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REVIEW

Accommodative Insufficiency: Prevalence, Impact and Treatment Options

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Purpose: Accommodative insufficiency (AI), defined as the inability to stimulate accommodation in pre-presbyopic individuals, has gained much attention over recent years. Despite the enormity of the available information, there is a significant lack of clarity regarding the criteria for definition, methodology adopted for testing and diagnosis, and the varied prevalence across the globe. This review aims to gather evidence that is pertinent to the prevalence, impact and efficacy of available treatment options for AI.

Methods: PubMed, Google Scholar and Cochrane Collaboration search engines were used with the keywords prevalence, accommodative insufficiency, symptoms, plus lens, vision therapy and treatment. Peer-reviewed articles published between 1992 and 2019 were included in the review. After reviewing the studies for study methodology and robustness, 83 articles were chosen for this literature review.

Results: The prevalence of AI ranges between <1.00% and 61.6% across studies. The prevalence shows considerable variation across ethnicities and age groups. There is significant variation in the study methodology, diagnostic criteria and number of tests performed to arrive at the diagnosis. Not many studies have explored the prevalence beyond 20 years of age. The prevalence of AI is high among children with special needs. There is no high-quality evidence regarding the standard treatment protocol for AI. Both vision therapy and low plus lenses have shown efficacy in independent studies, and no studies have compared these two treatment options.

Conclusion: The understanding of AI prevalence is currently limited owing to the lack of a standard set of diagnostic criteria and wide variations in the study methodology. There is a lack of high-quality evidence suggesting the best possible treatment for AI. The current gaps in the literature have been identified and future scope for exploration is elucidated.

Keywords: accommodation insufficiency, amplitude of accommodation, lag of accommodation, asthenopia, vision therapy, binocular vision, accommodative facility, plus lens

Introduction

Accommodative insufficiency (AI) is a non-strabismic binocular vision anomaly that is characterized by an inability to focus or sustain focus for near vision.[1] AI is a sensory-motor anomaly, clinically manifesting as a reduced amplitude of accommodation compared to age-matched norms.[2] Although AI commonly has a non-pathological and functional origin, it may co-occur with lesions disrupting the parasympathetic pathway to the ciliary body, other systemic illnesses, neurological diseases and ocular conditions.[3] The prevalence of AI is reported to be as high as 17% of all children aged between 8 and 16 years.[4] The affected individual usually

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reports blurred near vision, headache, visual fatigue and other asthenopic symptoms. There also exists a possibility of secondary convergence insufficiency (CI) in AI, and the symptoms in these cases are predominantly due to AI.[1,5]

Various studies have spoken in length about the prevalence, diagnosis and treatment options available in AI. In this paper, we review the prevalence of the condition, diagnostic criteria, efficacy of available treatment options and gaps in the current understanding of this condition.

Methods

In this review, a systematic literature search was conducted using Google Scholar, PubMed and Cochrane Collaboration using the following keywords in various combinations: accommodative dysfunctions, accommodative insufficiency, prevalence, incidence, vision therapy, plus lens, and treatment ((“prevalence”[All Fields] OR “incidence”[All Fields] OR “diagnosis”[All Fields]) AND (“accommodative insufficiency”[All Fields] OR “accommodative dysfunction”[All Fields] OR “vision therapy”[All Fields]) OR “plus lens”[All Fields])).

All the pertinent articles were thoroughly assessed and their reference lists checked to retrieve further articles that are of importance to the review. The search was conducted separately by two independent reviewers (authors JRH and AM). On removing repeated articles from the review, we chose 83 peer-reviewed articles that are of relevance to this review paper. Studies involving epidemiology, diagnosis and treatment of AI were selected; only studies published in English were reviewed. For studies involving treatment options, prospective studies were chosen, and studies published after 2000 were given precedence. No attempt was made to recover unpublished articles.

