Introduction

The ciliary body is a circular structure (as appears in coronal section and triangular in cross section) forming a complete ring which is continuous anteriorly with the iris periphery and posteriorly with the choroid. It measures about 6mm wide (6.5-mm on temporal side and 5.5-mm on the nasal side) and extends forward to the scleral spur and backward to the ora serrata of the retina. It presents two main zones, the smooth pars plana (orbiculare ciliaris) posteriorly and the pars plicata (corona ciliaris) anteriorly. The equator of the lens is situated about 0.5-mm from the ciliary processes. The postganglionic parasympathetic fibers derived from the oculomotor nerve innervate the ciliary muscle via short ciliary nerves.

As regards crystalline lens, it is a transparent, biconvex structure situated behind the iris and the pupil and in front of the vitreous body. The convexity of its anterior surface is less than that of its posterior surface. In the adult the lens measures approximately 10-mm in diameter and 4 mm thick. The equator of the lens is encircled by the ciliary processes of the ciliary body. Its capsule is an elastic membrane that envelopes the entire lens. This elastic capsule can be stretched up to about 60% of its circumference without tearing. The capsule receives the insertion of the zonular fibers anteriorly and posteriorly at the lens periphery as well as at the lens equator.

Suspensory ligament of the lens (ciliary zonule) consists of a series of fibers passing from the ciliary body to the lens forming a ring, holding the lens in position and enabling the ciliary muscle to act on it during accommodation. The zonules pass through the valleys between the ciliary processes to whose lateral walls they are closely attached by tension fibers. Tension fibers are thought to play an important role in the accommodation process by stabilizing the zonules. The zonular apparatus is always bent at the zonular fork, showing the strength of the anchorage of the zonular plexuses to the ciliary processes. This secondary anchorage is thought to be extremely important in relation to accommodation as it explains how an equatorial force is exerted upon the lens by fibers that originate partially in the pars plana.

Presbyopia and Accommodation

Presbyopia is the reduction of accommodation range and power, which occurs with aging. The near point recesses, while the far point is unaffected. Accommodation refers to the process of focusing and maintaining retinal image of an object of regard at the fovea through changing the dioptric power of the crystalline lens. A variety of ideas have been proposed regarding the clear sight at different distances some of them included pupil size changes with the effort to see clearly at near. However, the depth of
focus is approximately 1.00 diopters (D) for the smallest normal physiological pupil diameter (2.0-mm), accounts for a small portion of the accommodative amplitude of the pre-presbyopes. Other ideas postulated a change of the antero-posterior position of the lens with variation in focal point, but the presence of amplitude of 15.00 D found in young children was a major drawback. Another idea explained the power of accommodation by changes in the shape, and therefore power, of the crystalline lens that allow objects at various distance to be focused on the retina. That was the nucleus of correct understanding the true mechanism of the human accommodative process.

In 1855 Helmholtz declared his theory of the physical mechanism of accommodation. He stated that the ciliary muscle is relaxed when the eye is focused for distance. The relaxed ciliary muscle maintains the zonules under tension, flattening the crystalline lens allowing clear distance vision. When the eye focuses on a near object, the ciliary muscle contracts and releases tension on the zonules thus the crystalline lens becomes more curved due to elastic forces in the lens. Fincham added additional experimental support to the accommodative theory of Helmholtz and also offered evidence that presbyopia was caused by the inability of the lens capsule to mould the hardened lens substance into the accommodative form. Fisher, Pau and Kranz found out that the lens hardens with age adding another support to Fincham theory of presbyopia. In addition, Fisher found out that capsular elasticity supposed by Young’s decreases by half between youth and 60 years of age. This finding also supports Fincham theory of presbyopia because a less elastic lens capsule would exerts less force on the hardening substance of the aging lens.

Helmholtz theory (Fig. 1) stated that the action of all parts of the ciliary muscle is to slacken the suspensory ligaments of the lens. This results in decreased tension on the capsule of the lens, which therefore becomes more convex acquiring a hyperbolic shape during accommodation. The circular fibers act directly as a sphincter diminishing the circumference of the ring formed by the ciliary body. This probably applies to the radial portions of the muscle. The posterior attachments of the ciliary muscle, consisting largely of delicate elastic tissue, seem to be admirably adapted to allow the posterior ends of the muscle to pass forward during contraction and to guide them back to their original positions on relaxation. All fibers of the muscle will thicken during contraction increasing the cross sectional diameter of the whole muscle so that the inner border of the muscle moves inward towards the outer edge of the lens. Thus the whole muscle acts as a sphincter to the ciliary ring.

