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REVIEW

Cyclodialysis: an update

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Abstract Cyclodialysis is the result of the separation of the longitudinal ciliary muscle fibers from the scleral spur, which creates an abnormal pathway for aqueous humor drainage that may lead to ocular hypotony. For many years cyclodialysis was considered a treatment option for glaucoma. However, today it usually occurs as a complication of blunt trauma or more rarely as a complication of anterior segment ocular surgery. Ocular hypotony can lead to cataract development, optic disk swelling, refractive changes, and several retinal complications, making accurate identification and timely intervention of the cleft mandatory. Traditionally gonioscopy was the only available technique to diagnose and localize the cleft. However, other tests such as optical coherence tomography, magnetic resonance imaging, transillumination, and specially ultrasound biomicroscopy are now available for the diagnosis of cyclodialysis. Multiple treatment options are also available for this condition. Although medical treatment can be effective to close small clefts, surgery is needed in most patients to restore ocular pressure.

Keywords Cyclodialysis · Blunt eye trauma · Ocular hypotony · Gonioscopy · Ultrasound biomicroscopy · Cyclopexia

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Method of literature search

A search was conducted on the Medline database, using cyclodialysis as the key word (Search fields: Title/Abstract). Additional references were culled from the bibliography of these articles. References spanned the period 1906–2014. Full-text articles were analyzed when written in English, French, German, or Spanish. Only the abstract was studied when the original article was written in other languages.

Introduction

Cyclodialysis is a rare condition, in which the longitudinal fibers of the ciliary muscle are disinserted from the scleral spur, creating a secondary pathway for the drainage of aqueous humor. It usually occurs as a complication of blunt trauma, and may lead to persistent and severe hypotony. Although medical treatment can help to close small clefts, laser treatment or surgery are usually needed to seal the fistula. Classically the diagnosis of this condition was based on gonioscopy; ab-interno Argon laser and direct cyclopexy were the only available options when medical treatment failed. However, new diagnostic techniques (ultrasound biomicroscopy [UBM], anterior segment optical coherence tomography [OCT], magnetic resonance imaging [MRI]) have appeared and new therapeutic approaches have been proposed (ab externo Nd-YAG laser, cyclodiode laser, cataract surgery, vitrectomy and gas tamponade). The aim of this review is to update the diagnostic and therapeutic aspects of this condition, and to develop a practical algorithm for the management of this infrequent condition.

History

A literature search on this topic shows two different approaches. Until trabeculectomy was described, cyclodialysis was considered a surgical alternative for treating glaucoma. Therefore, until the Seventies, most publications focus on how to open an effective fistula. In the Seventies, cyclodialysis virtually disappeared as a surgical procedure. Since then, most of the literature has focused on how to close a traumatic (or less likely iatrogenic) cyclodialysis.

In 1900, Ernst Fuchs reported for the first time that when a gap between the root of the iris and the scleral spur is opened during cataract surgery, it results in devastatingly low intraocular pressure. Shortly after, Heine described a surgical technique for the creation of a cleft: cyclodialysis ab externo [1–3]. In 1932, Elschnig reported on the pathologic findings: he noted a direct communication between the anterior chamber and the suprachoroidal space, with a choroidal detachment. Cyclodialysis ab externo was associated with complications such as hyphema, hypotony, cataract progression, and suprachoroidal hemorrhage and was never a popular procedure [3–5]. Nevertheless, several modifications of the technique were described, and improvements were made on the cyclodialysis spatula that Heine had developed [1, 5–12]. One of the latest models had a light at the tip to guide the surgeon during the procedure [13]. In cyclodialysis ab externo, the conjunctiva and sclera are opened and a spatula is passed from the suprachoroidal space into the anterior chamber, separating the ciliary body from the scleral spur [3, 5, 14, 15]. Today, ab-externo cyclodialysis is rarely performed, although favorable results have been reported performing a technique that combines trabeculectomy and cyclodialysis [16, 17].

Epidemiology

Cyclodialysis is a rare condition and most ophthalmologists see only a few cases. It is difficult to determine its prevalence because most of the published papers are single case reports. Although cyclodialysis has been described after penetrating trauma [18], most of the cases follow blunt trauma, with reported rates ranging between 1 and 11 % [19]. It is more frequent in men, who are more prone to suffer trauma. In Küchle's series, 26 of the 29 cases were male; in Agrawall's series 16 of 17 cases, and in Ionnidis' series 16 of the 18 cases were male [20–22]. A wide variety of agents like balls [23], stones [24], champagne corks [25], BB pellets [26, 27], punches [28], airbags [29], fire crackers [30], and elastic-cords have been reported to cause cyclodialysis [28, 31]. Cyclodialysis can also occur as a complication of anterior segment surgery. Although improvements in ocular surgical techniques have made iatrogenic cyclodialysis uncommon, it has been reported after trabeculectomy [32–35], goniotomy [20, 36], iridectomy [37], holmium laser sclerostomy [38], trabectome surgery [39], intracapsular cataract surgery [37, 40], angle-supported IOL implantation [28], implantation of a posterior chamber phakic IOL and surgical iridectomy [41], intravitreal ganciclovir implantation [42], suture fixation of a posterior chamber intraocular lens [5, 34], extracapsular cataract extraction [20, 40, 43], phacoemulsification [32, 44], removal of anterior chamber phakic IOL [45], resection of anterior uveal melanoma [46], or even intravitreal injection [47]. In summary, any surgical procedure which involves iris manipulation can potentially produce iatrogenic cyclodialysis [40]. Indeed in one of the largest series, 7 of the 52 cases occurred after ocular surgery (phacoemulsification, trabeculectomy, and vitrectomy) [48]. Cases of mixed etiology have also been reported: Mushtaq et al. published 3 cases in which a previous dormant fistula of traumatic etiology reopened after phacoemulsification [49].

Pathogenesis

Biomechanics

Although the porcine eye is more resistant than the human eye, it is considered a good model for studying the effects of ocular trauma. Ballistic studies after paintball impacts have demonstrated that moderate energies of up to 5 joules can produce traumatic cyclodialysis. Ocular explosion took place with 10 joules impact [50].