Study Selection

For prevalence analysis, cross-sectional or cohort studies published between 1992 and 2019, involving a hospital- or community-based sample, with a definition for AI were chosen. No cut-offs for sample size or age range were set for the review. One very old study, published in 1897,[6] was also included as this was a seminal work that discussed non-strabismic binocular vision dysfunction in the context of characterizing it into vergence, accommodation and oculomotor dysfunction. To report the prevalence of accommodation insufficiency, the prevalence stated by the study is reported as such, along with the number of diagnostic criteria used for defining AI. Studies were excluded if the definition or diagnostic criteria were not mentioned. Studies that discussed generalized accommodation weakness, ill-sustained accommodation and accommodation fatigue were excluded. To assess the efficacy of treatment options in AI, studies that adopted a definition for AI along with a clear definition of the treatment were included. No restriction was placed on the type of study design and sample size.

Definition of Accommodation Insufficiency (AI)

Various studies have adopted different definitions for AI. The most common definition states that AI is a non-strabismic binocular vision anomaly characterized by an inability to focus or sustain focus at near distance.[1] Cacho et al defined AI as a condition in which the patient has difficulty stimulating accommodation.[2] Wahlberg et al defined AI as a condition in which the amplitude of accommodation as measured with push-up accommodative stimuli is constantly below the lower limit of the expected amplitude for the patient’s age.[7] Most studies have adopted a primary criterion of 2 diopters lesser than Hofstetter’s minimum expected amplitudes for age.[2,5,8-10] The complementary signs include monocular accommodative facility <6 cpm with −2.00 D lenses, binocular accommodative facility <3 cpm with −2.00 D lenses, lag of accommodation >0.75 D in monocular estimate method (MEM) retinoscopy and a positive relative accommodation <1.25 D.[2,8,10,11]

Prevalence of AI

The prevalence of AI in the published literature ranges between <1%[8] and 61.7%,[12] and this vast range could be attributed to the differences in sample characteristics including age, diagnostic criteria used, sample size, study methodology,[13] varied near-work demand[9] and ethnicity (Table 1). Dwyer in 1992 reported the prevalence of AI to be 8% among children in the age group 6– 17 years.[14] In 1996, Scheiman et al reported a prevalence of 2% among the age group 6 months to 18 years in a hospital-based setup.[15] In 1999, Rouse et al reported a prevalence of 11.5% among children in the age group 9–13 years.[16] A hospital-based study on asthenopic patients found a prevalence of 3%.[17] The prevalence of AI in an adult population was shown to be 6.2% in people with Caucasian ethnicity. Among college students, the prevalence of AI was reported to be 4.07% and 4.5% in Iran and South Africa, respectively.[18,19] A school children-based study in southern India reported a low prevalence of 0.2%[8] and this

Table 1 Summary of Selected Studies for AI Prevalence

Authors (Publication Year)	Sample Size	Diagnostic Criteria	Sample Characteristics	Country	Prevalence (%)	Standard Test Instruction Given (Yes/No)	Details of Refractive Correction Provided (Yes/No)	Tests Done for Diagnosis
Dwyer (1992)[14]	144	AI-5	School children (7–18 years)	USA	8	No	Yes	NPA, NRA, PRA, MAF, BAF, MEM
Scheiman et al (1996)[15]	2023	AI-7	School children (6–18 years)	USA	2	No	Yes	NPA, PRA MAF, BAF, MEM
Porcar and Martinez-Palomera (1997)[10]	65	AI-7	College students (18–19 years)	Spain	6.2	No	Yes	NPA, PRA, MAF, BAF, MEM, FCC
Rouse et al (1999)[16]	453	AI-2	Children (9–13 years)	USA	11.5	No	Yes	NPA, MEM
Cacho et al (2002)[2]	328^	AI-6	Symptomatic clinic population	Spain	12.5	No	Yes	NPA, PRA, MEM, MAF, BAF
Borsting et al (2003)[29] $	392	AI-2	School children (8–15 years)	USA	10.5	No	Yes	NPA, MEM
Sterner et al 2006)[9] $	72	AI-1	School children (5–10 years)	Sweden	33.3	Yes	Yes	NPA
Marran et al 2006)[5] $	299	AI-1 and 4	Elementary school children (mean [SD] age: 11.5 [6.3] years)	USA	AI-1: 4.7 AI-4: 3.3	No	Yes	NPA
Hussaindeen et al (2016)[8]	920^	AI-8	School children (7–17 years)	India	0.2	No	Yes	NPA, MAF, MEM
Davis et al 2016)[4] $	484	AI-1 and 4	School children (8–16 years)	USA	17.8	No	Yes	NPA
Wajuihian and Hansraj 2016)[19]	1201^	AI-6	High-school students (13–19 years)	South Africa	4.5	No	Yes	NPA, PRA, MAF, BAF, MEM
Hashemi et al 2019)[18]	726	AI-6	University students (18–22 years)	Iran	4.07	Yes	Yes	NPA, PRA, MAF, BAF, MEM
Nunes et al (2019)[20] $	292	AI-3	School children (10–14 years)	Portugal	6.8	No	Yes	NPA, MAF
Abdi and Rydberg 2005)[12]	120	AI-1	School children (6–16 years)	Sweden	61.6	No	Yes	NPA