**Fig. 1. HELMHOLTZ Theory of accommodation.**
In 1992 Schachar proposed a new theory for the mechanism of accommodation (fig.2). He stated that the crystalline lens is under tension during accommodation. The anterior radial muscle fibers of the ciliary muscle arch towards the sclera during accommodation, increasing the tension on the equatorial zonules, while the posterior longitudinal and posterior radial muscular fibers move anteriorly, producing relaxation of the anterior and posterior zonules. The increased tension on the equator of the crystalline lens produces central steeping with peripheral flattening.

Based on this new theory, for the first time Schachar has been able to construct a model single element, variable focus lens that can change the optical power in the order of 10 (D). These measurements have been verified by measurements from the nodal point of the lens using a Gaertner optical bench, vertical scanning interference microscopy, and finite element analysis. Geometric finite element analysis of a solid polyvinyl chloride model of the human crystalline lens demonstrates marked increase in the central optical power with equatorial stretching.

The new theory predicts that tension on the equator of the lens, or the crystalline lens, will decrease its central radius of curvature (increasing its central optical power) while increasing its peripheral radius of curvature (decreasing its peripheral optical power), therefore decreasing its spherical aberration. Profile photographs, vertical scanning interference microscopy and finite analysis of the model single element, variable-focus lens have demonstrated an increase in the peripheral radius of curvature with equatorial stretching. Likewise, mathematical analysis of the model lens has demonstrated that spherical aberration decreases with increased equatorial tension. These predictions and experiments with the model lens are consistent with the decrease in spherical aberration observed during human accommodation. Because the crystalline lens grow through out life (20-µm/year) tension on all the zonules decrease with age. The decreased tension on the equatorial zonules should decrease the central optical power of the lens and emmetropes become hyperopic. It also predicts that disinsertion of the anterior ciliary muscle will produce loss of accommodation and hyperopia. Indeed, disinsertion of the ciliary muscle of primate eyes does produce those results.

The new theory states that the equator of the lens is always under tension. In the non-accommodative state, all the zonules are under tension. During accommodation the equatorial zonules are under tension while the anterior and posterior zonules relax. Therefore, the lens is stable, and gravity should not – and does not – affect the accommodation amplitude.
The new theory states that 5 different component muscle groups make up the ciliary muscle according to muscle fiber orientation. During accommodation, each ciliary muscle fiber group has mainly the following functions:

- The anterior longitudinal muscle fibers open the trabecular meshwork.
- The posterior longitudinal and posterior radial muscle fibers move the choroid forward and relax the anterior and posterior zonules. The anterior and posterior zonules originate at the posterior part of the ciliary body.
- The anterior radial muscle fibers apply increased tension on the equatorial zonules.
- The circular muscle fibers contract isometrically to supply a buttress for the anterior and posterior radial muscle fibers to pull against.

Because the anterior radial muscle fibers are primarily responsible for accommodation, they should be the first to atrophy following presbyopia; it has been demonstrated that these muscle fibers are the first to show collagen deposition and atrophic changes.

**Theories of Presbyopia**

- Helmholtz-Hess–Gullstrand theory attributes all the loss in accommodation to the biochemical changes in the lens capsule and the lens and none to the ciliary muscle. According to this account, the amount of ciliary muscle contraction required to produce unit change in accommodation remains constant with age. Age brings no loss of power of the ciliary muscle. Furthermore, because the lens responds progressively less with age, whereas the ciliary muscle does not, the amount of potential ciliary muscle force in reserve increases with age. The following example demonstrates this point. Suppose a 5-year-old child has 15.00 (D) accommodative amplitude. The amount of ciliary muscle contraction necessary to produce the initial 1.00 (D) change would be 1/15th of full amount. Each succeeding 1.00 (D) change would require another 1/15th of the total ciliary muscle force. At the 15.00 (D) accommodative amplitude, all the ciliary muscle force would be exerted. When the child became middle-aged, he would have only 1.00 (D) of accommodation remaining. The ciliary muscle effort to exert that remaining 1.00 (D) would still equal 1/15th of its full amount there would now be 14/15ths of its contractile force in reserve.