Cyclodialysis results from momentary axial compression and rapid equatorial expansion that stretches the ocular tissue, leading to the separation of the meridional ciliary muscle fibers from their attachment in the scleral spur [51]. The attachment of the uvea is weaker at the ciliary body than at the choroid, where short posterior ciliary arteries, ciliary nerves, and vortex veins perforate the sclera, anchoring it to the choroid [52]. The detachment of the ciliary body from the scleral spur seems to be the most common mechanism for persistent ocular hypotension after blunt trauma. However, occasionally traumatic tears of the ciliary body have been reported to produce a similar outcome after blunt trauma [53].

There does not seem to be a preferential location for cyclodialysis. In the series published by Küchle et al., the most common location was superior (66 %) [20]. However in the more recent series published by Agrawall et al., the predominant localization was inferior (48 %) [21], and Ioannidis et al. failed to identify a preferential location [22].

Suprachoroidal space

The direct communication between the anterior chamber and the ciliochoroidal space allows an unrestricted flow which overcomes the hydrostatic and osmotic forces that normally maintain the apposition of choroid and ciliary body to the sclera [14, 54, 55]. This flow of aqueous humor leads to ocular hypotony. Indeed closing the fistula restores ocular pressure. Nevertheless, several authors have reported that the intraocular pressure drop is not proportional to the cleft size, so other factors might influence the outcome [56], such as decreased aqueous production due to a reduction in blood supply to the ciliary body [56].

Ciliochoroidal detachment

In 1936, in his review article on cyclodialysis surgery, Barkan wrote: “the question has not yet been settled whether the dialysis acts by disturbing the function of the ciliary body through severance of its nervous and vascular supply with consequent atrophy and reduced production of aqueous, or whether it acts by permitting outflow of aqueous through the cleft into the suprachoroidal space where it is absorbed.” [3]. Eighty years later, this question has not been answered yet. We know that a cyclodialysis cleft creates an abnormal pathway for the drainage of the aqueous humor into the suprachoroidal space, increasing the uveoscleral flow, and lowering IOP. The choroidal detachment thus produced would decrease the production of aqueous humor in the ciliary epithelium, leading to hypotony [57, 58]. Although some experimental studies in which cynomolgus monkeys underwent surgical cyclodialysis suggest that increased uveoscleral outflow is the main cause of the hypotony [59], others point to reduced production of aqueous as the main mechanism [60]. Apparently there is no correlation between the extension of the cleft and the severity of ocular hypotension [21, 56], suggesting that hypofunction of the ciliary body plays a significant role.

Clinical manifestations

Ocular hypotony syndrome

Ocular hypotony is defined as an IOP of 5 mmHg or lower. It can be due to the decreased production of aqueous humor (inflammation, medications, proliferative retinopathy) or due to aqueous loss. This loss can be external (positive Seidel test after ocular surgery) or internal (cyclodialysis or retinal detachment) [61].

Clinical manifestations of chronic hypotony involve all ocular tissues and include corneal edema, shallowing of the anterior chamber, refractive changes, cataract, choroidal effusion or detachment, retinal and choroidal folds, optic disk swelling, venous tortuosity, and maculopathy (Fig. 1) [20]. All these conditions may lead to visual loss, which may become permanent if the hypotony is not resolved promptly.

Visual loss is usually associated with hypotonic maculopathy (Fig. 2) [62]. It results from an inward collapse of the scleral wall and is more frequent in young myopic patients, whose sclera is thinner and more elastic [24, 51]. Decreased vision is probably due to the distortion and misalignment of the photoreceptors [51, 63]. However, there have also been reports of hypotonic maculopathy with normal visual acuity [64]. Occasionally, cyclodialysis has been associated with the development of unilateral arcus lipoides [65, 66]. Hermel et al. reported a case in which an anterior chamber IOL disappeared because it was periodically luxated into the suprachoroidal space through an open cyclodialysis cleft [67].

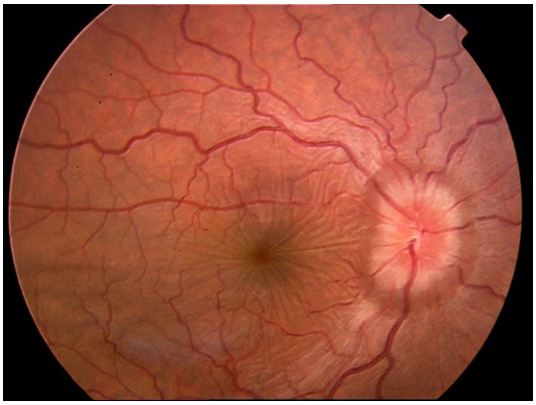

Fig. 1 Choroidal folds, optic disk swelling, venous tortuosity, and maculopathy in a patient with chronic hypotony secondary to a traumatic cyclodialysis cleft (From Gonzalez Martin-Moro et al. [23]; reproduced with permission of Archivos de la Sociedad Española de Oftalmología)

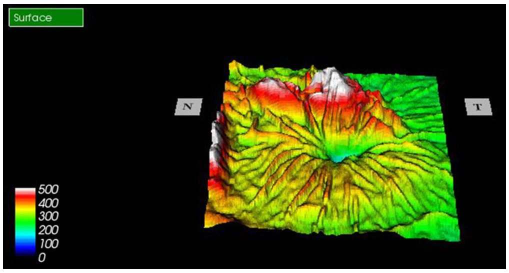

Fig. 2 3D Optical coherence tomography showing choroidal folds in the macular area of a patient with chronic hypotony secondary to a traumatic cyclodialysis cleft

Refractive changes

Most publications describe hyperopia as part of the manifestations of the ocular hypotensive syndrome and attribute it to a reduction in ocular volume and axial length. Nevertheless, this is probably not the case in cyclodialysis-related hypotony. Although refraction is taken into consideration only in a few series, it seems that most patients suffered a hyperopic shift when IOP was restored after cyclopexia [20, 68]. The myopic change induced by hypotony is probably produced by the thickening and anterior displacement of the lens, due to the ciliary body detachment and the loosened zonules [68, 69]. To the best of our knowledge, only one article has studied the effect of ocular hypotension on corneal curvature. With-the-rule astigmatism decreased significantly after successful closure of the cleft and intraocular pressure rise. It therefore seems that ocular hypotension also induces with-the-rule astigmatism, probably as a result of the pressure exerted by the eyelids on the cornea [70].

