Gases in Vitreoretinal Surgery

Jančo L., Vida R., Bartoš M., Villémová K., Izák M.

2nd Eye department , SZU, FNsP F. D. Roosevelta, Banská Bystrica,
Head: MUDr. Mária Molnárová, PhD.

SUMMARY

Gases in Vitreoretinal Surgery

Aim: To evaluate the importance and benefits of using gases in vitreoretinal surgery.
Material and Methods: The gases represent a wide group of substances used in eye surgery for more than 100 years. The role of intraocular gases in vitreoretinal surgery is irreplaceable. Their use is still considered to be the "gold standard". An important step in eye surgery was the introduction of expanding gases – sulfur hexafluoride and perfluorocarbons into routine clinical practice. The most common indications for the use of intraocular gases are: retinal detachment, idiopathic macular hole, complications of vitreoretinal surgery and others.
Results and conclusions: The introduction of intraocular gases into routine clinical practice, along with other modern surgical techniques resulted in significant improvement of postoperative outcomes in a wide range of eye diseases. Understanding the principles of intraocular gases use brings the benefits to the patient and physician as well.. Due to their physical and chemical properties they pose far the best and most appropriate variant of intraocular tamponade. Gases also bring some disadvantages, such as difficulties in detailed fundus examination, visual acuity testing, ultrasonographic examination, difficulties in application of intravitreal drugs or reduced possibility of retina laser treatment. The gases significantly change optical system properties of the eye. The use of gases in vitreoretinal surgery has significantly increased success rate of retinal detachment surgery, complicated posterior segment cases, trauma, surgery of the macula and other diseases.

Key words: gas, vitreoretinal surgery, retina, vitreous body

Čes. a slov. Oftal., 68, 2012, No. 1, p. 3-10

First author:
MUDr. Ladislav Janão
2nd Eye Department, SZU, FNsP F. D. Roosevelta,
Banská Bystrica
e-mail: infoskk@skkartik.sk

HISTORY

The first mention in literature of the presence of gas in the eye is attributed to Sir Robert Boyle from the year 1670, who observed an air bubble in the anterior chamber following an injury to the eye of a snake which he had killed (6).
Further records and a first in the intraocular injection of gas belong to Koster, who in 1902 applied an injection of air into the anterior chamber for the purpose of treating tuberculosis of the iris (25).
In the following period, several reports emerged on the use of air on disorders of the anterior segment of the eye in the case of phlyctenular conjunctivitis keratoconjunctivitis, corneal ulcer, hypopon and syphilitic scleritis.
The first record of intravitreal injection of air is by Ohm from the year 1911 (50). Ohm applied air to the eyes of cats and observed its resorption. He subsequently described the use of air on a patient with detachment of the retina. After aspiration of the subretinal fluid via inferonasal sclerotomy, he applied 1 ml of air into the vitreous area and left the patient to position. After two days the air was reabsorbed and upon examination Ohm found the retina attached. In the second patient with a detached retina, this procedure was not successful despite repeated application of air into the vitreous area.
In the subsequent period Rosengren understood, described and clarified the principles of tamponade of a retinal rupture by an air bubble. He emphasised the role of air in accelerating absorption of subretinal fluid, the ability of the bubble to press the edge of the retinal rupture to the choroid thanks to the pressure force, which prevents the penetration of further fluid beneath the retina. In his sample of 29 eyes from the year 1938 he achieved a 45% success rate of the operation after diathermy, and an 84% success rate in a sample of 25 eyes after diathermy, puncture of the subretinal fluid and injection of air into the vitreous area (52). In 1947 he described his surgical technique in detail in his publication, and presented the results of the sample of his first 100 patients with retinal detachment. He found that his surgical technique had good results in the treatment of acute retinal detachment, but insufficient results in the case of persistence of retinal detachment for more than one year (51). In his concluding works in 1952 and 1953 he published the results of samples of 300 cases of retinal detachment. In patients with flat retinal detachment he was successful also after diathermy with puncture of the subretinal fluid, without application of air. Retinal detachment in the lower quadrants responded well to diathermy alone.
His surgical technique was surpassed at the end of the 1950s by the introduction of the technique of external plombage of the sclera by Custodis and Schepens.
The introduction of expansive gases in eye surgery can be credited to Lincoff, who in the years 1965-67 (36) sought gases with a longer lasting effect in the eye and slower resorption. He studied the effects of neon, argon, air, ethane, propane, neopentane and non-specific chlorofluorocarbon, until it was converted to sulphur

hexafluoride (SF6). Several experts in the subsequent period examined the safety and dynamics of various gases, of which perfluorocarbons proved to be the most beneficial.

The possibilities of tamponade and treatment of large retinal ruptures with gases in combination with diathermocoagulation and cryoretinopexy were published by Norton et al. in 1969 (47).

The first mention of the use of a combination of SF6 with plombage of the sclera upon retinal detachment is by Norton from 1973 (45). In the following period (1974) McLean and Norton (40) published possibilities for treatment of primary retinal detachment using tamponade by gas with retinopexy without the use of a sclera filling in selected patients with minimal vitreous traction (pneumatic retinopexy). This technique was progressively extended and in the American ophthalmological literature we find a range of publications on this theme. In 1987 Hilton et al. (21) published a sample of 100 eyes operated on using this technique. After the primary operation they attained a success rate of 84% for retinal reattachment, and the definitive success rate in the sample after reoperation was 98%.