Notes: ^A priori sample size estimation. [9] Convergence Insufficiency Symptom Survey (CISS): Nunes et al (2019),[20] Davis et al (2016),[4] Marran et al (2006),[5] Borsting et al (2003); [$]Use of other symptom surveys: Sterner et al (2006).[29]
Criteria for AI diagnosis: 1) Push-up monocular AA at least 2 D below Hofstetter's calculation for minimum amplitude: 15–0.25 × age (years); 2) High values on monocular estimation retinoscopy >+0.75 DS; 3) Fails monocular AF testing with −2.00 D < 6 cpm; 4) AI with co-morbid CI; 5) Monocular AA below Hofstetter's calculation for minimum amplitude: 15–0.25 × age (years); 6) PRA <−1.25 DS; 7) Push-up monocular AA below age-expected norms for the population: 16–0.3 × age (years) with complaints of near blur.
AI-1: Criterion 1 is used as the only diagnosis; AI-2: Criteria 1 and 2 are used together; AI-3: Criteria 1 and 3 are used together; AI-4: Criterion 1 is used for AI diagnosis along with a diagnosis of co-morbid CI; AI-5: Criterion 5 is used without additional details; AI-6: Three criteria are used (Criteria 1, 2 and 3); AI-7: Four criteria are used (Criteria 1, 2, 3 and 6); AI-8: Criteria are used as mentioned.
Abbreviations: NPA, push-up near point of accommodation; NRA, negative relative accommodation; PRA, positive relative accommodation; MAF, monocular accommodative facility; BAF, binocular accommodative facility; MEM, monocular estimation method; FCC, fused cross-cylinder testing.

study questioned the validity of accommodation amplitude norms adopted for difference ethnicities. A study in 2019 estimated the prevalence to be in the magnitude of 6.8% among school children in Portugal. The literature has reported AI and CI to be co-morbid conditions, with prevalence ranging between 1.9% and 14.7%.[20]

Children with developmental dyslexia in general show an increased prevalence of visual deficits including accommodative dysfunction,[21] and the prevalence of AI in children with learning difficulties was reported to be 26%.[22] Similarly, children with Down syndrome are found to have poorer accommodative amplitudes for their age, resulting in a high prevalence of AI ranging between 55% and 76%.[18,23-27]

Although all these studies were primarily cross-sectional in nature and conducted on student populations at school or university level, there is a vast heterogeneity across studies. The huge variation in the sample size and methodological differences are potential confounders limiting the comparison of prevalence statistics. Future studies should focus on standardizing the methodology with an a priori-based sample size estimation.

Symptomatology in AI

Asthenopia is the commonest reported symptom in AI.[9,12,28,29] The asthenopic symptoms can be diverse, ranging from chronic blurred vision, headache, eyestrain, reading difficulties, visual fatigue, sleepiness, loss of comprehensionand movement of print, to avoidance of reading and other close work.[30–33]

Various studies have shown high correlations between asthenopic symptoms and AI.[9,12,34] A Swedish school children-based study examining 216 children of grades 1–8 reported asthenopic symptoms among 23.1%, of which 11.1% had abnormal near point of accommodation. Earlier studies in children with lower accommodative amplitudes showed that the subjects had severe difficulty reading near text for long hours, diplopia and severe asthenopic symptoms.[5,9,35,36] Sucher and Stewart (1993) reported abnormal accommodation functioning resulting in increased effort reading and troubled academic progress.[36] Sterner et al in 2006 studied the relationship between subjective symptoms and reduced accommodative amplitude among children in the age group 6–10 years. This study concluded that headache and asthenopic symptoms were the most appreciated symptoms, followed by floating of text and accommodative facility issues.[9] Another study, carried out among 299 elementary school children, stated blurring of words, rereading or trouble following words, double vision and headache as the most common symptoms.[5] The same study group also compared the symptom scoring between CI, AI, CI with AI and other non-strabismic binocular vision dysfunctions, and reported that AI and CI with AI had elevated symptoms compared to only CI and other non-strabismic binocular vision issues. Table 2 summarizes the symptoms in AI as reported by various studies.

