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REVIEW

Accommodative esotropia: the state of the art

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Abstract
Purpose To review the state of the art of Accommodative Esotropia (AE) through careful study of what has been reported up to the point in literature.
Methods A literature search was done on PubMed using key words including "Accommodative esotropia", "Infantile esotropia", "Strabismus" and "Accommodation". We systematically reviewed and critically appraised what has been written about AE and we tried to analyze that according to the current management of AE.
Results Accommodative Esotropia (AE) is a form of strabismus characterized by convergent misalignment of the visual axes that can be associated with hyperopia and abnormal fusional divergence. Also abnormal accommodative convergence/accommodation ratio could be found. In lots of cases, AE initially presents as an intermittent esodeviation at age 1.5 to 4 years. The prevalence of AE has been estimated near 1-2% in the United States. The only treatment with an optical correction usually is successful in re-establishing alignment, but surgical correction is necessary in approximately 30% of cases.

Keywords Accommodative esotropia · Infantile esotropia · Strabismus · Accommodation · Amblyopia

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Introduction

Accommodative esotropia (AE) is a form of strabismus characterized by convergent misalignment of the visual axes that is typically associated with hyperopia and/or abnormal fusional divergence [1, 2]. It usually presents between ages 1.5 and 4 years as an intermittent esodeviation, exacerbated by fatigue or near viewing [3]. Accommodative esotropia is the most common form of childhood esotropia [4] (Table 1). The prevalence of AE has been estimated to be approximately 1–2% in the USA [5]. Although treatment with optical correction (hyperopic correction and/or bifocals) is usually successful in restoring ocular alignment, strabismus surgery is required in approximately one-third of cases [6, 7]. Herein, we provided review of the literature on AE with emphasis on clinical management.

Table 1 Forms of childhood esotropia and incidence in general population [5]

Esotropia type	%
Accommodative	53
Pure	(40)
Partial	(13)
Central nervous system defects	17
Congenital	(8)
Acquired	(9)
Acquired non-accommodative	11
Sensory	7
Congenital	5
Paralytic	3
Unknown age at onset (non-accommodative)	4

Risk factors

AE is influenced by the normal maturational sequence for binocular vision, fusion, and stereopsis [8]. While most children with infantile esotropia (ET) have low hyperopic errors ($< 3.00D$), the majority will develop AE after successful surgical treatment at approximately 3 years of age [9, 10]. The risk is doubled by increasing hyperopia after the initial surgery for infantile ET, duration of infantile ET > 3 months after onset, and absence of measured stereopsis [11].

The high prevalence of AE among children treated for infantile ET may be the result of preexisting binocular sensory dysfunction, which allows AE to occur at low levels of hyperopic refractive error. Disruption of binocularity associated with anisometropia may also be a predisposing factor [12]. Many children with AE have reduced stereoacuity even after ocular realignment by optical or surgical means. The pervasiveness of binocular sensory dysfunction in these patients with onset of esodeviation after maturation of fusion and stereoacuity is mostly complete and should give important clues about critical periods in binocular sensory development. Although fusion and stereoacuity are almost fully developed by age 2 years, AE with onset after this time can still be associated with profound impairment of binocular sensory function [13].

Little is known about the critical period for treatment and whether it extends beyond the ages of greatest susceptibility. Duration of abnormal visual experience may be an important factor in limiting the potential for recovery. There are some evidences that brief period of constant misalignment of the visual axes before 3 months of age may result in permanent deficits in the binocular sensory function, regardless of the age of onset or the age at which ocular alignment is restored. Although maturation of binocular sensory function is nearly complete by 18 months of age, AE presenting after this time still places the child at risk of permanent binocular sensory deficits. Some of these deficits may be preexisting and make the child more prone to develop strabismus, while others result directly from the abnormal binocular experience after the onset of the disease. The functional organization of the maturing visual system is highly sensitive to disruption by abnormal visual experience during the first months of life, but declining levels of susceptibility continue until at least 4 years of age [11]. Moreover, we can say that, in general, deterioration in patients with AE is known to occur usually by 5 years of age and rarely after age 7 [14]. Nowadays, we can affirm that AE etiology is multifactorial.

Pure accommodative esotropia

AE can be caused only by uncorrected hyperopia associated with insufficient fusional divergence. This can lead to excessive accommodative convergence, resulting in esotropia at both near and distance viewing. When the distance and near angles of deviation are approximately equal, we describe the condition as "Purely Refractive AE" (PRAE). Treatment, if required, is usually full-time wear of the full hyperopic refractive error, as determined by cycloplegic retinoscopy.