- In contrast, Donder- Duane theory attributed all of the age related loss of accommodation to the ciliary muscle, and none to the lens and lens capsule. According to this theory, the amount of ciliary muscle contraction needed to produce a unit change in accommodation progressively increases with age. Thus, as one ages, the reduced amplitude is due to progressively weakening of the ciliary muscle itself. There is no loss in the ability in the lens or the lens capsule themselves. So, the amount of potential ciliary muscle force in reserve progressively decreases with age. The following example demonstrates this point, suppose a 5-year-old child has 15.00 (D) accommodative amplitude. At that age, the amount of ciliary muscle contraction necessary to produce the initial 1.00 (D) change in accommodation would again equal 1/15th of its full amount. Each succeeding 1.00 (D) change would require another 1/15th of the total ciliary muscle force. At the 15.00 (D) accommodative amplitude, all the ciliary muscle force would be exerted. When the child became middle-aged, he or she would have only 1.00 (D) of accommodation left. The ciliary muscle effort necessary to exert that remaining 1.00D would equal 15/15ths of its full amount, leaving no contractive force in reserve.

- According to the Schachar hypothesis, presbyopia occurs as a natural result of lens growth. The lens, an ectodermal tissue, grows at 20-µm/ year. As the lens
grows, the distance between the lens equator and the ciliary body decreases linearly throughout life. Therefore, the effective force that the ciliary muscle can apply to the lens is consequently reduced. Presbyopia occurs when the ciliary body decreases to the point that the muscle can no longer apply adequate force to change the shape of the lens.

**SURGICAL MANAGEMENT OF PRESBYOPIA USING PSEUDOACCOMMODATION PRINCIPLE**

The effect of bifocal or multifocal IOLs is based on the reception of simultaneous images at the retina through various foci. The ability to process these different images is called pseudoaccommodation. Physiological aspects of vision and the interaction of multifocal imagery have not been fully investigated, although some reports seem to confirm the benefit of a bifocal system. The human retina recognizes only one image; parallel perception is not possible. An important factor of multifocal vision is the individual ability of pseudoaccommodation and the capability of the multifocal cornea to produce comfortable vision. The ability of increase depth of focus and the perception of a focal interval was described as polymetrophia.

**Accommodative IOLs**

**Development**

About 10 years ago, Dr. Cumming implanted a large number of plate lenses and noticed that some of the patients who were virtually plano could see at distance and near without glasses, and this intrigued him. He had put these patients behind the phoropter, and refracted them with maximum plus, giving them their best corrected distance vision. Then he put a reading card in front of the phoropter and dimmed the lights in the examining room and found that a few of these patients could still read under these circumstances. He had eliminated the possible pseudo-accommodative effects of myopia, cylinder and a small pupil. A literature search familiarized Dr. Cumming with work on ciliary muscle action and accommodation done by Busacca in 1955 and Coleman in 1986. Further research demonstrated that a plate lens is "shrink wrapped" during fibrosis of the anterior capsule and the optic forced posteriorly to lie up against the vitreous face. "Armed with this logic, a series of lenses were designed to take advantage of pressure changes in the vitreous cavity," he said. Dr. Cumming explained that immediately after implanting the accommodating lens, the ciliary muscle is paralyzed with a drop of atropine to prevent the intermittent increases of vitreous cavity pressure from moving the optic forward. This allows the optic to center well and fixate in its most posterior position during fibrosis of the capsular bag. After a decade of research and development and almost as many lens designs, J. Stuart Cumming, MD in collaboration with Jochen Kammann, MD, have devised an accommodating IOL that manages to move forward to accommodate without dislocating. Of this seventh design of the accommodative lenses (fig.3), they have implanted 185 lenses and there have been no dislocations. Dr. Cumming explained that the centration was excellent, because the ciliary muscle is paralyzed with atropine and constriction and relaxation of the muscle during the period of fibrosis of the capsular bag is the main reason that lenses decenter.