Other Associated Signs and Symptoms

A decreased range of cervical motion and neck pain have been reported as co-occurring symptoms in accommodative dysfunctions.[37,38] The common sympathetic innervation link that is shared with the accommodation system is proposed as one possible reason for this. Nonetheless, neck pain can also be secondary in AI owing to abnormal neck and head retractions during reading resulting from

Table 2 Symptomatology in AI as Reported by Various Authors

Authors (/Year)	Symptoms Reported in AI					Symptoms Related to Academic Performance			
	Blurred Near Vision	Headache	Double Vision	Eye Strain	Facility Problem	Difficulty with Continuous Reading	Fatigue	Avoiding Reading	Downward Academic Progress
Marran et al (2006)[5]	√	√	√						
Sterner et al (2006)[9]	√	√			√		√		
Schieman and Wick2008)[31]	√	√		√		√	√	√	
Borsting et al2003)[29]	√							√	√
Abdi and Ryderg 2005)[12]	√	√							√
Chase et al (2009)[37]								√	√

the visual fatigue and blur. This emphasizes the need to investigate associated musculoskeletal symptoms in patients presenting with accommodative dysfunctions.[39]

It is also important to understand the association between psychosocial concerns and accommodative dysfunctions, as children and younger adults may not be able to express in words psychological concerns that can manifest physically as ocular symptoms.[40,41]

Visual Analogue Scales

Visual analogue scales (VASs) are utilized to estimate the degree of severity of pain and discomfort. Abdi et al (2006) graded asthenopic symptoms of AI using a VAS and compared the scoring pre- and post-AI treatment. The subjects with normal binocular vision reported VAS scoring in the range of 0–2, while subjects with AI reported VAS scoring in the range of 6–10. The same study also showed improvements in the VAS score after 12 weeks of near addition in 89.8% of subjects, and the mean scoring dropped to 0–2 from 6–10.[42] Chase et al used the Conlon visual discomfort scoring, and suggested that a Conlon score of 27 and above accurately predicted AI in 78.3% of subjects with 75% sensitivity and 80% specificity.[37]

Clinical Testing for AI

Assessment of accommodative parameters in individuals enables investigators to determine whether the given parameter is within the normal range based on data from age-matched controls. Various tests, such as near point of accommodation (NPA), positive and negative relative accommodation, accommodative facility, accommodation lag estimation using MEM retinoscopy[43] and near point of convergence (NPC), are utilized in the diagnostic process. NPC is used to identify any co-existing CI with AI.

Near Point of Accommodation

The early literature considered accommodative amplitude based on NPA measurement as the primary and the only diagnostic criterion for AI.[7] The push-up method has been accepted as a standard procedure, where a near stimulus equal to or one line better than the best corrected near visual acuity is brought closer to the subject until a sustained blur is noted. The distance measured in centimeters (cm) is converted to dioptric form to represent the amplitude of accommodation (AA).[35] The test is done both monocularly and binocularly. NPA measurements can also be done using other methods apart from push-up, such as push-down, minus lens and open-field autorefractors.

Repeatability of the NPA measurement is necessary to monitor change in AA during the course of treatment. It is said that the push-up method tends to overestimate accommodative amplitude, followed by the push-down and minus lens methods.[44] The agreement between the three tests has also been reported to be poor, with large test–retest variability. However, the repeatability of the push-up and push-down methods showed agreement in a Ghanaian population.[45]

Chase et al[37] suggested that objective measures of accommodation be utilized to diagnose AI, as repeated measures of accommodation testing can elicit accommodation fatigue that would not be detected otherwise in routine testing. The WAM-5500 is an infrared-based open-field autorefractor that provides objective static and dynamic measures of accommodation. It is found to show superior sensitivity and high reliability and repeatability compared to subjective testing. Thus, it is proposed as a valuable clinical tool to objectively quantify accommodative amplitude and dynamics.[46] Objective testing of the accommodation response for extended periods of time using instruments such as the WAM-5500 can help the clinician to diagnose and differentiate between ill-sustained accommodation and accommodation insufficiency.[47] However, the availability of the WAM-5500 in clinical practice is currently limited, making the push-up method the standard and most feasible approach to measuring NPA.