Today it is well known that poor compliance with spectacle use largely increases the risk of poor sensory outcomes in children with PRAE [15].

Now the question arises, if uncorrected hyperopia can often cause esotropia [16], how much correction is necessary? It is clear that accommodative effort, if fusional divergence is absent or weakened, can result in manifest esotropia. This is also demonstrated by the fact that timely and complete correction of the hyperopic refractive error protects normal binocular vision [17]. For this reason, complete correction of hyperopia is the most reliable method of straightening the eyes and allowing for the continued development

of binocular single vision [18]. Some studies have shown that spectacle lenses can alter eye growth, with compensating refractive changes in both the hyperopic and myopic directions, suggesting a possible adverse effect of complete correction in altering the normal emmetropization process in hyperopic patients [19]. Alternatively, under correction may carry a risk of decompensation of a previously controlled deviation and loss of binocular vision [20]. In fact, eyes with high degree of hyperopia have a higher tolerance for undercorrection, although there was a wide variation in the maximal tolerable amount of undercorrection among patients with similar baseline refractive errors. Most moderate to high hyperopic patients can withstand to 1*D* of spectacle under correction and maintain satisfactory ocular alignment, which may prevent intermittent distance blur and improve compliance wearing glasses. This is important, since any pair of glasses that is actually worn work better than glasses left in the drawer. That being said, a certain rate of deterioration should be anticipated in previously controlled esotropia with plus lenses, and insufficient correction of hyperopia as one of the major causes of deterioration. Visual acuity, stereoacuity, and fusional ability did not deteriorate after undercorrection when followed up for 2 years [21].

Furthermore, a partial fusional capacity is associated with stereopsis in some patients with refractive accommodative esotropia. A good stereopsis, according to some recent reports, may be achievable only with a misalignment of $\leq 4\Delta$ at distance and $\leq 5\Delta$ at near fixation [22].

Only a few patients who developed worsened esotropia did not return to the baseline alignment after wearing trial spectacles with complete hyperopic correction. Judicious under correction of patients with high hyperopia therefore seems reasonable, providing they are monitored for decompensation.

Finally, talking about patients with PRAE it is important to emphasize that in some cases the sensory state may be compromised despite an immediate and adequate treatment; nevertheless, PRAE remains a pathology with low risk of amblyopia [23].

Partly accommodative esotropia

When refractive accommodative factors contribute to the esotropia, but do not account for the entire deviation, we describe this condition as partly (or partial) accommodative esotropia (PAE) [24]. The term is customarily applied if a residual esotropia of > 10 PD remains at distance viewing wearing full hyperopic correction. Accommodative components are usually expected to resolve after 6–8 weeks after beginning glasses wear. PAE can develop secondary to neglected AE, due to contraction of the conjunctiva muscles and Tenon's capsule. In many cases, surgical treatment is warranted for the residual deviation after spectacle correction eliminates the accommodative component. The preferred operation is medial rectus muscle recession [25], which typically performed bilaterally, but may be useful unilaterally for some deviations < 20 PD.

Amblyopia is common fellow traveler with PAE. To avoid the risk of amblyopia and to achieve a stable outcome after strabismus surgery, it is desirable that patients are prepared for fusion before surgery.

Some recent reports have shown that there is no hurry to operate high hyperopia associated with strabismus and amblyopia. In fact, the initial treatment of the amblyopia, in some cases, supports the resolution of the non-accommodative component and may significantly decrease the need for surgery [26].

For sensory fusion to occur, the images must not only be located on corresponding retinal areas, but also must be sufficiently similar in size, brightness, and sharpness. Amblyopia can be a major obstacle to fusion. The aim of amblyopia treatment is to provide similar images to the corresponding retinal points, whereas the aim of strabismus surgery is to decrease deviation within the limits of individual motor fusion amplitudes. In contrast to some surgeons who initiate surgery before treating amblyopia, other authors suggest that amblyopia treatment should be performed first [27]. Some patients will demonstrate a progressive decrease in the angles of deviation while undergoing occlusion therapy which may change the surgical plan or obviate the need for further treatment altogether. Maybe it is not the occlusion treatment itself, but the time spent on this treatment, which allows time for resolution of the non-accommodative component in PAE. It is important to remember that the effects of occlusion can vary widely, and occasionally may worsen the alignment by converting a phoria to tropia, presumably by interrupting binocularity and fusion.