Hypertensive spike

Frequently, closure of the cleft is followed by a painful IOP spike. This spike is considered to be the result of the restoration of aqueous humor production by the ciliary body with an incomplete recovery of trabecular meshwork function. Some authors have reported that these pressure spikes are extremely painful, more than that would be expected by the pressure reading [20]. They can be easily controlled with topical medication. Miotics are contraindicated as they could lead to reopening of the cleft [32]. After a few hours, as the trabecular meshwork recovers, IOP returns to normal values. IOP spikes occur in more than half the patients [21], although they do not appear to produce significant damage to the optic nerve. Some authors have claimed that they contribute to flatten retinal and choroidal folds and to reattach the ciliary body to the scleral spur [20, 51, 71]. Indeed Chaudhry et al. reported one case of cyclodialysis in which in addition to cyclopexy, a trabeculectomy was performed to prevent this IOP spike and choroidal folds persisted [31]. Although the extension of the fistula does not seem to be a prognostic factor, it seems to be correlated with the time required for IOP normalization after cyclopexy [68].

Progression to glaucoma

Most of the patients who suffer from traumatic cyclodialysis also have some degree of angular recession. Therefore, these eyes might eventually develop secondary open angle glaucoma. However, this outcome seems to be infrequent. In the series published by Küchle, none of the 29 patients developed glaucoma or ocular hypertension [20]. In Agrawal's series, none of the 17 patients developed glaucoma or ocular hypertension after 44 months' follow-up [21]. In fact in a recent series, the presence of a cyclodialysis was found to be a protective factor against the development of glaucoma [72].

When should surgery be performed

Maintained ocular hypotension can produce irreversible damage to the retina [57, 68]. Although Ormerod reported that eyes in which IOP was restored within two months had better prognosis [19], other authors have reported significant recovery in visual function many years after the onset of hypotony. Delgado et al. described a patient with a 7-year-history of hypotony maculopathy whose visual acuity improved from 20/200 to 20/30 after successful treatment of his cyclodialysis with Argon laser. Other authors have reported visual improvement with resolution of the hypotony up to 30 years after onset [21, 73]. Some authors have found no correlation between the duration of hypotony and final visual acuity [20, 21, 25, 68]. Although publication bias may be responsible for this surprising finding, it seems that isolated low IOP per se does not lead to phthisis. The eye subjected to very low IOP goes into a state of "hibernation" and almost complete recuperation is possible when IOP is restored. The extension of the cyclodialysis has not been correlated with visual prognosis [68]. Visual acuity seems to be mainly determined by the presence of concomitant pathology (macular scars, retinal detachment) rather than by the duration of hypotony or the extension of the dialysis [22, 25]. Thereby, a protracted history of ocular hypotony should not discourage the ophthalmologist from surgical repair of the cleft [21].

Diagnosischamber and may facilitate visualization

Correctly locating the cleft is vital for performing laser or surgical treatment. Cyclodialysis clefts can be multiple and each one must be identified in order to achieve surgical success [74].

Gonioscopy

Classically, gonioscopy has been considered the gold standard for the diagnosis of cyclodialysis (Fig. 3). However, gonioscopy may be difficult due to the presence of corneal folds, hazy media, or a shallow anterior chamber. Not all clefts are visible; microclefts and oblique channels may be particularly difficult to detect [22, 74]. Some authors recommend the use of midriatics because they deepen the anterior chamber and may facilitate visualization [62], while others recommend the use of miotics to open the angle and the cleft [54, 75]. Evaluation in the slit-lamp or the operating theater after the injection of viscoelastic material into the anterior chamber may be necessary in some cases [14, 32, 54, 76, 77].

The permeability of some clefts may depend on the position of the iris. In certain cases, re-evaluatong IOP and looking for corneal folds after performing gonioscopy may be very useful. Gonioscopy will open the cleft and cause a transient flow of aqueous into the suprachoroidal space, resulting in postgonioscopy hypotony and inducing a significant reduction of IOP and the appearance of visible folds in Bowman's membrane [78].

Ultrasound biomicroscopy

Although conventional ultrasonography (9 MHz) may detect cyclodialysis clefts [79], UBM (50–100 MHz immersion technique) is more useful to diagnose,

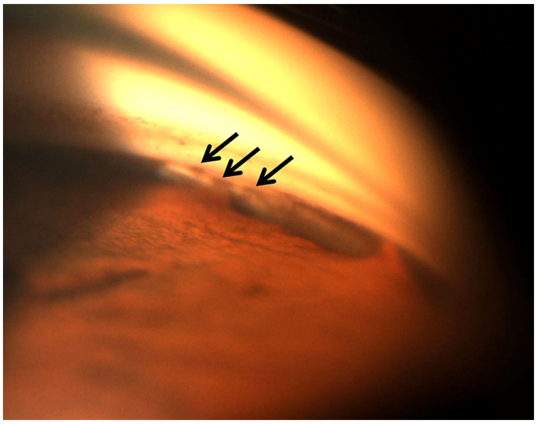

Fig. 3 Gonioscopy showing the location of the cleft in a patient with chronic hypotony, secondary to a cyclodialysis. Gonioscopy is not easy to perform, due to the presence of corneal folds, hazy media, or a shallow anterior chamber