With the development of vitreoretinal surgery and the introduction of Pars Plana Vitrectomy (PPV) into practice by Machemer and his students in the 1980s, expansive gases gained an important place in the field of intraocular tamponade. The significance of tamponade of the retina by gases following primary vitrectomy in the case of rhegmatogenous retinal detachment was published by Escoffery in 1985 (14), who noted a wide range of potential complications following plombage of the sclera: expulsion of the filling, infection, restricted movement of the bulb, subretinal haemorrhage, ischemia of the anterior segment of the eye, ametropia, disorder of blood flow through the posterior segment of the eye.

The subject of further studies was the significance of longer lasting tamponade by gases in comparison with SF6. In 1985 Chang et al. (9) published the results of their sample of 56 patients with complicated retinal detachment. They observed markedly better results upon tamponade using perfluoroethane (C2F6) and perfluoropropane (C3F8) in comparison with SF6, upon which several reoperations were required. The first multicentric randomised controlled trial comparing the results of pneumatic retinopexy and plombage of the sclera were published in 1989 by Tornambe et al. (62). The result was a significantly lower success rate of primary pneumatic retinopexy in comparison with plombage of the sclera (75% as against 90% in phakic eyes and 67% as against 73% in aphakic eyes). It is however important to note that in plombage of the sclera, application was gas was also used into the vitreous cavity in as many as 36% of cases.

In the 1990s indications of pneumatic retinopexy extended also to macular hole, large retinal ruptures and optic nerve disc pit.

The use of expansive gases in combination with pars plana vitrectomy for idiopathic macular hole was first published in 1991 by the authors Kelly and Wendel (24). In their work they placed emphasis on thorough vitrectomy, removal of all epiretinal membranes, tamponade by gas and positioning of the patient face down. In the study they achieved an improvement in the vision of 42% of eyes. In the subsequent period reports emerged on the possibility of improving the results of macular hole surgery through the use of the growth factor beta or application of autologous platelet concentrate.

Table 1

Non-expansive gases	Expansive gases
Air	Sulphur hexafluoride (SF6)
Nitrogen	Octafluorocyclobutane (C4F10)
Helium	Perfluoromethane (CF4)
Oxygen	Perfluoroethane (C2F6)
Argon	Perfluoropropane (C3F8)
Xenon	Perfluorobutane (C4F10)
Krypton	Perfluoropentane (C5F12)
Carbon dioxide	

PROPERTIES OF GASES

Physical properties of gases

A large quantity of gases have been developed for the requirements of vitreoretinal surgery (table 1). From the perspective of clinical practice the most important are air, sulphur hexafluoride (SF6) and perfluorocarbon gases.

Air is composed of 78% nitrogen, 20.5% oxygen, 1% argon, 0.3% carbon dioxide and water vapour. As a result nitrogen is the most important component with regard to physical properties.

SF6 is a gas with no colour, taste or odour. It is approximately five times heavier than air. It is chemically inert and thermally stable. Thanks to its low solubility in water it diffuses very slowly from the eye and a bubble with a volume of 1 ml of 100% SF6 disappears from the eye after approximately 10 days. It is available in a highly purified form in a concentration of 99.99%.

Perfluorocarbons are also inert, colourless, non-combustible gases without odour. Perfluoropropane is approximately 6 times heavier than air. These gases are produced in highly purified form (more than 99.7%). Their solubility in water decreases with increasing length of the carbon chain and thus higher molecular density, with the result that their capability of expansion and duration of tamponade increases.

Chemical properties of gases

Under physiological conditions the majority of gases are inert. Chemical changes may however take place under special conditions, e.g. electric arc or laser radiation. Sulphur decafluoride, which may be produced by the breakdown of SF6, is considered to be potentially toxic (20). The results of scientific works however have not led to a limitation of the use of expansive gases (23).

Biological properties of gases

Fears of potential undesirable effects surfaced immediately after the introduction of gases into clinical practice. These were partially fears of harm to staff upon the potential leakage of gas in the operating theatre, as well as fears of possible damage to the eye. However, these fears were never substantiated. Clinical trials and tests on animals did not confirm any toxicity (7, 16, 23).

The majority of regularly used gases also have certain anaesthetic properties, above all under hyperbaric conditions. Under atmospheric conditions the anaesthetic effect of SF6 is lower than in the case of nitrous oxide, and C3F8 has only weak anaesthetic effects. This relative potential links to their solubility in lipids (12).

Liquid – gas boundary

The liquid – gas boundary is directly responsible for the therapeutic and also undesirable effects of the gases. Surface tension represents one of the most important physical forces of the gases inside the eye. Thanks to the high surface tension of the gas, this prevents the flow of fluid through the hole or rupture in the retina. The anterior chamber fluid has a surface tension of approximately 24 dyne/cm2, sodium hyaluronate approximately 50 dyne/cm2, gases have the greatest surface tension (70 dyne/cm2) of all the available retinal tamponades. Thanks to the inert gas – liquid boundary the proliferative cells are unable to settle on the surface of the gas bubble.

The elasticity and lifting force of the bubble plays a very important role in the mechanism of the effect of intravitreal gases. The desired effect is attained by the correct positioning of the head so as to ensure that the surface of the bubble tamponade the retinal rupture.

There are two optical effects of the aforementioned boundary: refractive and reflexive. The optical density of the eye filled with gas depends on the localisation of the bubble, its size and the position of the eye. The size of the image is reduced as a result of the optical properties of the liquid – gas boundary. If the vitreous cavity is completely filled with gas, refraction of the eye is shifted towards myopia by approximately 10 dioptres. Conversely, upon filling of the anterior chamber of the eye with gas there is a shift towards hypermetropia by approximately 12.7 dioptres. The situation is different in aphakic eyes. In this case the gas practically neutralises the optical density of the cornea, and as a result it is possible to examine the fundus even without the use of a lens. Reflections of light from the liquid – gas boundary cause difficulties upon direct ophthalmoscopy, as well as in attempted coagulation of the retina.

