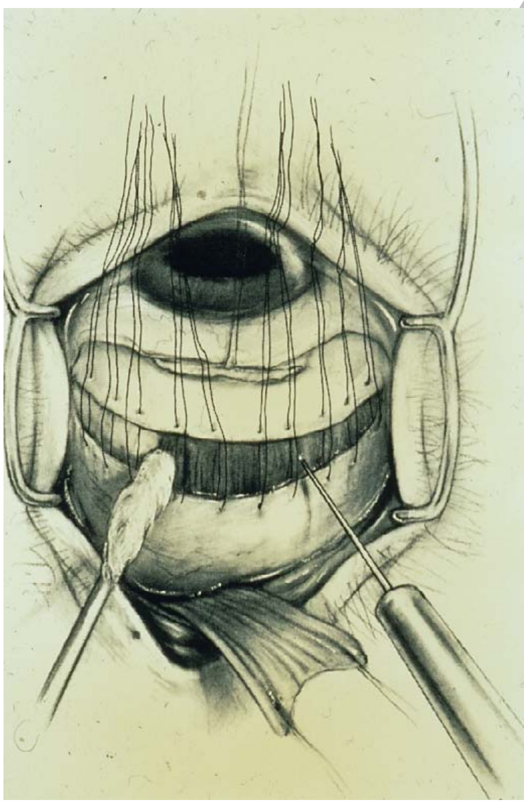

Fig. 5 Scleral resection with coagulations, located posterior to the break resulting in indentation to create a better barrier ab externo.

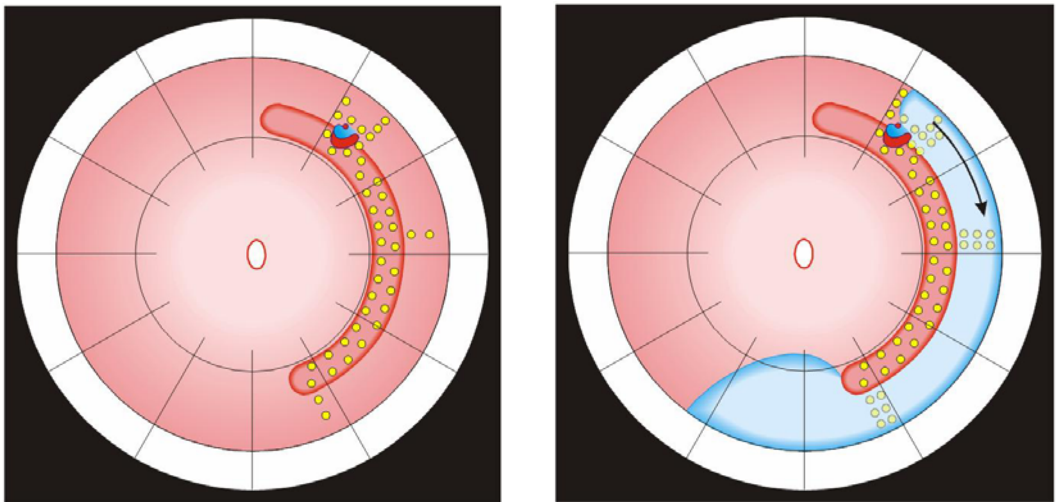

Fig. 6 **a.** Segmental plombe embedded into scleral resection. The retinal break is positioned on the anterior edge of the buckle and additional diathermy coagulations are placed on the buckle and as well towards the ora.
b. Retinal break starts to leak again anteriorly, resulting in a redetachment anterior to the buckle which subsequently crosses the barrier of coagulation and finally progresses towards the posterior retina, resulting in redetachment.
(from Harvey Lincoff, MD, New York)