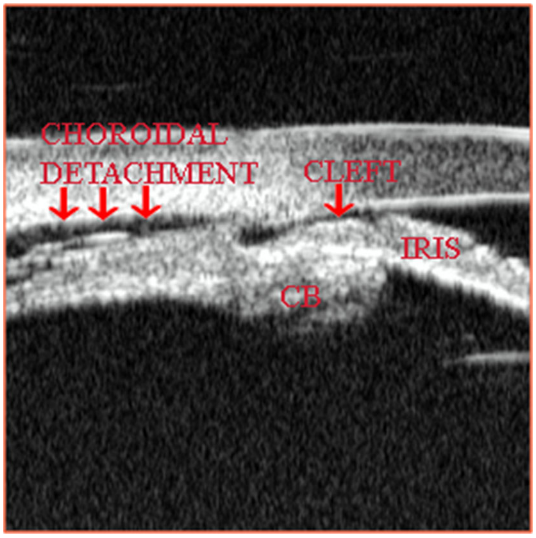

Fig. 4 Ulatrasound biomicroscopy (UBM) is probably the most sensitive technique for detecting an active cyclodialysis cleft. *CB* ciliary body (From Gonzalez Martin-Moro et al. [23]; reproduced with permission of Archivos de la Sociedad Española de Oftalmología)

localize, measure, and monitor cyclodialysis (Fig. 4) [80]. The ability of UBM to detect tractional ciliary body detachment, ciliary body atrophy, suprachoroidal effusion, and cyclodialysis makes it an essential tool in the differential diagnosis of ocular hypotony [81]. Gentile et al. first used UBM in 1996 to diagnose this condition [82]. Since then, many articles have shown that UBM is more sensitive than gonioscopy for detecting a cyclodialysis cleft [27, 72], and a very useful method for measuring the extension of the fistula. In a recent prospective series of 121 eyes with closed globe injuries, Sihota et al. found a good correlation between UBM and gonioscopy in the evaluation of the extension of angle recession, and the absence of correlation between both diagnostic techniques in the evaluation of the extension of the cyclodialysis clefts [72].

UBM should be considered not an alternative, but a complementary technique to gonioscopy. While gonioscopy allows anatomic evaluation from the anterior face of the ciliary cleft, UBM provides more global information. The contrasting reflectivity of the aqueous and the adjacent tissue allows a cross-sectional image of the cleft, which provides an indirect estimation of the streamflow [56]. Most publications have demonstrated that UBM is a more sensitive technique for detecting an active cyclodialysis cleft [83, 84]. Hyphema or iris bowing can hide the mouth of the fistula when gonioscopy is performed [83]. On the other hand it is also more specific, because in some cases suprachoroidal space adhesions may close the fistula [83]. Therefore, UBM should be the preferred technique both for planning surgery and evaluating surgical success [51].

However, it must be taken into account that most studies compare UBM with simple gonioscopy. When gonioscopy is performed after injecting viscoelastic into the anterior chamber, the sensitivity of gonioscopy improves [22] and might even be better than that of UBM.

Optic coherence tomography

Recently some publications have reported that anterior segment optic coherence tomography (AS-OCT) can be useful for the diagnosis of cyclodialysis [76, 85]. It is a noninvasive, painless, noncontact technique that provides reproducible images of the anterior segment. Obtaining the images is faster and easier than with UBM and it produces less discomfort. It is performed in an upright position (while UBM is usually performed in a supine position), so the findings may more likely reflect gonioscopic and slit-lamp biomicroscopic clinical findings. Nevertheless, the structure posterior to the iris is not visible with OCT and traditionally its sensitivity has been considered inferior to UBM, however the higher resolution of the new generation of AS-OCT could make this technology more sensitive than UBM. Indeed Arnalich-Montiel et al. reported a case in which a small cleft that had not been detected by UBM and gonioscopy was located using AS-OCT [41].

Magnetic resonance imaging

Only one publication has addressed this topic. In this article, MRI after intravenous injection of gadolinium was able to detect a 3 clock-hour dialysis in humans and rabbits [86].

Transillumination

Transillumination has also been proposed as an ancillary technique to localize the extension of the cleft. The disinsertion of the ciliary body from the scleral spur is visible as an area of marked transillumination against the dark background of the iris [74].

Intravenous injection of fluorescein

Elder et al. reported that the injection of this colorant could help to localize an occult cleft. An area of increased scleral fluorescence could be demonstrated adjacent to the cleft [87].

Treatment

Several options have been proposed for treating this condition (Table 1) [62]. The scientific evidence which supports each technique is weak, because most publications report individual cases. Series are scarce and no randomized trial has been performed. Some cases resolve spontaneously or with medical treatment [23, 27]. Surgical treatment should be considered only if hypotony is associated with morphological and functional complications [32, 77]. Corneal thickness could account in part for the reported individual tolerability to ocular hypotension.

At least twenty different techniques have been proposed for treating cyclodialysis. The goal is to reseal the anterior chamber and they can be classified as ab interno and ab externo procedures (Table 1). The extension of the cyclodialysis and the presence of concomitant ocular pathology should be taken into account when deciding which technique is to be performed. In 1991, Ormerod published an algorithm for treating cyclodialysis (Fig. 5) which, to the best of our knowledge has not been updated to include the new diagnostic and therapeutic techniques [14].

Medical treatment

Systemic steroids, topical steroids, and atropine should be prescribed to reduce the ciliary and anterior segment inflammations which are usually associated with cyclodialysis [79]. Atropine relaxes the ciliary muscle, increasing its contact with the sclera. Steroids can raise ocular pressure and reduce choroidal effusion. Nevertheless, they should not be used for extended periods since they can hinder the healing process that closes the fistula. Indeed some authors have found that rapid tapering of steroid treatment can lead to the closure of the fistula [53]. Medical treatment can achieve closure of small clefts [23, 24, 29, 32, 88]. Recent studies have reported the potential utility of ibopamine to increase IOP in certain situations [89]. However, the efficacy of ibopamine in cyclodialysis-induced hypotony has not been studied yet.

Injection of viscoelastic into the anterior chamber

Viscoelastic can produce a transient increase in IOP, improving visual acuity [90]. The viscoelastic could avoid the clearance of fibrinogen from the anterior chamber, promoting the closure of the fistula, but it has not been reported to achieve closure of the fistula. Nevertheless, the injection of viscoelastic material can facilitate argon laser application.

Injection of blood plasma

The injection of autologous blood into the anterior chamber was proposed in the seventies as an effective method to treat this problem. The patient's blood plasma is injected in the anterior chamber and fibrinogen is transformed into fibrin by recalcification [91].