DYNAMICS OF GASES

The dynamics of the used intravitreal gases have been intensively researched in experimental models and also clinically. Changes to the volume of the gas bubble in the eye can be divided into three phases: expansion of the bubble, balanced state and disintegration (absorption). The factors which have an influence on the change of the size of the gas bubble are: size of surface of bubble, diffusion coefficient of bubble in liquid, solubility of bubble in liquid, difference in partial pressure of gases in bubble and liquid, thickness of diffusion barrier, through flow of blood in eye, properties of vitreous area.

Expansion of bubble

Expansive gases do not expand in the true sense of the word. Increase of the volume of the gas bubble occurs as a consequence of the diffusion of gases in the surrounding area of the bubble into the bubble (primarily nitrogen, oxygen and carbon dioxide) up to the point when the speed of diffusion of the gases out of the bubble and the base become imbalanced. At this moment the bubble attains its largest volume. The diffusion of oxygen and carbon dioxide takes place rapidly, and attain a balanced state within the course of a few hours. Nitrogen diffuses very slowly and takes several days if it attains a balanced state.

Nitrous oxide, which is used in inhalation anaesthesia, has a special position in this phase. This gas is up to 34 times more soluble than nitrogen and 117 times more soluble than SF6, and as a result diffuses extremely rapidly into the gas bubble in the vitreous cavity. These properties have significant clinical use. If we plan the use of a gas bubble in a patient in general inhalation anaesthesia, inhalation of nitrous oxide should be discontinued at least 15 minutes before application of the gas (60). Another option is exclusion of nitrous oxide during anaesthesia – for example the use of total intravenous anaesthesia.

A sudden drop in atmospheric pressure during an aeroplane flight may cause a sudden increase in intraocular pressure in the case of a large gas bubble in the vitreous cavity as a consequence of the increase in volume of the bubble. As a result of this, ocular pressure increases, which may lead to a closure of the central retinal artery. The first case of sudden eye pain after vitrectomy with an SF6 gas bubble during an aeroplane flight was described by Norton and Fuller (48) in 1976. Clinical experiments demonstrate that aeroplane flight should be safe if the gas bubble in the eye is smaller than 1 cm3. In contrast with this, some studies demonstrate that an intravitreal bubble with a size of 0.25-0.5 cm3 may cause a dangerous increase in intraocular pressure (10).

Balanced state

A balanced state represents a state in which the bubble remains relatively the same size and has reached its maximum volume. At this moment the diffusion of gases in and out of the bubble is approximately equal. Upon perfluoropropane this phase lasts approximately 2-3 days. Some authors dispute the existence of this phase.

Desintegration of bubble

This phase occurs when diffusion of gases out of the bubble is faster than in the opposite direction. The reduction in size of the bubble over time copies the exponential curve. Highly diverse data can be found in the literature about the half-life of the disintegration of the gas bubble, which is influenced by several factors. For example, the presence of the vitreous area plays an important role in the disintegration of the bubble. It has been demonstrated in experiments that the half-life of the breakdown of sulphur hexafluoride or perfluoropropane is 2.2 to 2.7 times longer in non-vitrectomy treated phakic eyes (63). Meyers et al. (42) determined that the half-life of the disintegration of the gas bubble fluctuates markedly upon repeated application on the same eye.

Table 2 presents a brief overview of expansion, the approximate point of duration of the bubble in the eye, non-expansive concentration and recommended concentration for application of individual gases.

Table 2

Gas	Expansion (x)	Duration (days)	Non-expansive concentration (%)	Recommended concentration (%)
SF6	2.0	10-14	18-20	25
C2F6	3.5	30-35	16	20
C3F8	4.0	55-65	12-14	20

PREPARATION OF GASES FOR OPERATION

Application and tamponade of the retina with air during vitrectomy is performed with the help of an air pump, which is a component of an instrument used for vitrectomy. Air is applied to the vitreous cavity continually under a certain adjustable pressure with the use of antibacterial filters. This technique was introduced into practice at the beginning of the 1980s with the development of instruments for vitreoretinal surgery (39). This method prevents the collapse of the eye also during open sclerotomies and subsequently enables the use of laser photocoagulation of the retina or cryoretinopexy.

Preparation of gases in expansive or non-expansive concentrations also takes place under aseptic conditions with the use of antibacterial filters. The necessary quantity of gas is aspirated through a filter into a syringe selected in advance, and applied either in undiluted form into the eye filled with air or in the desired diluted concentration. If the retina is completely reattached during tamponade by air, a non-expansive or minimally expansive concentration of gas is used, whilst if there is residual subretinal fluid beneath the retina at the end of the operation, application of a slightly expansive concentration of gas is recommended. The preparation of the gas should take place just before its use, since longer storage of the prepared gas leads to a decrease of its concentration in the syringe (57). However, the data in the literature differs greatly in the individual sources. Humayan et al. (22) observed a reduction of the concentration of SF_6 after aspiration into a 10 ml plastic syringe from 100% to 89% over the course of 15 minutes, and after 1 hour a decrease of the concentration of SF_6 to 76%. After 18 hours the concentration of SF_6 was only 2%.

The most modern instruments for vitreoretinal surgery now offer the option of application of gas or a compound thereof directly from the instrument.