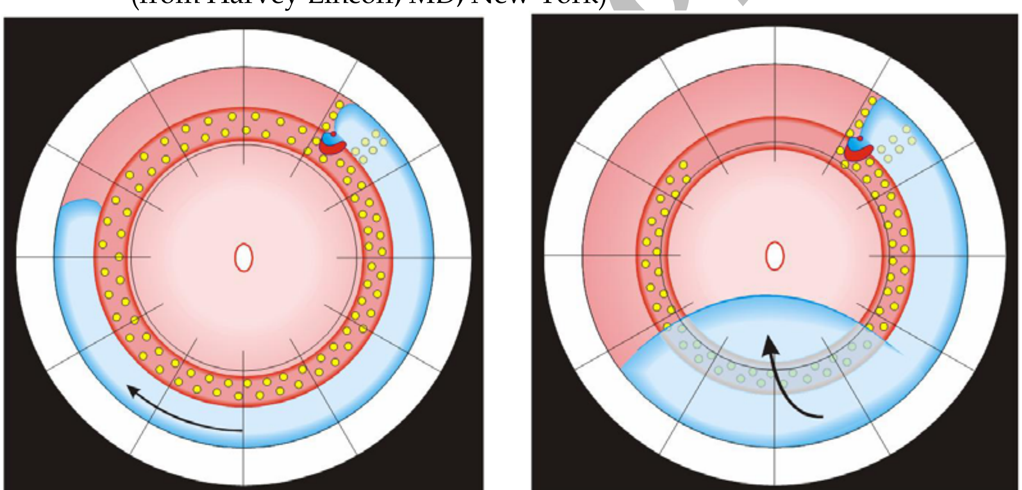

Fig.7 **a.**Circular buckle (so-called cerclage) with coagulations on and anterior to the entire buckle.Redetachment descending anterior to the buckle. Due to the very anterior position of the cerclage, the momentum of subretinal fluid seems not enough to cross the cerclage and to redetach the posterior retina.
b. More posteriorly positioned cerclage with coagulations on the buckle and anterior to it. This time the anterior redetachment, originating from the leaking break, crosses the barriers of coagulations, but due to the larger momentum of subretinal fluid, it crosses the cerclage inferiorly and progresses towards the posterior retina.
(from Harvey Lincoff, MD, New York)

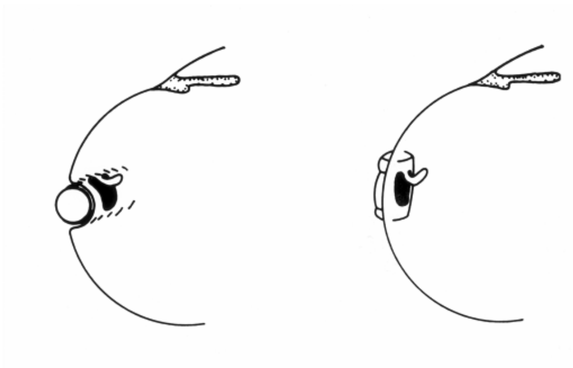

Fig. 8 Optimal orientation of segmental buckle for tamponade of a horseshoe tear. Using a *circumferential buckle* (**left**), the horseshoe tear is not tamponaded adequately. The operculum, an area of future traction, is not on the ridge of the buckle, but on the descending slope. In addition there is a risk of posterior radial folds ("fishmouthing") with subsequent leakage. A short *radial buckle* (**right**) provides optimal tamponade for the horseshoe tear. The entire tear is placed on the ridge of the buckle, this counteracts posterior "fishmouthing" of the tear and provides optimal support for the operculum and at the same time counteracting future anterior vitreous traction.

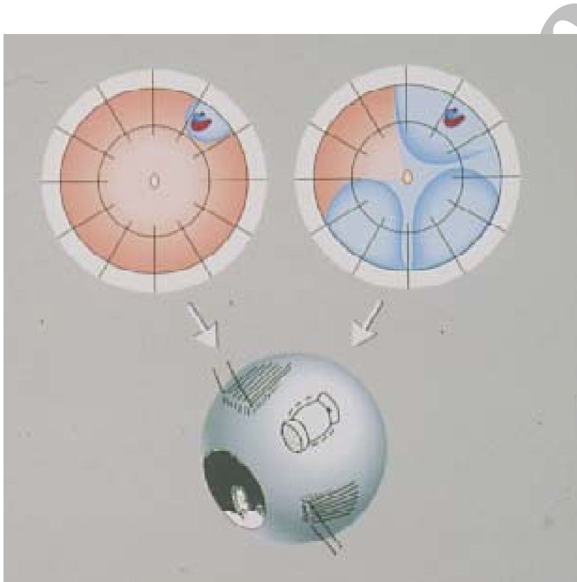

Fig. 9 Minimal segmental buckling without drainage, so-called extraocular minimal surgery. Treatment is limited to the area of the break and not determined by the extent of the detachment. The small (**top left**) and the more extensive detachment (**top right**) are caused by the same horseshoe tear at 1:00. The treatment of both is the same, consisting of buckling the tear either by a segmental sponge (as depicted) or a temporary balloon without drainage of subretinal fluid.