Laser treatment

Laser treatment is usually applied under local anesthesia. It was first proposed in 1980 by Joondeph [92], who employed Argon laser to apply laser impacts as in conventional trabeculoplasty, only slightly more posteriorly, on the cleft. Most authors try to apply laser on both sides of the cleft (ciliary muscle and scleral side) [32]. Since the anterior chamber may be shallow in some of these patients, hindering the procedure, Partamian proposed the use of a Zeiss four-mirror goniolens, instead of a Goldmann goniolens in order to deepen the angle [93]. Han el al propose bubble formation as an index of good tissue response to Argon laser [94]. Other authors have proposed the use of an argon laser endophotocoagulator and a Swan-Jacobs goniolens [54]. Ormerod et al. proposed the use of pilocarpine and viscoelastic [14]. The combined use of pilocarpine and viscoelastic keeps the cleft wide open and facilitates the diagnosis and the application of laser. A drawback is that the viscoelastic should be completely removed after the procedure to avoid IOP spikes.

Laser photocoagulation can be an excellent treatment for small clefts [14]. Han et al. have demonstrated that Argon laser and surgical cyclopexy have

Table 1 Description, advantages, and limitations of the main treatments used to close a cyclodialysis

Method	Description	Advantages and limitations
Medical treatment	Atropine	It only achieves closure of small clefts
	Steroids should be tapered quickly to promote closure of the fistula	
Laser treatment		
Argon laser	Ab interno	It only achieves closure of small clefts
	Ideally laser should be delivered on both sides of the cleft	It is necessary to open the angle (viscoelastic, pilocarpine, Zeiss four-mirror goniolens)
Transscleral Nd:YAG laser	Ab externo, two rows of impacts	Easier to apply than argon laser
Transscleral diode laser	Ab externo, two rows of impacts, lower energies than in cyclodestructive procedures	Easier to apply than argon laser
Other semi/invasive methods		
Diathermy	Ab externo	Abandoned because it induces scleral damage
Cryocoagulation	Ab externo	It does not induce scleral damage
		Moderately effective
Surgical methods		
Direct cyclopexy	Different techniques	Very effective
	If scleral flap is not dissected: indirect cyclopexy	Potential complications: intraocular hemorrhage, endophthalmitis, cataract, vitreous loss, retinal detachment, wound dehiscence, and secondary glaucoma due to peripheral anterior synechiae. Extensive dissection could affect anterior segment irrigation
	Viscoelastics, or a posterior infusion cannula could be used to raise IOP and harden the eye during the procedure	
Scleral buckling	Inducing indentation at the site of the cleft	Foreign body sensation, dellen and poor cosmesis
	The principles of retinal detachment surgery can also be applied to treat this condition	
Pneumocyclopexy	Injection of SF6 or C3F6	Minimally invasive and simple to perform and it avoids the difficulty involved in operating on a hypotonic eye
		It can be performed in the office
Vitrectomy	Combined with cryotherapy, and endotamponade (gas/silicone oil)	Useful in extensive clefts (direct cyclopexia in these cases could induce anterior segment ischemia) or cases with concomitant retinal pathology
Sulcus CTR/IOL	CTR or IOL should be implanted in sulcus	Indicated if cataract is present
	IOL should be carefully orientated so the haptics press the area of the cleft	IOL can only close small clefts, sulcus CTR may be able to close extensive clefts
		Potential risk of ciliary body damage, erosion, hemorrhage and pain from the compressive effects of the haptics or the CTR
		Very few cases reported

SF6 Sulfur Hexafluoride, *C3F6* Hexafluoropropylene, *CTR* capsular tension ring, *IOL* intraocular lens

similar results in small clefts (less than 1.5 clock-hours) [94]. Considering cost, time, and complications, laser treatment should be tried in small clefts. Ormerod et al. suggested that surgical treatment should only be recommended if several sessions of laser had failed. It usually requires retrobulbar anesthesia but some authors have performed it under topical anesthesia [95]. As the laser is applied directly on the cleft, it avoids scleral contraction [14, 54]. How laser application produces the closure of the cleft is uncertain. It has been suggested that swelling of the choroid following laser treatment closes the cleft,

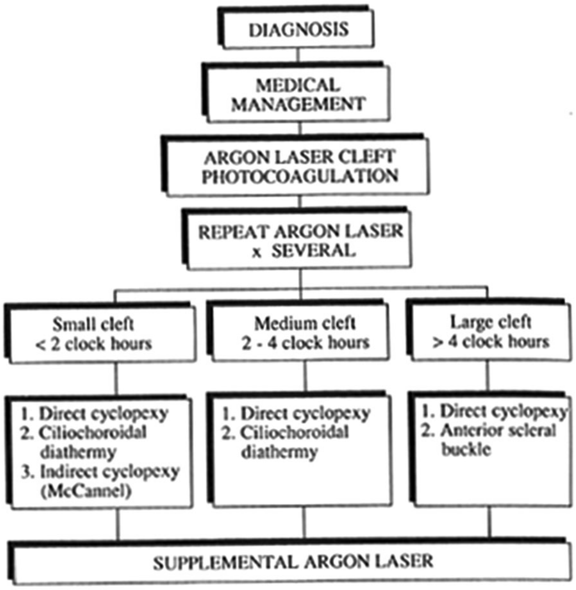

Fig. 5 Ormerod algorithm, published in 1991 (from Ormerod et al. [14]; rerproduced with permission of Elsevier)

helped by the induced iritis [32, 40, 95]. Nd-YAG laser and diode laser have also been used.

Transscleral Nd:YAG laser was used by Brooks et al. to close three cases of traumatic cyclodialysis in which direct application of Argon or YAG laser or external cryotherapy had not been successful [96]. Transscleral diode laser therapy has also been proved to be useful [35, 97, 98]. In some cases hypertensive spikes are not observed. This has been attributed to partial destruction of the ciliary muscle [97, 99]. Usually two parallel rows of confluent burns are applied at the conjunctival limbus in the area overlying the cleft. Transslceral diode laser treatment is easy to perform and its cost is low, making it a very convenient treatment when medical treatment has failed. We consider transscleral diode laser therapy the best approach for small and medium size clefts that have not responded to medical therapy.