CLINICAL USE OF GASES IN VITREORETINAL SURGERY

According to Norton (45) indications in the field of "classical" retinal detachment surgery have not changed significantly since 1973. The main indications are: large retinal ruptures with a tendency towards "fishmouth" phenomenon, massive retinal rupture in the upper half of the fundus, ruptures localised on the posterior pole, macular holes, replacement of volume upon drainage of subretinal fluid, retinal detachment with multiple ruptures of the retina and radial shirring of the retina.

Upon pars plana vitrectomy gases are used in the treatment of more complex cases of retinal detachment, massive ruptures, proliferation vitreoretinopathy (PVR) and other disorders (23, 25). An important group of disorders are pathologies of the macula, primarily macular hole (11, 26, 28).

The selection of gas, its concentration and volume, preparation and method of application depends on the individual requirements of each case and naturally on the clinical experiences and preferences of the vitreoretinal surgeon. In general it is possible to state that the more complicated the case, for example tractional retinal detachment or PVR, the more the use of longer lasting gas is recommended.

Pneumatic retinopexy

Pneumatic retinopexy represents one of the most effective indications for use of intraocular gases. It represents a possibility of treatment of the disorder without more a extensive surgical intervention. Even today it has its place in detached retina surgery, although its use is indicated only in selected cases (1, 15, 62, 64).

Use of gases in scleral plombage

The use of gases during scleral plombage is a regular procedure, which is however suitable only when it produces a sufficient effect. The injection of gas is beneficial for the purpose of temporary tamponade of retinal rupture. In certain cases it is probable that temporary tamponade of the rupture is sufficient and plombage of the rupture is not necessary. The use of gas is also beneficial upon the occurrence of a "fishmouth" rupture phenomenon (as a result of pronounced traction of the vitreous area or significant shortening of the perimeter of the eye by the filling or cerclage) (45, 46). Gases represent an alternative to the use of solutions, which have to be injected upon refilling the volume of the eye following drainage of the subretinal fluid (SRF). They also help accelerate and complete drainage of the SRF. Intravitreal application of gas can also be used in further management of unsuccessful plombage of the sclera or cerclage (49).

Gases in pars plana victrectomy for retinal detachment

The introduction of the technique of gas – fluid exchange represented a fundamental milestone in vitreoretinal surgery. Before the era of vitrectomy, reports multiplied about this technique also on non-vitrectomy treated eyes, which was successful in the case of condensated vitreous body. By this method the authors Meyers et al. (43) achieved tamponade of approximately 50% of the vitreous cavity.

Gas can be used during vitrectomy to tamponade retinal ruptures and holes by active or passive suction of the subretinal fluid (SRF) through the existing rupture or for drainage of central and peripheral retinotomy. After the drainage of the SRF, tamponade of the retina is completed by suction of the fluid from the vitreous cavity. Gases are also suitable for tamponade of wounds on the sclera, help create an optically clear vitrous cavity in the case of repeated haemorrhage, identify residual traction or shortening of the retina as a result of PVR. Thanks to its optical properties, visualisation of the peripheral retina is significantly improved up to the ciliary muscle during gas tamponade of the retina.

Retinal tamponade by gas creates good preconditions for subsequent sufficient tamponade with silicon oil by technical replacement of oil with air, which fills the vitreous cavity from below. With the help of gas – fluid exchange it is also possible to remove temporary retinal tamponade from the vitreous cavity with heavy liquids – heavy perfluorocarbons. Retinal tamponade by gas enables the subsequent treatment of degenerations, ruptures and holes of the retina with cryoretionpexy or laser retinopexy. Positioning of the patient with the aim of correct tamponade of the specific retinal pathology is a matter of course in the postoperative period.

Gases in the treatment of idiopathic macular hole

The first reports of the use of gases without vitrectomy in the case of macular hole emerged in connection with retinal detachment (32). Idiopathic macular hole was initially considered untreatable. However, reports emerged of the improvement of visual acuity following laser photocoagulation (56).

The initial reports from Kelly and Wendel from 1991 (24) on the results of pars plana vitrectomy on idiopathic macular hole were not very encouraging. The improvement of the surgical technique, the introduction of colouring of the epiretinal membranes and the membrana limitans interna (MLI) and the extension of the use of the technique of MLI peeling led to a marked improvement of postoperative results. Prognostic factors before the operation, the potential undesirable effects of colourings, the extent of necessary MLI peeling, type of tamponade and whether and how long to position remain the subject of discussion (11, 26, 28, 44, 61).

Other possibilities for use of gases

Gases can also be used in the case of other diagnoses in eye microsurgery. This most frequently concerns cataract surgery, refractive surgery, glaucoma surgery and expulsive haemorrhage.

Use of gases in cataract surgery

The gas (air) applied to the anterior chamber improves its visualisation and helps restore its shape and volume, which in the past was used mainly in extracapsular cataract extraction. The use of air to ease anterior capsulotomy was first described by Binkhorst et al. in 1978 (5). It was highly useful during this period also in the protection of the endothelium upon implantation of artificial intraocular lenses. It was also used in cataract surgery upon management of the loss of the vitreous body (8) and upon correction of the shape of the pupil. Air effectively tamponades corneal wounds, and so today it can be used for tamponade of insufficiently sealing corneal wounds and prevention of the occurrence of anterior synechias into wounds after operations or injuries. The miotic effect caused by its action upon the iris is also beneficial.

Use of gases in glaucoma surgery

The first reports of the use of air in glaucoma surgery were from MacMillan in 1939 (41), when he used air for the reconstruction of the anterior chamber in a filtering operation as prevention of the occurrence of synechias. Other reasons for the application of air were visualisation of the iris-cornea angle in goniotomy, control and stopping of haemorrhage in the anterior chamber, reconstruction of the anterior chamber during operation and in the postoperative period, mainly upon persisting shallow chamber to athalamia, disturbance and prevention of the occurrence of anterior synechias, prevention of increased intraocular pressure.