Consecutive exotropia may occasionally occur spontaneously after treatment for PAE, but is most frequently follows strabismus surgery. The presence of amblyopia and hyperopia is the most common risk factors for the development of consecutive exotropia and is commonly associated with PAE cases. Another risk factor for the development of consecutive exotropia is postoperative underaction of the medial rectus muscles. High hyperopic patients may also be at greater risk more owing to their smaller globe size. It should be remembered in any case that surgery is rarely urgent, and preliminary occlusion of the dominant eye in patient with suspected amblyopia is almost always indicated. This allows time for resolution of the non-accommodative component in the strabismus. The surgical dose for bilateral medial rectus muscle recession for PAE with excessive convergence is often difficult to determine, and undercorrection is common in these patients [28]. A common surgical approach involves targeting an intermediate angle of esotropia that lies between the angle for distance and near viewing (almost always greater), measured wearing full hyperopic correction. An alternative to standard surgery is the "augmented surgical formula": in this case, target surgical angle is chosen between distance and near angle. In highly hyperopic patients, it may also be necessary to augment the surgical dose to account for the base out prism artifact of the lenses when esotropia is present, which is about 2½%/*D* [29]. However, some authors prefer standard dose surgery which has less risk of postoperative over-correction [28, 30].

Various means to augment the effects of bilateral medial rectus muscle recession for near angle have been reported [31–33]. Pulley posterior fixation lessens the effectiveness of the medial rectus muscle in its field of action by limiting the movement of the muscle belly through its pulley. It has been demonstrated that scleral posterior fixation sutures may collide with the relatively immobile muscle pulley [34], creating a mechanical restriction by preventing the muscle belly from telescoping through its pulley sleeve [35]. In this way, some surgeons achieve pulley posterior fixation by using a suture to fixate the muscle belly directly to the pulley to produce a comparable mechanical restriction [36]. This new technique may be as effective as scleral posterior fixation sutures at decreasing near-distance disparity in PAE, while offering the advantage of avoiding possible scleral perforation. Like conventional posterior fixation, pulley fixation has also been used to augment bilateral medial muscle recession and decrease the disparity between children with AE and PAE with excessive convergence.

It is well now known that most patients with PAE, after strabismus surgery, maintain a good eye alignment with hyperopic spectacle correction [37].

Various other approaches have also been described: each approach tries to improve on the frequent surgical undercorrection for near vision that occurs with conventional bilateral medial rectus recessions. It is known that medial rectus recessions reduce near–distance disparity in AE/PAE with excessive convergence by around 2/3 [38, 39]. Scleral posterior fixation sutures also appear to reduce the near–distance disparity. Among children with a near–distance disparity $> 10D$, a statistically significant difference is observed between augmented surgery for the near angle and the use of posterior fixation sutures [33]. In cases where the distance–near disparity is unusually large, such measures may be justified in spite of their greater complexity and morbidity [40].

In a recent review, it was observed that the spherical refractive errors decrease after surgery and the myopic shift in amblyopic eyes is lower than that of non-amblyopic fellow eyes or normal eyes in patients with PAE [41]. In addition, the initial hyperopic error appears to be greater in amblyopic eyes, and it may be possible that the presence of amblyopia is correlated with the pattern of change of the equivalent spherical refractive error in PAE.

The accommodative convergence/accommodative ratio

Whenever is exerted, a certain amount of convergence, called "accommodative convergence," is evoked. The amount differs from person to person and is customarily described as the "AC/*A* ratio." When fixation is changed from a distant to closer target, convergence is required to maintain eye alignment. This requirement, expressed in prism diopters (Δ), depends on fixation distance (D) and the patient's interpupillary distance (PD). The relationship is a simple one: the requirement is the fixation distance in diopters (or reciprocal of distance in meters) multiplied by the interpupillary distance in

centimeters. Thus, a patient without strabismus having a PD of 6.5 cm fixating at 1/3 m has a convergence requirement of $6.5 \times 3 = 19.5\Delta$. To fulfill the requirement by accommodative convergence alone, a person would have to produce $6.5\Delta/D$ for each unit of accommodation, that is, have an AC/*A* ratio of $6.5\Delta/D$. However, most people have a measured AC/*A* ratio that is much less. Fusional convergence is the mechanism that allows them to make up for the insufficient accommodative convergence. If the fusional convergence is inadequate, the patient will have an exotropia at the near fixation distance. On the other hand, patients with a high AC/*A* ratio will converge excessively and exhibit an esotropia (or esophoria) if the fusional divergence is of sufficient amplitude to hold the eyes straight [42].