Other authors have proposed using a laser endophotocoagulator. They inserted a 20-gauge endophotocoagulator through a corneal paracentesis into the anterior chamber to apply laser impacts directly over the internal and external ciliary body surfaces [100]. Direct visualization enables a very precise placement of laser impacts, but this technique associates the risks of intraocular surgery.

Transscleral diathermy

In the past, some authors proposed the application of penetrating diathermy to the sclera. It was usually applied in a semicircular pattern, around the cyclodialysis, in order to wall off the cleft [37, 101]. Diathermy induces a thermal burn and a secondary inflammatory reaction, similar to argon laser photocoagulation [75]. It was usually applied after dissecting a scleral flap. However it can damage the lens and induce scleral ectasia [37, 62]. Therefore, diathermy was abandoned in the Seventies and has been replaced by cryotherapy or laser, although it is sometimes applied during direct cyclopexia to enhance adhesion [20].

Cryocoagulation

A series of overlapping applications (temperature -50° to -60°) can be applied at a distance of 2 to 3 mm from the limbus [75]. Other authors have used lower temperatures [33]. When cryocoagulation is used without gas injection or vitrectomy, the rate of success is low [62]. Cryotherapy has several advantages. It is a noninvasive ab externo method. Contrary to diathermy, cryotherapy does not damage the sclera, and it can be used isolated or preferably combined with gas injection or vitrectomy to ensure apposition [75]. However, it may lead to destruction of ciliary processes.

Direct cyclopexy

The first attempts to fix the ciliary body to the sclera were undertaken by Vannas and Bjorkenheim in the Forties, and reported in 1952 [25, 102]. Direct cyclopexy is the oldest and probably the most effective technique for closing a cyclodialysis. Ormerod et al. report complete success in 28 out of 29 eyes submitted to this procedure [14], while Agrawal et al., in a more recent series, report a success rate of 94 % [21]. Different approaches have been described. In the most popular, a limbal based lamella in the area of the cyclodialysis is dissected and the sclera is penetrated 1 mm behind the scleral spur, suturing the insertion of the ciliary muscle to the scleral spur with 10/0 nylon [25]. It is important to remember that the suprachoroidal fluid usually forms an annular lake. Thereby the presence of fluid at the suprachoroidal space does not mark the position of the cleft [22]. A cyclodialysis spatula should be used to locate the cleft and determine its extension. To promote an inflammatory reaction to aid cleft closure, some authors apply diathermy [20, 21, 26, 71, 103]. Other methods that have been employed to enhance adhesion include the use of bovine albumin or cryocoagulation [25].

Several variations of this technique have been reported [52]. Some authors prefer partial-thickness scleral flaps while others prefer full-thickness flaps [22]. Other authors prefer a simpler procedure in which after conjunctival peritomy sutures are passed through the corneal side of the limbus, the iris root, and ciliary body without previously dissecting a scleral flap. This method is called indirect cyclopexy. It is less challenging but the surgeon does not always monitor the path of the needle [43, 77], it induces broad peripheral anterior synechia [14], and it frequently produces pupil distortion [73].

Direct cyclopexy requires extensive surgical skills and the needle must be inserted several times through the ciliary body. [104] Potential complications include intraocular hemorrhage, endophthalmitis, cataract, vitreous loss, retinal detachment, wound dehiscence, and secondary glaucoma due to peripheral anterior synechiae [51]. Although the ciliary body is a highly vascularized structure, bleeding has seldom been reported in the major series. Küchle et al. reported no severe complications after treating 29 eyes with direct cyclopexy [20]. Occasionally, a conjunctival bleb is formed [20, 105]. García-Serrano et al. attributed this outcome to the incarceration of a bridle of vitreous in the cleft [105].

In the presence of large or multiple clefts, direct cyclopexy would imply the dissection of an extense scleral lamella. This could affect anterior segment irrigation [106] or disrupt aqueous humor drainage channels [14]. In these cases vitrectomy with gas tamponade would be a safer approach [106].

Suturing a hypotonic eye can be challenging. Some authors have proposed using anterior chamber viscoelastics to restore tone [26]. Rabinowitz et al. used a posterior infusion cannula, which can also reduce the risk of bleeding [107]. Wang et al. suggested the use of a probe to determine more exactly the extension of the cleft [108]. After opening the sclera a probe is inserted into the anterior chamber through the cleft and moved toward the edge of the cleft, stopping where the ciliary muscle is attached. Obviously such maneuvres could enlarge the cleft, although the authors did not report significant complications [108].

Scleral buckling

Cyclodialysis shares some characteristics with rhegmatogenous retinal detachment. Thereby, the principles of retinal detachment surgery can also be applied to treat this condition. Several authors have reported that scleral buckling can resolve cyclodialysis. Portney et al. used silicon rods [109]; Jurgens et al. employed a 0.6-mm silicone tube, sutured with mattress sutures, to indent the cyclodialysis at the sulcus [110, 111], and Mandaba et al. used a sponge [112]. Inukai et al. reported three cases in which scleral buckling successfully repaired cyclodialysis after failure of other surgical procedures [113]. These techniques have the disadvantage of producing foreign body sensation, dellen, and poor cosmesis [75]. For all these reasons, some authors have proposed removing the implant once the cleft has closed [112].

Pneumocyclopexy

Ceruti et al. reported the use of a single bubble of 20 % sulfur hexafluoride (SF6) and the application of cryotherapy. This technique sealed a 6-hour-cleft. Pinheiro-Costa et al. reported success using a longer lasting gas (C2F6) [114]. This approach shares advantages with pneumatic retinopexia. It is minimally invasive, simple to perform, and it avoids the difficulty involved in operating a hypotonic eye [115].

Vitrectomy

The use of vitrectomy with cryotherapy and gas endotamponade to close a cyclodialysis was first reported by Helbig et al. in 1996 [66]. Several small series have reported high success rates [116]. Some authors have also used silicone oil as an endotamponade [28]. This procedure is employed to close very extensive clefts (direct cyclopexia in these cases could lead to anterior segment ischemia) or those cases in which concomitant retinal pathology is present [90]. If possible, the area of cyclodialysis should be avoided when performing the sclerotomies. Contrary to retinal detachment, supine positioning is usually recommended, so in phakic patients, this procedure would lead to cataract development and therefore it is often combined with phacoemulsification [90]. The gas tamponade and supine positioning decrease aqueous humor outflow, which prevents permanent scarring by washing away fibrin before it clots.