Other use of gases

Many other uses of gases are obsolete today, but some remain usable in today's practice.
An important role was played by air in refractive surgery, during penetrating and lamellar keratoplasty, primarily in connection with the then non-existent viscoelastic material. The first use of air in penetrating keratoplasty was attributed to Strampellini in 1949 (53). Air was applied to the anterior chamber for its reconstruction and maintenance and as a prevention of contact of the donor cornea with the vitreous body. In 1967 Sparks (58) first described the use of air upon peeling of the Descemet's membrane. The use of air in lamellar keratoplasty was first described by Ambos in 1971 (3). Modern techniques include the "big bubble" technique upon anterior deep lamellar keratoplasty and endothelial lamellar keratoplasty, in which the use of air is decisive.
The first report on the use of air in expulsive haemorrhage is from Frenkel and Shin (17). In 1987 Adriano and Ball (2) described the treatment of suprachoroidal haemorrhage by external drainage in connection with vitrectomy and tamponade by gas.
Past indications which are obsolete today include the use of air in the treatment of keratitis and uveitis, subconjunctival or retrobulbar application of air upon haemorrhage into the vitreous area, paraocular application of air as a contrast medium, anaesthetic use of air injection beneath the conjunctiva.

COMPLICATIONS UPON USE OF GASES

The most frequent complications upon use of intraocular gases are increases in intraocular pressure and generated lens cataracts. Less frequent complications may be bullous keratopathy, presence of gas beneath the retina, new or extended retinal ruptures, or dislocation of an artificial intraocular lens. These complications can be minimised through the use of the correct surgical techniques, thorough examination and postoperative care.

Management of intraocular pressure

Control of intraocular pressure before, during and after surgery can have a considerable impact on the result of the surgical procedure. Preoperatively we often encounter hypotonia in vitreoretinal surgery in the case of retinal detachment, which usually becomes more pronounced with the longer duration of the disorder. In the Silicone Study (4) preoperative hypotonia was observed as a significant risk factor for postoperative hypotonia.
During operation it is possible to use gas in the correction of hypotnia, which frequently occurs after drainage of a larger quantity of fluid upon retinal detachment. If an undesirable increase in intraocular pressure occurs during the operation as a result of the use of gas, this can be corrected by paracentesis of the anterior chamber. If the anterior chamber is shallow, it is recommended to reduce intraocular pressure by partial suction of the gas from the vitreous cavity via pars plana.
Postoperatively monitoring of intraocular pressure is an important component of management of the patient. Hypotonia may occur as a consequence of an unsealed wound or reduction of the formation of intraocular fluid as a result of ablation or fibrosis of the ciliary muscle, excessive laser coagulation and cryocoagulation of the retina (55). In conservative treatment it is possible to use mydriatics and steroids in local or general form (65) for the correction of hypotonia. In surgery it is possible to use a number of techniques for the correction of hypotonia. One of the options for treatment of persistent hypotonia is repeated intraocular injection of gases with slow resorption (59). High intraocular pressure (IOP) as a cause of postoperative reduction to loss of visual functions following the use of gases was described immediately after their introduction into practice (45). There are several possible causes of the increase of IOP after intraocular surgery, especially after retinal detachment surgery. This may concern a pre-existing open-angle glaucoma, neovascular or steroid glaucoma, haemorrhage into the anterior chamber, narrow-angle glaucoma, uveitis, papillary block formed by gas or excessive expansion of gas.
In 1974 McLean and Norton (40) described the possibilities for control of increased intraocular pressure by using acetazolamide in conservative treatment. In the short postoperative period it is possible to use this in the prevention of an undesirable increase in IOP and support for resorption of subretinal fluid. Practically all eye hypotensives are of significance in the conservative treatment of increased IOP.
If there is excessively large expansion of the gas bubble, this should be corrected by suction of the gas. However, each case requires an individual approach. Machemer et al. (38) consider the limit for surgical intervention to be IOP of 40 torrs.

Complicated cataract

The formation of a cataract upon contact of gases with the lens has been the subject of several studies since their introduction (9, 37). After pars plana vitrectomy with gas tamponade, a transitory posterior subcapsular "rosette" or "gas cataract" is typical, usually appearing if more than 2/3 of the volume of the vitreous cavity is filled with gas (37). Lens cataracts probably form due to insufficient intake of nutrients upon contact of the bubble with the lens. This effect on the lens can be eliminated by correct positioning of the patient and the use of gases with faster absorption. An anterior subcapsular cataract can similarly form during the presence of gas in the anterior chamber (33). From the long-term perspective, a posterior subcapsular or nuclear cataract forms over the course of the months following PPV with gas tamponade. Sabates et al. (54) described the progression of a cataract as a result of an intraocular injection of gas in 67% of eyes in the period up to 6 months following the operation. Further important risk factors which influence the speed of the formation of a complicated cataract are previous intraocular operations, associated eye and general disorders, for example diabetes mellitus, age.

Other complications

The effect of gases on all structures of the eye has been studied and described in detail.