![Fig.3. The current design of accommodative IOL.](attachment:Fig3.png)
Dr. Cumming described the theory of how the lens functions. When plate lenses are placed into the capsular bag, the anterior capsule fibroses and applies end-to-end pressure on the plates, which vault. The lens can’t vault anteriorly because of the fibrosed anterior capsular rim, so it vaults posteriorly and the optic comes to lie up against the vitreous face (fig.4) the ciliary muscle constricts, it redistributes its mass like any other muscle and encroaches on the vitreous cavity space, increasing the vitreous cavity pressure, moving the optic forward. (fig.5)
Design

The current design is characterized by semi-rigid plates with a hinge across the plate adjacent to the optic (fig.6). The overall length of the lens, plate tip to plate tip, is the same as standard plate silicone lenses, 10.5-mm, with polyamide loops making the overall length 11.5-mm (fig.3). In order to get more leverage and therefore more movement of the optic, the plates were lengthened by making the optic 4.5-mm. The lens with this design, after implantation and paralysis of the ciliary muscle with atropine, becomes the anterior wall of the vitreous cavity space. This leaves the optic, with its adjacent grooves, as the section of the vitreous cavity wall with the least resistance to an increase in vitreous cavity pressure, which occurs on constriction of the ciliary muscle. An increase in vitreous cavity pressure thus moves the optic forward; 1 mm of movement is equivalent to almost a 2 D power change.

Exclusion Criteria

Patients with previous ocular surgery, anterior segment pathology, uncontrolled glaucoma or glaucomatous field loss, more than 1D of cylinder, damaged zonules, aniridia, congenital bilateral cataracts, microphthalmos, previous retinal detachment or pathology, diabetic retinopathy, or macular degeneration were excluded in the initial core phase of the FDA-monitored study in the United States.

Operative Technique

Simultaneously bilateral phacoemulsification is the procedure of choice, done under topical anesthesia using Lidocaine 2%. A corneal incision is made at 11 o’clock using a 3.2mm phaco-slit. Viscoelastic
materials, HPMC and Viscoat, are injected in the anterior chamber followed by performing a paracentesis using a 1mm MVR blade. Capsulorhexis (about 6mm in diameter) is then performed using Alio or other capsulorhexis forceps. Hydrodissection of the nucleus using a J hooked and a straight 25-gage cannula is then performed. Phacoemulsification is carried out using the Legacy 2000 phaco-machine (Legacy, Alcon) adjusting the parameters according to the technique of phaco as following:

**Phaco Stop and Chop Technique**

Begins with a short horizontal groove, as if the surgeon was preparing for Shepherd’s cross nucleofracture, then the nucleus is chopped. This produces a space for U/S tip and the hook, which will be able to fracture the nucleus into two parts, using a phaco power of 100%, and a vacuum of 60mmHg. At this point, the surgeon stops, and rotates the nucleus through 90 degrees. The phaco power is changed to 60%, and the vacuum is increased to 400mmHg in pulse mode. The surgeon fixes the lower half of the nucleus with the U/S tip, and a crack is created with a chopper instrument. A number of fragments result, which can be easily mobilized from the capsular bag to be emulsified.

**Phaco-Out Technique**

In this technique, excess hydrodissection is performed. The corneal endothelium is protected using abundant viscoelastic material, HPMC and Viscoat. A Sinskey hook and a fine blunt-ended spatula are used to deliver the nucleus into the anterior chamber. The nucleus is then approached with a 30 degree phaco tip, ultrasound power is set at 60 and the vacuum is set at 400mmHg (using the pulse mode), the nucleus is approached at the equator of one sector, removing the first the superficial layer, then the intermediate part, and eventually the deep portion. The chopper is used to rotate the nucleus 90 to 180 degrees and fragment another sector. Then the surgeon turns again and removes a further sector, thus reducing progressively the nuclear volume. This technique will prevent early fragmentation of the nucleus, which might wander around the anterior chamber with possible contact with the endothelium. Through out the procedure, the second instrument is always pushing the nucleus backwards preventing any possible contact with the back of the cornea. Adjusting the parameters at 50% power surgeon control, 200 vacuum, aspiration at 30cc/min., and with continuos irrigation provides the best working conditions.

In both techniques, cortex removal is performed through the second side port incisions using Koch Cannulas. The capsular bag is subsequently filled with 2% hydroxypropyle methylcellulose.