Internal tamponade using a capsular tension ring (CTR) or an intraocular lens (IOL)

Internal tamponade using a CTR, IOL implanted in the sulcus or even a combination of CTR and sulcus IOL has also been proposed [30, 57, 104, 117]. An IOL inserted in the sulcus and carefully oriented can exert the necessary pressure to achieve reattachment of the ciliary muscle [57, 117]. To avoid postoperative refractive surprise, IOL power calculation should rely on the contralateral eye (taking into account the important reduction of axial length induced by hypotony) [30]. The IOL should be rotated until one of the haptics faces the site of the cyclodialysis. If the cleft is extense, an IOL would not be sufficient. In this case, placing a CTR in the sulcus would be a better option. Internal tamponade was first proposed by Jurgens et al. [110, 111]. A CTR has been reported to close even a 360° fistula [104]. The CTR should be implanted in the sulcus, because in the bag implantation may limit the expansion of the ring. The authors recommend a size that corresponds to the diameter at 1 mm posterior to the surgical limbus [104]. The scarring process induced by postoperative inflammation and a moderate internal compression by the haptic or the CTR, results in closure of the fistula. We should not forget that, in many cases, zonule damage is also present, making cataract surgery more complicated. Nevertheless, from a technical point of view this procedure is not significantly different from high-risk cataract surgery [56]. Although these are interesting alternatives when cataract is present, only a few cases have been reported, and the potential risk of ciliary body damage, erosion, hemorrhage, and pain from the compressive effects of the haptics or the CTR should not be dismissed [75].

Endoscopic closure

Gnanaraj et al. used this procedure in a 4-year-old girl, in whom external cyclopexy had failed twice. Pars plana lensectomy and vitrectomy with injection of C_3F_8 was performed. Before gas exchange, endoscopic-guided suture of the ciliary body detachment was performed. The endoscope was inserted through the pupil, allowing simultaneous internal and external visualization. A major limitation of this approach is the risk of cataract in phakic patients. Besides, the authors acknowledged that it is difficult to separate the effects of gas and cyclopexy, as gas tamponade by itself is an effective method to treat cyclodialysis [36].

Comparative studies

Most of the articles report individual cases and only a few series have been published. These series are usually retrospective and do not have a control group (Table 2). In Ioannidis et al. retrospective series, a trend was observed toward cleft size as a risk factor for failure of cryopexy [22]. Agrawal et al. compared direct cyclopexy with cryotherapy. Direct cyclopexy was superior to cryotherapy (94 vs. 34 %). Therefore, these authors recommended cryotherapy only for small fistulas [21]. In this study cryotherapy was employed initially, while cyclopexy was used in those cases in which cryotherapy failed to close the fistula. This design obviously introduces an important bias that penalizes cyclopexy. Despite this, Agrawal et al.

Table 2 Outcome and conclusions from the main series describing treatment options for cyclodialysis

	Design	Success rate	N	Conclusions
Agrawal 2013	Retrospective	Cryotherapy 36 % Direct cyclopexy 94 %	17	Cryotherapy is useful only to close small fistulas
Wei/Wei Xu 2013	Prospective comparative trial Nonrandomized	Direct cyclopexy 50 % Vitrectomy, endophotocoagulation, and gas or silicone oil endotamponade 62.5 %	52	Both methods are similar
Ioannidis 2013	Retrospective	Direct cyclopexy 6/11 Cryotherapy 3/6	18	Trend toward higher success with cyclopexy

found a trend toward higher success with cyclopexy [21].

In a recent prospective study, Wei-Wei Xu et al. compared direct cyclopexy with vitrectomy, endophotocoagulation, and gas/silicone oil endotamponade [48]. This study included 52 eyes, representing the largest and only prospective series published on this topic. The success rates were similar with both procedures, although the author considered it unethical to randomize the patients, and inclusion criteria were different for both groups. If the patient had vitreous hemorrhage or retinal detachment, he was assigned to the vitrectomy group. This design can explain why postsurgical visual acuity was inferior in the vitrectomy group. Progression of cataract was documented more frequently in the vitrectomy group. Subjective pain was higher in the vitrectomy group but IOP spikes were more frequent in the direct cyclopexy group [48]. The authors concluded that both procedures were equally effective. If vitreous hemorrhage is present, vitrectomy should be chosen. However, direct cyclopexy is a simpler procedure, associated with less discomfort and lower rates of cataract progression and should be the preferred procedure in the absence of associated vitreoretinal pathology [48].

Algorithm for the management of cyclodialysis

Ormerod proposed an algorithm in 1991 (Fig. 5) [14]. However, the information provided by new studies and the development of new diagnostic technology and treatment options require an update in this algorithm.

Ocular hypotony is defined as an IOP of 5 mmHg or lower. However, tolerance to ocular hypotension may differ among patients. Treatment should only be started if hypotony is affecting ocular function (in the presence of hypotony maculopathy). Phthisis is considered the end-stage result of ocular hypotony [61]. Some authors believe that a delay in the closure of the cleft could lead to the development of irreversible damage to the retina and that immediate surgical treatment should be performed [71]. However, most authors think that medical treatment should always be employed first because some cyclodialysis resolve spontaneously and a slight delay in IOP restoration does not change the visual prognosis. A step-by-step approach would include (Fig. 6):