The endothelium of the cornea may come into contact with gas during various intraocular operations. All gases cause damage to the endothelial cells, primarily causing their decimation. Clinically the first symptoms may be manifested in a change to the thickness of the cornea – thickening or bullous keratopathy. The mechanism of the effect is not precisely known, but if gas is in contact with the endothelium it represents a mechanical barrier which prevents access and exchange of the necessary substances from the anterior chamber fluid to the endothelium. In the literature we find a number of reports which confirm this effect. Lee et al. (33) confirmed these effects in experimental conditions on the eye of a rabbit. In a clinical prospective trial by the authors Eiferman and Wilkins (13) the decimation of endothelial cells of the cornea was observed following intracapsular extraction of a cataract, after which the anterior chamber was filled with air at the end of the operation. The average decimation of endothelial cells represented 18.5%, in comparison with 8.5% in a control group, in which gas was not used. Friberg et al. (18) attained striking results, describing a decimation of endothelial cells of the cornea by up to 16.9% after PPV with lensectomy and gas tamponade, despite positioning.

An important subject of interest has been and continues to be the effect of gases on the vitreous body. An injection of gas into the vitreous body leads to a breach of the internal and external hemato-ocular barrier. As a result of this, levels of serum proteins in the vitreous area increase markedly, cells and mediators of inflammation accumulate (34).

Intraocular injection of gas causes compression of the fibres of the vitreous body, primarily in the direction towards the lens and towards the disc of the optic nerve. The vitreous cortex is mostly forced against the retina by the pressure of the gas bubble, which may the cause of the occurrence of further postoperative complications. Contraction of the vitreous cortex may cause repeated retinal detachment or further damage to the external layers of the retina or choroid (35). The shift of the vitreous body may lead to the formation of new retinal ruptures.

The potential undesirable effects of gases on the retina were not confirmed by the experimental studies by Lincoff and Kreissig (34) or in clinical practice. Short-term changes in the electroretinogram following resorption of bases were not confirmed upon long-term observation (19).

The presence of subretinal gas has been described less frequently, and may result from the use of an incorrect surgical technique. During surgery it is necessary to have the end of the needle or cannula by which the gas is applied under control. In rare cases it may be necessary to completely remove the gas from the eye during the operation due to these causes, and repeat the injection of gas into the vitreous cavity.

CONCLUSION

The introduction of gases into routine clinical practice, together with other modern surgical techniques, has brought a marked improvement in postoperative results in a wide range of eye disorders. An understanding of the principles and possibilities of use of gases brings benefits for the patient and the doctor. Thanks to gases we have emphatically improved the success rate of retinal detachment surgery in both classic operations and pars plana vitrectomy. The results of surgery of complicated states of retinal detachment and injuries, as well as surgery of the macula and other eye disorders, have been improved.

LITERATURE

1. Abecia, E., Pinilla, I., Olivan, J.M et al.: Anatomic results and complications in a long-term follow-up of pneumatic retinopexy cases. Retina. ISSN 0275-004X, 2000; 20, 2: 156–161.
2. Adriano, M.L., Ball, F.: Delayed nonexpulsive suprachoroidal hemorrhage after trabeculectomy. Ophthalmic Surg. ISSN 0022-023X, 1987; 18, 9: 661–666.
3. Ambos, E.: Luftinjektion in die Hornhaut. Eine tierexperimentelle Studie zur Hornhautplastik. Klin Monatsbl Augenheilkd. ISSN 0023-2165, 1971; 159; 4: 505–506.
4. Barr, C.C., Lai, M.Y, Lean, J.S. et al.: Postoperative intraocular pressure abnormalities in the Silicone study. Silicone Study Report 4. Ophthalmology. ISSN 0161-6420, 1993 ; 100, 11: 1629–1635.
5. Binkhosrt, C.D., Nygaard, P., Loones, L.H.: Specular microscopy of the corneal endothelium and lens implant surgery. Am J Ophthalmol. ISSN 0002-9394, 1978; 85, 5, 597–605.
6. Boyle, R.: New pneumatic experiments about respiration. Philos Trans R Soc Lond (Biol). 1670; 5: 2035.
7. Brand, K.P.: Discussion. On the toxicity of SF6 insulating gas. IEEE Trans.Electr. Insul. ISSN 0018-9367, 1983; 18: 93.
8. Castroviejo, R.: Handling of eyes with vitreous prolapse. Am J Ophthalmol. ISSN 0002-9394, 1959; 48: 397–399.
9. Chang, Lincoff, H.A., Coleman, D.J. et al.: Perfluorocarbon gases in vitreous surgery. Ophthalmology. ISSN 0161-6420, 1985; 92, 5: 651–656.
10. Dieckert, J.P., O'Connor, P.S., Schacklett, D.E. et al.: Air travel and intraocu lar gas. Ophthalmology. ISSN 0161-6420, 1986; 93, 5: 642–645.
11. Eckardt, C.: 2009. Macular hole surgery with air tamponade and OCT-based duration of prone positioning. Retina Today. ISSN, 2009; 4: 61–63.
12. Eger, E.L.2nd, Lundgren, C., Miller, L. et al.: Anesthetic potencies of sulfur hexafluoride, carbon tetrafluoride, chloroform and Ethrane in dogs: correlation with the hydrate and lipid theories of anesthetic action. Anesthesiology. ISSN 0003-3022, 1969; 30, 2: 129–135.
13. Eiferman, R.A., Wilkins, E.L.: The effect of air on human corneal endothelium. Am.J.Ophthalmol. ISSN 0002-9394, 1981; 92, 3: 328–331.
14. Escoffery, R.F., Olk, R.J., Grand, M.G. et al.: Vitrectomy without scleral buckling for primary rhegmatogenous retinal detachment. Am J Ophthalmol. ISSN 0002-9394, 1985; 99, 3: 275–281.
15. Eter, N. - Böker, T., Spitznas, M.: Long-term results of pneumatic retinopexy. Graefes Arch Clin Exp Ophthalmol. ISSN