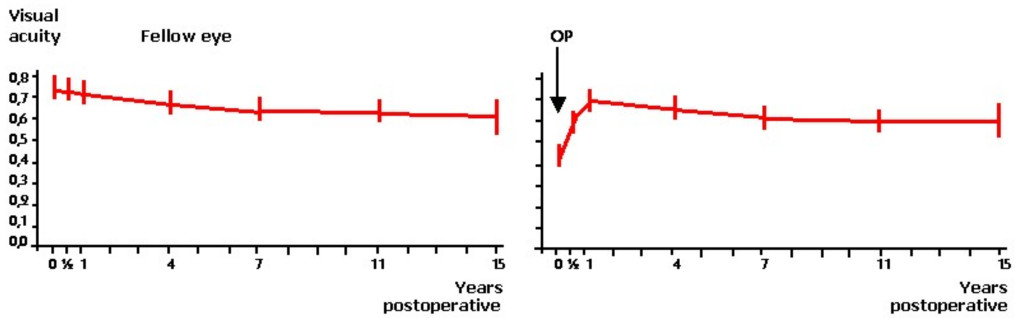

Fig. 10 Course of mean visual acuity of fellow and operated eyes during 15 years. Course of mean visual acuity in the 107 unoperated fellow eyes during the 15-year follow-up (**left**). Course of mean visual acuity in the 107 eyes with retinal detachments operated with extraocular minimal surgery, consisting of segmental sponge buckle(s) without drainage during 15 years after surgery (**right**). During the study period of 15 years the difference in decrease of visual acuity was not statistically significant between the unoperated fellow eyes and operated eyes with the segmental buckle(s) in place at any interval.

Fig. 11 Lincoff-Kreissig balloon. The presented balloon has (1) a metal stylette to facilitate insertion into the parabulbar space and (2) calibrations (black marks) on the tube to enable a more precise determination of the balloon's position in the parabulbar space. Deflated balloon catheter with stylette in place; beneath is the adapter (top). Inflated balloon (0.75 ml of sterile water) with self-sealing valve in place; beneath it the withdrawn stylette (bottom).

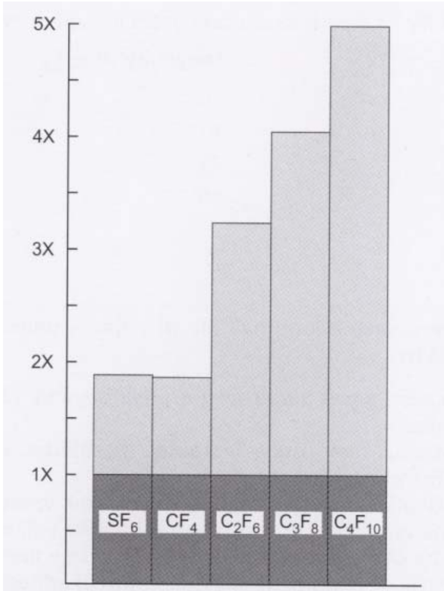

Fig. 12 Expansion of SF_6 and the 4 straight-chain perfluorocarbon gases.

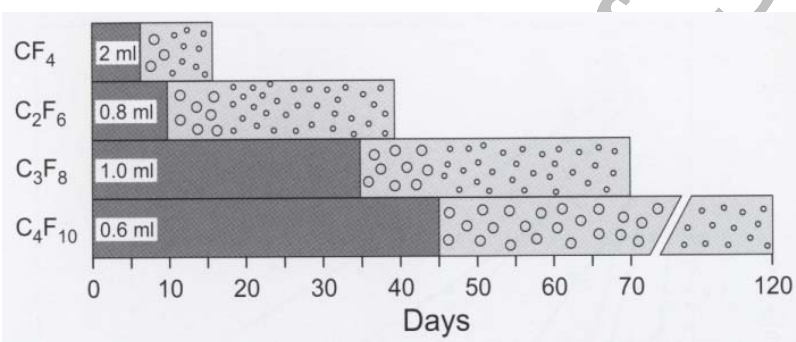

Fig. 13 Disappearance time of the 4 straight-chain perfluorocarbon gases in patient eyes. The left portion of each bar (darker gray) indicates the time for the expanded volume of gas to diminish to half volume.

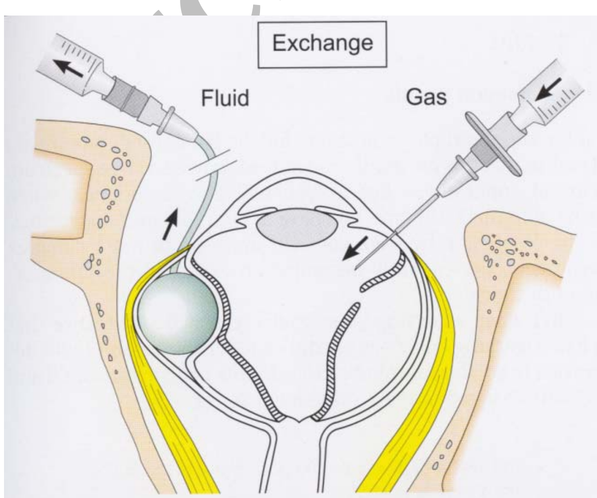

Fig. 14 Balloon-gas procedure: The balloon is used for providing fluid-gas exchange. The intraocular space for subsequent gas injection without drainage of subretinal fluid is created by prior insertion of a parabulbar balloon that induces internal drainage of fluid due to continuous compression. About 2 hours later, the obtained space is replaced by injection of gas combined with simultaneous withdrawal of balloon contents. This provides space for injection of a larger gas bubble without prior drainage or vitrectomy.

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