There are two commonly used methods for measuring the AC/*A* ratio: the heterophoria method and the lens gradient method. Both methods are based on changing the patient's accommodation and then measuring the associated change in convergence. Accommodation is changed by either changing the fixation distance ("heterophoria" method) or changing the amount of accommodation needed for a specific fixation distance by introducing various plus or minus spherical lenses ("lens gradient" method). While actual accommodation is about 10% less than accommodative "requirement," it is close enough for clinical purposes.

When measuring the AC/*A* ratio using either of these methods, it is important to use accommodative targets, have the patients wear their full optical correction, use alternate cover testing to measure deviation, and control the fixation target distance. The heterophoria method compares the distance and near deviation to determine the AC/*A* ratio. It requires measurement of distance and near deviation in prism diopters and the PD in centimeters. In the heterophoria formula, *D* is distance deviation, *N* is near deviation, and *A* is diopters of accommodation required for near fixation.

Formula (heterophoria)

$$\text{AC}/A = \text{IPD} + N - D/A$$

The lens gradient method determines the AC/*A* ratio by measuring the change in ocular deviation associated with a specific change in lens-induced accommodation. Measurements are usually made in the distance to minimize proximal convergence, and a + 3.00 diopters lens is usually used.

Formula (lens gradient method)

$$\text{AC}/A \text{ ratio} = \text{deviation without lens} - \text{deviation with lens/lens power in diopters [43].}$$

In any case, distance–near incomitance is a source of amblyopia. It needs to be corrected while treating an esotropia [44].

Esotropia with high AC/*A* ratio (non-refractive AE)

A subgroup of patients with AE has a high AC/*A* ratio, which results in a substantially greater esotropia at near than distance viewing. High AC/*A* ratio esotropia usually occurs in patients with hyperopia, but may occur in patients with little or no refractive error, and rarely myopes [45].

Around 15% of AE patients have been found to have a high AC/*A* ratio. Patients with an AC/*A* ratio of 10:1 or greater pose more of a therapeutic problem. The refractive correction may full correct the deviation in distance fixation, but there remains a deviation that may be rather large, cosmetically objectionable, and above all functionally detrimental at near. In fusing patients, this can be manifested by loss of binocularity/stereoacuity, blepharospasm, and occasionally reports of diplopia. Near ocular alignment can usually be restored by either reducing the need for accommodation (by giving additional plus power for near vision) or decreasing the accommodative effort required to fixate at near. While we assume that miotic drops, such as phospholine iodide, work by reducing required accommodative effort (and resulting accommodative convergence), this explanation may be incomplete. If effort to accommodate is the key point, there should be a steady increase in AC/*A* as we age. The crystalline lens becomes less elastic and the ciliary body atrophies. Hence, more effort is needed for the same amount of accommodation. But, in reality, we usually see AC/*A* ratio decrease with age, if any change occurs. There must be feedback mechanism such that as we age, and the effort to accommodate increases, the convergence response decreases yielding an acceptable clinical balance.

Bifocal glasses are normally prescribed when there is acceptable ocular alignment at distance, but a residual esotropia at near in patients capable of fusion and/or stereopsis. When prescribing bifocals, we usually start with a near add of $+2.50D$. Lesser amounts are prescribed when near control is good or as part of the weaning process occurs later. Children tolerate additional plus power in the form of bifocal lenses remarkably well.

In recent years, the effective use of bifocal lenses has been questioned. Olitsky reported that, although there are some theoretical advantages of bifocal lenses use in patients with excessive exothermic convergence, the latest data did not highlight the need for active treatment of these patients [46].

Raab also concluded that in many reports there is lack of consensus on the correct use of bifocal lenses for high AC/*A* patients and that often there may be a poor tolerance for glasses or premature presbyopia. In addition, recent studies have found that prolonged convergence at near may result in anatomic and physiologic alterations in medial rectus muscles tone [47]. Ultimately, he has chosen to reserve the surgical treatment for the over-convergence at near, for the unusual case of an extremely high distance–near disparity, and for the teenager or adult not showing likelihood that the condition will resolve.

If residual esotropia is present, miotic drops may be added for additional effect [36]. It is important to understand that the likelihood of deterioration in AE is greater in patients with a high AC/*A* ratio. Therefore, full correction should be achieved when possible [48]. Proper management of high AC/*A* includes prescription of bifocal glasses, single-vision distance lenses (SVL), and surgery [49].