0721-832X, 2000; 238, 8: 677–681.
16. Fineberg, E., Machemer, R., Sullivan, P. et al.: Sulfur hexafluoride in owl monkey vitreous cavity. Am J Ophthalmol. ISSN 0002-9394, 1975; 79, 1: 67–76.
17. Frenkel, R.E. - Shin, D.H.: Prevention and management of delayed suprachoroidal hemorrhage after filtration surgery. Arch.Ophthalmol. ISSN 0003-9950, 1986; 104, 10: 1459–1463.
18. Friberg, T.R., Doran, D.L., Lazenby, F.L.: The effect of vitreous and retinal surgery on corneal endothelial cell density. Ophthalmology. ISSN 0161-6420, 1984; 91, 10: 1166–1169.
19. Frumar, K.D., Gregor, Z.J., Carter, R.M. et al.: Electrophysiological responses after vitrectomy and intraocular tamponade. Trans. Ophthalmol. Soc. UK. ISSN 0078-5334, 1985; 104: 129–132.
20. Greenberg, L.A., Lester, D.: The toxicity of sulfur pentafluoride. Arch Ind Hyg Occup. ISSN 0273-1045, 1950; 2, 3: 350–352.
21. Hilton, G.F., Kelly, N.E., Salzano,T.C. et al.: Pneumatic retinopexy. A collaborative report of the first 100 cases. Ophthalmology. ISSN 0161-6420, 1987; 94, 4: 307–314.
22. Humayun, M.S., Yeo, J.H., Koski, W.S. et al.: The rate of sulfur hexafluoride escape from a plastic syringe. Arch Ophthalmol. ISSN 0003-9950, 1989; 1047, 6: 853–854.
23. IEC 60376: 1971, Specification and acceptance of new sulphur hexafluoride.
24. Kelly, N.E., Wendel, R.T.: Vitreous surgery for idiopathic macular holes. Results of a pilot study. Arch Ophthalmol. ISSN 0003-9950, 1991; 109, 5: 654–659.
25. Koster: Sitzungsberichte. Niederländische ophthalmologische Gesellschaft. Klin Monatsbl Augenheilkd. ISSN 0023-2165, 1902; 40: 338.
26. Krásnik, V.: Chirurgická liečba idiopatickej makulárnej diery. Súborný referát. Čs Oftal. 55, 1999; 6: 377–383.
27. Krásnik, V., Strmeň, P., Hasa, J., Izáková, A., Hrachovcová, J.: Chirurgická liečba makulárnej diery a makulopatie v spojení s jamkou terča zrakového nervu. Čs Oftal. 55, 1999; 5: 263–267.
28. Krásnik, V., Strmeň, P., Javorská, L.: Dlhodobé sledovanie zrakových funkcií po anatomicky úspešnej chirurgickej liečbe idiopatickej diery makuly. Čes a Slov Oftal. 57, 2001; 2, 80–87.
29. Krásnik, V., Strmeň, P., Javorská, L.: Chirurgická liečba traumatickej diery makuly. Čes. a slov. Oftal., 58, 2002, 84–88.
30. Krásnik, V., Strmeň, P., Štefaničková, J., Ferková: Chirurgická liečba makulopatie pri jamke terča zrakového nervu. Čes a Slov Oftal. 63, 2007, 1, 10–16.
31. Kreissig, I., Lincoff, H., Stanowsky, A.: The treatment of giant tear under detachments using retrohyaloidal perfluorocarbon gases without drainage or vitrectomy. Graefes Arch Clin Exp Ophthalmol. ISSN 0721-832X, 1987; 225, 2: 94–98.
32. Landers, M.B., Yamanashi, B.S.: The treatment of retinal detachments secondary to macular holes. South Med J. ISSN 0038-4348, 1973; 137, 12: 1–4.
33. Lee, D.A. Wilson, M.R.Yoshizumi, M.O. et al.: The ocular effects of gases when injected into the anterior chamber of rabbit eyes. Arch Ophthalmol. ISSN 0003-9950, 1991; 109, 4, 571–575.
34. Lincoff, A., Kreissig, I.: Intravitreal behavior of perfluorocarbons. Dev. Ophthalmol. ISSN 0250-3751, 1981; 2: 17–23.
35. Lincoff, H., Kreissig, I.: Posterior lip traction caused by intravitreal gas. Arch. Ophthalmol. ISSN 0003-9950, 1981; 99, 8: 1367–1380.
36. Lincoff, H.: Limitations and prospects for retinal surgery. Panel discussion: chapter II. Mod Probl Ophthalmol. ISSN 0077-0078, 1974; 12: 342.
37. Lincoff, H., Coleman, J., Kreissig, I. et al.: The perfluorocarbon gases in the treatment of retinal detachment. Ophthalmology. ISSN 0161-6420, 1983; 90, 5: 546–551.
38. Machemer, R., Aarberg, T.M.: Vitrectomy. 2nd ed. New York: Grune & Stratton, 1979, 187. ISBN 0808911465.
39. McCuen N, B.W. 2nd, Bessler, M., Hickingbotham, D. et al.: Automated fluid-gas exchange. Am.J.Ophthalmol. ISSN 0002-9394, 1983; 95, 5: 717.
40. McLean, E.B. - Norton, E.W.1974. The use of intraocular air and sulfur hexafluoride gas in the repair of selected retinal detachments. Mod. Probl. Ophthalmol. ISSN 0077-0078, 1974; 12: 428-435.
41. MacMillan, J.A.: Air injection as a factor in maintaining filtration following corneoscleral trephining in glaucoma. Trans.Am.Ophthalmol.Soc. ISSN 0065-9533, 1939; 37: 127–134.