The incision is enlarged to 3.5/3.7-mm, and after the posterior chamber accommodative IOL is implanted (see later), the viscoelastic is removed from the second side port incisions. A single 10/0 Nylon suture (Alcon,) is used to close the corneal incision followed by intracameral injection of Curoxima 2% antibiotic (Glaxo-Welcoming). Finally, hydration of the corneal incision and the side port incision is made to insure complete closure of their wounds.

**MICS Technique**

This technique is effective in removing cataract with density of +1/+3 using improved Dodick laser system or U/S power using the newly developed software and sleeveless phaco tips. The procedure could be done under topical anesthesia. Two watertight paracentesis in clear cornea 90° apart, at 10 and 2 o’clock with 1.4mm blade are performed (due to high vacuum created) but the only drawback
is the needs to screw a bit the tips in to the incision. This is followed by injecting 1% Lidocaine preservative free diluted 1:1 in BSS. Two different viscoelastic solutions are used in the anterior chamber, first Viscoat to protect the endothelium, then Healon to increase volume in the AC. A 5.5-mm continuous curvilinear capsulorhexis (CCC), is performed with Alio or Condon capsulorhexis forceps which are found to be effective through the water tight incision. After the hydro-dissection of the cortex and nucleus with a flat cannula, the irrigation cannula is introduced first through the second port side, at 2 o’clock incision, then the phaco laser tip at 10 o’clock incision. The laser lysis of the cataract can be described as “touch, pulse, aspiration”. In fact the ablation of the nucleus begins by applying lightly the probe on the anterior surface of the cataract then a pulse of laser is delivered at the lower laser set power with vacuum level of 250 mmHg using the Venturi pump of the Accurus device (Alcon) and the fragment is aspirated. The nucleus is craked after creating a deep initial groove, as soon as is possible. In the instance of using the new sleeveless phaco tip, the irrigation cannula with two port side, in introduced at 2 o’clock incision then the phaco tip is introduced at 10 o’clock incision and the procedure is carried out using the preferable phaco technique as described above. When all the nucleus is aspirated, we insert at 10 o’clock position the aspiration cannula decreasing the vacuum till 100 mmHg and we finish to clean the cortex remnants. After the injection of a dispersive cohesive viscoelastic solution like Healon in the capsular bag, the 10 o’clock incision was enlarged up to 3.5/3.7-mm and the accommodative IOL is implanted either using a McPherson forceps or though an injector. The procedure terminates with the aspiration of the viscoelastic solution using specific I/A cannula (Geuder, GmbH) in continuous irrigation and hydrating the two wound with BSS.

Usually with +1/+2 density cataracts, 40 -100 pulses are sufficient to complete the procedure, while with +3 density it’s about 300 - 400 pulses. The bottle of BSS is fixed at 75 cm high from the patient’s head. If placed at a higher level, the excessively high intraocular pressure, may induce initial vagal response to the patient due to the induction of oculo-vagal reflex.

**Technique of Accommodative Lens (CrystaLens™) Implantation**

The lid of the CrystaLens™ case is designed to easily PUSH and LIFT off. (Do NOT rotate.)

A slot in the case allows the forceps to be positioned for a single grasp for removal of the CrystaLens™ from the case and insertion of the leading plate haptic into the capsular bag. A McPherson forceps is recommended.

Grasp the CrystaLens™ so that the forceps extend across the distal hinge to stabilize the leading plate haptic.

Advance the forceps to place the leading plate haptic of the CrystaLens™ into the distal capsular bag.

With a second instrument, hold the proximal polyimide loop to maintain position of the CrystaLens™ as you withdraw the forceps to re-grasp.

Re-grasp at the tip of the trailing plate haptic. Do not release the tip until insertion is complete, as indicated below.

As you advance the trailing plate haptic into the anterior chamber, the polyimide loops will bend back on themselves as they traverse the small incision. The leading plate haptic will bend to a right angle deep in the bag.

Maintain your grasp at the tip of the trailing plate haptic. Tuck the polyimide loops, one by one, into the capsular bag. Release and withdraw the forceps. The CrystaLens™ will self-center.