As far as surgical treatment is concerned, a combined technique may be useful, with resection and recession of the medial rectus muscle for patients with excessive exothermic convergence, according to Somer et al. [50]: it is necessary to make a resection of the insertional end of the medial rectus muscles with recession from the original insertion, based on the patient's angle of esotropia at 1/3 m while wearing full cycloplegic refraction, with an additional recession for each rectus muscle based on current surgical tables. The main advantage of this technique seems to be an improvement in alignment for distance, while selectively reducing the near angle in patients with different levels of AC/*A* ratio.

Otherwise, many other surgical techniques have been proposed to treat these patients, and most are involved in increasing the magnitude of the medial rectus recession to either partially or fully correct the larger near deviation. First of all, a maximal recession of medial rectus muscles, which proved useful in correcting the near esotropia without overcorrecting the distance deviation. It was then proposed a posterior fixation sutures to reduce the excess near esotropia, without utilizing very large medial rectus recessions. The pulley posterior fixation technique takes advantage of improved understanding of the biomechanics underlying the surgical effects of posterior fixation sutures. Because the posterior fixation creates its effect through the formation of a collision between the suture and muscle pulley, the suture can be placed through the pulley tissue itself instead of the posterior sclera. This technique has been judged very effective in reducing the excess near esotropia and, in addition, can overcome the long-term risk of overcorrecting the esotropic distance [51].

Infantile accommodative esotropia

Infantile AE occurs during the first year of life. The key to diagnose this form of esotropia, according to Wright, is noting the presence of hyperopia $> 2.00D$ and a variable angle of esotropia at onset [43]. But it rarely occurs in the absence of hyperopia $< 4D$. Since both essential (congenital) infantile esotropia and infantile AE may present with an intermittent and variable angle deviation, distinguishing them may not always be straight forward [17]. In infantile esotropia, defects in the sensory mechanism and in the binocular cortical cells have been put forward as the cause of strabismus [52]. This is different from infantile AE, where sensory function and neuroanatomy of the visual cortex are presumed to be normal prior to the onset of the strabismus [53–62]. Treatment for suspected infantile accommodative esotropia should be immediate and consists of full hyperopic correction (as determined by cycloplegic refraction), as well as treatment of amblyopia, if present or suspected. If spectacles do not align the eyes within 8 to 10 PD, then strabismus surgery is usually indicated [63]. Unless spectacle intolerant, the child should wear refractive correction for at least 4 weeks prior to surgery.

Refractive surgery

Refractive surgery has become a common alternative to spectacles and contact lenses for the correction of refractive errors in adults [64]. Its use in children, however, remains controversial. There are several studies on treating refractive AE by photorefractive keratectomy (PRK) or laser in situ keratomileusis (LASIK) with different results [65–69]. One of the greatest limitations is a short follow-up duration for young patients after laser treatment. In general, the results of these studies show that in young adults, hyperopia and esotropia associated with PRAE can be corrected with PRK [70]. In theory, PRAE would be an ideal indication for refractive surgery, especially in children with developmental delay or psychiatric disorders which preclude spectacle wear [71].

Theoretical advantages of refractive surgery include the elimination of dependency on spectacles for alignment of the eyes and social benefits of not wearing spectacles. Refractive surgery, although seemingly "unnecessary," can provide the benefit of a definitive treatment for esotropia and the elimination of dependency on spectacles without the undesirable side effects of strabismus surgery. It would circumvent the issues of emmetropization and compliance. However, these procedures are rarely performed in children because of the need for general anesthesia, unpredictability of long-term refractive change, and potential complications [72]. The use of both refractive and conventional strabismus surgery in the same patient has been reported. [73].

Minghua et al. [74] recently reported a cohort of patients in which hyperopic corneal refractive surgery may improve alignment, uncorrected visual acuity, and stereopsis in patients with accommodative esotropia and amblyopia. They emphasize that in their patients with AE and amblyopia, even in the case of severe amblyopia anisometropia, they obtained satisfactory outcomes after corneal refractive surgery. In addition, their refractive surgery not only improved the uncorrected ocular alignment and visual acuity but also binocular visual function.

In response to this report, Tibrewal et al. [75] point out that, although all patients were over 14 years of age, the response to refractive surgery in very young patients could not be predictable, with a progressive increase in the non-accommodative component and loss of fusion. We agree with this group of authors, and definitely, we think that it is interesting to talking about refractive surgery in patients with AE, but it is also notable making the best possible selection of the patients to whom these procedures are proposed.

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Compliance with ethical standards

Conflict of interest The authors have no financial or proprietary interest in any product mentioned herein.

Human and animals rights This research does not involve some human participants and/or animals.

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