42. Meyers, M. Ambler, J.S., Tan, M. et al.: Variation of perfluoropropane dissapearance after vitrectomy. Retina. ISSN 0275-004X, 1992; 12, 4: 359–363.
43. Meyers, M., Fitzgibbon, E.J.: Simultaneous external subretinal fluid drainage and intravitreal gas injection. Arch Ophthalmol. ISSN 0003-9950, 1985; 103, 12: 1881–1883.
44. Mittra, R.A., Kim, J.E., Han, D.P. et al.: Sustained postoperative face-down positioning is unnecessary for successful macular hole surgery. Br J Ophthalmol. ISSN 0007-1161, 2009; 93, 5: 664–666.
45. Norton, E.W.: Intraocular gas in the management of selected retinal detachments. Trans Am Acad Ophthalmol Otolaryngol. ISSN 0002-7154, 1973, 77, 2, OP85–98.
46. Norton, E.W.: Use of gas in retinal surgery. Management of the fishmouth phenomenon. Trans Ophthalmol Soc U.K. ISSN 0078-5334, 1980; 100, Pt 1: 66–68.
47. Norton, E.W., Aaberg, T., Fung, W. et al.: Giant retinal tears. I. Clinical management with intravitreal air. Am J Ophthalmol. ISSN 0002-9394, 1969; 68, 6: 1011–1021.
48. Norton, E.W., Fuller, D.G.: The use of intravitreal sulfur hexafluoride in vitrectomy. Irvine, A.R. et al. Advances in vitreous surgery. Springfield : Thomas, 1976. ISBN 0398033919.
49. O'Connor, P.R.: Intravitreal air injection and the Custodis procedure. Ophthalmic. Surg. ISSN 0022-023X, 1976; 7, 2: 86–89.
50. Ohm, J.: Über die Behandlung der Netzhautablosung durch operative Entleerung der subretinalen Flüssigkeit und Einspritzung von Luft in der Glaskörper. Graefes Arch Klin Exp Ophthalmol. 1911; 79: 442.
51. Rosengren, B.: On the operative treatment of retinal detachment. Acta Ophthalmol. (Copenh). ISSN 1755-3768, 1947; 25, 2: 111–125.
52. Rosengren, B.: Results of the treatment detachment of the retina with diathermy and injection of air into the vitreous. Acta Ophthalmol. 1938; 16: 573.
53. Ricci, L.: Sulla introduzione di aria nella chirurgia endobulbare. Boll.Ocul. ISSN 0006-677X, 1956; 35, 9–12, 789–795.
54. Sabates, N.R., Tolentino, F.I., Arroyo, M. et al.: The complications of perfluoropropane gas use in complex retinal detachments. Retina. ISSN 0275-004X, 1996; 16, 1: 7–12.
55. SchiŅdte, N.: Intraocular pressure and panretinal photocoagulation. Arch. Ophthalmol. ISSN 0161-6420, 1988; 106, 10: 1346.
56. Schocket, S., Lakhanpal, V., Miao, X.P. et al.: Laser treatment of macular holes. Ophthalmology. ISSN 0161-6420, 1988; 95, 5: 574–582.
57. Schrader, W., Rodemann, K ., Schrader, B.: Dosierungsfehler und ihre Vermeidung bei der intraokularen SF6--Injektion zur Endotamponade bei der pneumatischen Retinopexie und nach Vitrektomie. Fortschr Ophthalmol. ISSN 0723-8045, 1991; 88, 6: 633–636.
58. Sparks, G.M.: Descemetopexy. Surgical reattachment of stripped Descemet's membrane. Arch Ophthalmol. ISSN 0003-9950, 1967; 78, 1: 31–34.
59. Stallman, J.B., Meyers, M.: Repeated-fluid-gas exchange for hypotony after vitreoretinal surgery for proliferative vitreoretinopathy. Am J Ophthalmol. ISSN 0002-9394, 1988; 106, 2: 147–153.
60. Stinson,T.W. 3rd, Donlon, J.V. Jr.: Interaction of intraocular air and sulfur hexafluoride with nitrous oxide: a computer simulation. Anesthesiology. ISSN 0003-3022, 1982; 56, 5: 385–388.
61. Tatham, A., Banerjee: Face-down posturing after macular hole surgery: a meta-analysis. Br J Ophthalmol. ISSN 0007-1161, 2010; 94, 5: 626–631.
62. Tornambe, P.E., Hilton, G.F.: Pneumatic retinopexy. A multicenter randomized controlled clinical trial comparing pneumatic retinopexy with scleral buckling. The Retinal Detachment Study Group Ophthalmology. ISSN 0161-6420, 1989; 96, 6: 772-783.
63. Wong, R.F., Thompson, J.T.: Prediction of the kinetics of disappearance of sulfur hexafluoride and perfluoropropane intraocular gas bubbles. Ophthalmology. ISSN 0161-6420, 1988; 95, 5: 609–613.
64. Zaidi, A.A., Alvarado, R., Irvino, A.: Pneumatic retinopexy: success rate and complications. Br J Ophthalmol. ISSN 0007-1161, 2006; 90, 4: 427–428.
65. Zarbin, M.A., Michels, R.G., Green, W.R.: Dissection of epiciliary tissue to treat chronic hypotony after surgery for retinal detachment with proliferative vitreoretinopathy. Retina. ISSN 0275-004X, 1991, 11, 2, 208–213.