1. Starting with conservative therapy with atropine during several weeks and quick tapering of steroids. If ocular hypotony maculopathy persists after two months of stopping steroids, then invasive methods should be considered.
2. If medical treatment is not effective, then invasive or semi-invasive methods should be performed. In the presence of concomitant pathology, the technique that can simultaneously address both pathologies should be chosen (vitrectomy in the case of retinal pathology and cataract surgery in the presence of significant cataract). If cataract surgery is performed, the reduction in axial length induced by hypotony should be taken into consideration to avoid refractive surprise.
3. In the absence of concomitant pathology, treatment selection should be guided by the size of the cleft:
   a. In small clefts (<3 clock-hours) semi-invasive therapy with laser should be tried. Ab-interno Argon laser is useful when “the mouth” of the fistula has been located. Pilocarpine can open the cleft and makes Argon laser photocoagulation easier. If the mouth of the cleft can’t be located, then transscleral methods allow treating a wider area and are probably more effective than Argon laser. We think that due to its ability to act through the sclera, transscleral diode laser is superior to YAG laser. We don’t recommend diathermy because it could damage the lens and induce scleral ectasia [37, 62]. Cryotherapy has shown only modest results [21] and it induces severe inflammation, so it should only be used when laser is not available.
   b. If medical treatment is not effective in medium size clefts (3 to 6 clock-hours), or if medical and laser treatment have failed in a small cleft, then direct cyclopexia should be performed. We dońt recommend direct cyclopexia for bigger clefts, since it would require the dissection of an extense scleral lamella, with the risk of anterior segment ischemia [106]. Vitrectomy might be necessary if direct cyclopexy is not successful in small and medium size clefts.

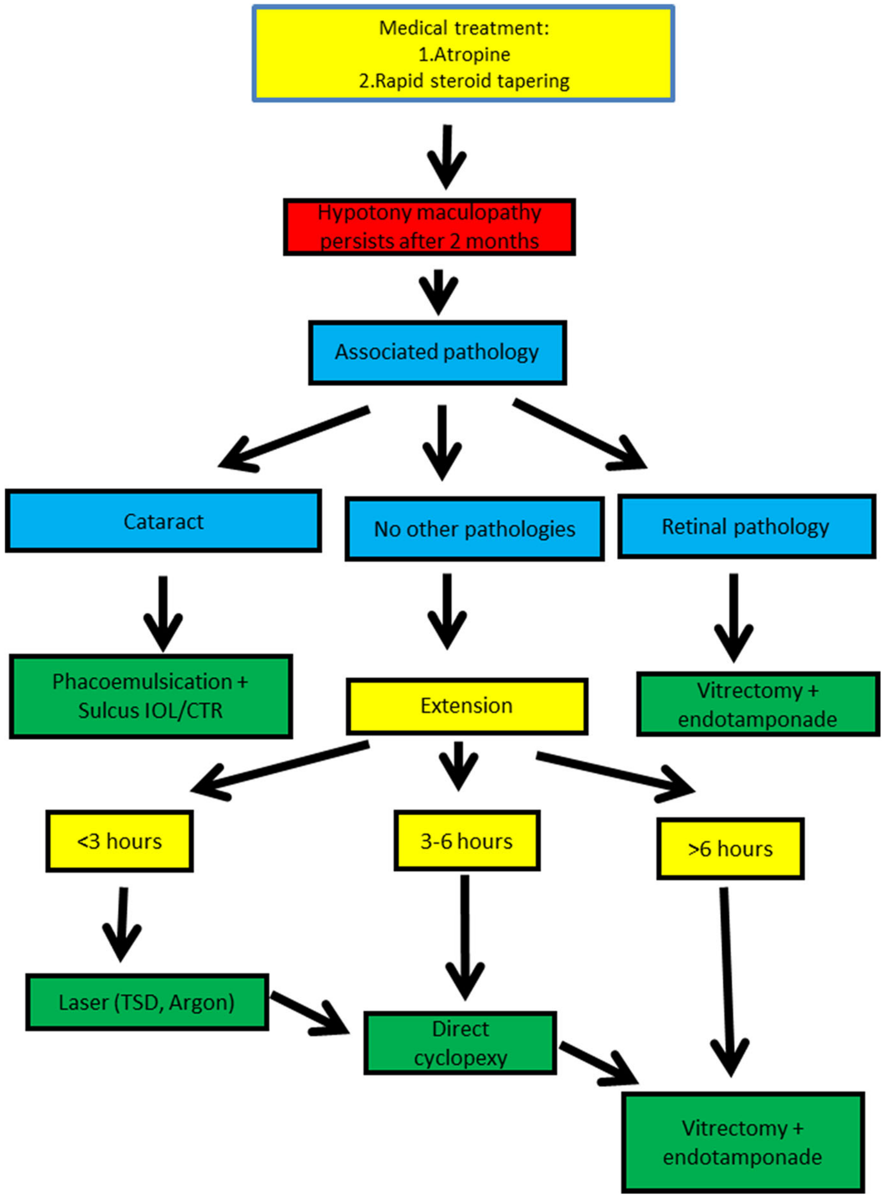

Fig. 6 Updated algorithm including new therapeutic approaches. *TSD* transscleral diode, *IOL* intraocular lens, *CTR* capsular tension ring

c. In extense clefts (>6 h), posterior segment surgery seems to be the safest option. Vitrectomy with gas endotamponade is probably the most effective approach. Although the insertion of a tension capsular ring in the sulcus has also been proposed in this scenario, we believe that the evidence available does not support its use if cataract surgery is not necessary.

Conclusion

Cyclodialysis is an uncommon condition. Although some cases are iatrogenic, nowadays most cases are produced by blunt trauma. There are no set guidelines for treating this condition. Ultrasound biomicroscopy is very useful to diagnose, localize, and determine the extension of the cleft. Nevertheless, gonioscopy remains essential and its sensitivity can be increased by injecting viscoelastic into the anterior chamber. As regards treatment, direct cyclopexy is probably the most effective method to close the cyclodialysis and remains the gold standard, but medical treatment with atropine and semiconservative methods like laser treatment should be tried in small and medium clefts. Vitrectomy with gas tamponade can also be very effective and should be considered when concomitant retinal pathology is present. Although a few reports suggest that the haptics of an intraocular lens or a capsular tension ring can help to heal a cyclodialysis, long-term outcomes are still uncertain.

Compliance with ethical standards

Conflict of interest Julio González Martín-Moro, Inés Contreras Martín, Francisco José Muñoz Negrete, Fernando Gómez Sanz, and Jesús Zarallo Gallardo have no financial or proprietary interest in a product, method, or material described herein.

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