The lens could also be implanted by using an injector. The injector and the cartilage are prepared as for standard acrylic lenses The lens is introduced slowly into the bag. (fig.7)
The results of the study are listed in the following Tables (1 & 2). Abbreviation listed include:

- **UDVA**: Uncorrected distance visual acuity
- **BCDVA**: Best-corrected distance visual acuity
- **UNVA**: Uncorrected near visual acuity
- **BCNVA**: Best-corrected near visual acuity

Fine et al performed a study in the United States involved 50 patients, inclusion criteria included patients have 50 years of age or more, adequate mental capacity, potential visual acuity around 20/30, and candidates for cataract surgery.

The surgical technique used in the study was clear corneal incision of 3.5-mm or less for 50% of patients and scleral tunnel incision of 3.5-mm or less for the other 50% of patients. Viscoelastic injection, rounded capsulorhexis of about 5-mm followed by standard phacoemulsification then lens implantation.

Post-operative atropine at the conclusion of the surgery and on the first post-operative day is instilled but miotics were not allowed following IOL implantation. Post-operative complications were limited to iritis and corneal edema which were rare and all resolved completely 1-2 weeks later.

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The results of the study are listed in the following Tables (3 & 4) and the abbreviation listed in the study included: UDVA: Uncorrected distance visual acuity, BCDVA: Best-corrected distance visual acuity, DCIVA: Distance-corrected intermediate visual acuity, UNVA: Uncorrected near visual acuity,

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DCNVA: Distance-corrected near visual acuity, BCNVA: Best-corrected near visual acuity (fig.8).

Arturo S. Chayet, MD, implanted this model in 14 presbyopic patients bilaterally in Tijuana, Mexico. Of those patients at one year of follow up, 79% are 20/30 and J3 uncorrected, and 100% are 20/40 and J3 uncorrected or better. About 93% of the patients with corrected distance vision without an add are 20/25 and J3. In the second year of follow up 2 patients were lost to follow up. Among the remaining 12 patients 67% only were 20/30 and J3 or better uncorrected vision, that decrease was attributed to the development of posterior capsular opacification.

In a Canadian prospective study reported by Dr. Francis Roy, MD, six patients had the new IOL implanted in both eyes and 2 in one eye. At a mean follow up of 23 months, all of the patients achieved 20/40 or better uncorrected vision, and all can read without correction.

The level of patients satisfaction in all the studies were excellent and no patient complained of glare, halos or unwanted retinal images. Neither the patients are happy with the results particularly those who received bilateral implantation.

Latest Design of Accommodative Lenses

Specifications

The most recent resign of accommodative IOLs is the lens "Akkommodative ICU". It’s a biconvex, foldable, hydrophilic acrylic and UV inhibitor lens. The refractive index is 1.46, the optic diameter is 5.5-mm and the A-constant is 118. It’s overall diameter is 9.8-mm and the dioptric range is +16.0 to -26.0 diopters in 0.5 steps.

The Lens Could be Implanted as Follows

The injector and the cartilage are prepared as for standard acrylic lenses (Fig. 9). A small quantity of viscoelastic is placed on the loading chamber and in the tunnel of the cartilage, the lens in removed with a forceps then is placed on the loading chamber of the cartilage. The hooks located at the extremities of the haptic and must be facing up and folding axis must be respected.

Fig. 8 Accomodative IOL implanted inside the bag. (Winn et al)

Fig. 9 (above). The lens being mounted on the injector.

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Using forceps or the folding fork press on both sides of the optic zone and partially close the cartilage. Place the haptics in the tunnel and fully close the cartilage. The lens then placed in the tunnel using lens loader and cartilage can now be placed into the injector (Fig. 10).

After injection of the lens the optic zone will unfold slowly and predictability. The haptics will usually require unfolding which could be achieved by injecting viscoelastic on the optic zone or using push/pull hook. (Fig. 11).

Fig. 10: The accommodative IOL being implanted

Fig. 11: The IOL being unfolded
Regression? Time Will Tell

There is some concern that the early accommodation seen with the lens could regress. In particular, it remains to be seen whether increasing fibrosis of the capsule over time will be associated with anterior movements of the posterior capsule, pressing that lens forwards. This could result in patients ending –2.5 or –3.0 D some five years after implantation. However, there have been no signs of this in patients who have had the lens for as long as one year as observed in the previous clinical studies.

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