Hofstetter, using Duane's and Donders' data, proposed equations for minimum, average and maximum expected AA across ages as 15–0.25 × age, 18.5–0.3 × age and 25–0.4 × age, respectively.[48–50] Abu et al compared AA by the push-up, push-down and negative lens methods with AA values calculated from Hoffstetter's formula, and suggested that AA measured through the push-up method was close to the calculated AA using Hofstetter's equation.[45] Hashemi et al measured AA in 5620 children and found that the mean AA among examined children was much less than that calculated from Hoffstetter's formula, and also observed that myopes showed greater AA compared to emmetropes and hyperopes.[51] They also added that the push-up method depends on participants' comprehension, which limited its validity among younger children. Amplitude of accommodation in Ghanaian school children aged between 8 and 14 years measured through the push-up method was different from that of Hofstetter's formula.[50,52] Similar findings of differences between norms proposed by other ethnicities[53] were reported in the Indian population as well.[43,54] The findings from many of these studies raised questions about the applicability of Hofstetter's equation to a wide range of ethnicities, emphasizing the need for indigenous population-based norms.

Castagno et al (2017) proposed that the median and percentile ranks are better estimates to represent AA so that outliers do not influence the values. Based on this study, conducted among South African school children, it can be concluded that ethnicity-based norms are required to be able to interpret accommodation parameters, rather than relying on Hofstetter's equation.[55]

It is also interesting to note that there exists diurnal variation in AA among normal subjects, with greater differences in younger adults, who show better amplitudes in the afternoon hours.[56] This brings another variable into the existing factors that can influence accommodation. Future studies need to consider this aspect while measuring AA; also, there is a lack of understanding as to how diurnal variability can impact AA in accommodative dysfunctions.

Other Tests Relevant to the Diagnosis

The battery of tests that are pertinent to diagnosing accommodative dysfunctions can be brought together under broader categories of assessment of amplitudes, response and dynamics. Assessment of accommodation response is another key aspect in understanding the severity of the accommodation insufficiency by using the lag of accommodation as an indicator. MEM retinoscopy is considered a standard clinical technique to measure the accommodative response of the visual system. It is performed by quickly neutralizing the retinoscopy reflex when the subject reads the appropriate near stimuli placed on the plane of the retinoscope. The accommodative response generally shows a lag in the order of +0.4±0.2.[43] A high lag of accommodation >+0.75 DS can be suggestive of AI.[2,8,10]

Nott retinoscopy is another method that is used to estimate accommodative response by varying the testing distance to find the neutrality point for the accommodation response instead of using lenses. Del Pilar Cacho et al (1999) compared Nott and MEM retinoscopy in 50 subjects and showed a statistically significant difference between the techniques, with MEM showing a much higher lag of accommodation.[47] As the use of additional lenses in MEM retinoscopy could change the blur-driven response, manipulating the true value, Nott retinoscopy is considered to show more reliable and consistent responses.[36,57,58]

Objective measurement of accommodative response can be carried out using open-field autorefractors. In a study that compared subjective (MEM retinoscopy) and objective measures (WAM-5500) of accommodative response and its correlation with visual discomfort, objective measures of accommodation as measured using the Grand Seiko WAM-5500 were found to be more reliable and showed better correlation with visual discomfort.[58–60]

Relative accommodation and accommodation facility are utilized to understand the agility or flexibility of the accommodation system. The expected normal values for negative relative accommodation (NRA) are less than or equal to +2.50 DS and positive relative accommodation (PRA) is ≥−2.50 D. In AI, the proposed cut-off point for PRA according to various studies is <−0.75 DS.[31] In accommodation facility testing, a +2.00/−2.00 DS lens at 40 cm is recommended as a standard testing method. Most studies have shown reduced accommodative facility with difficulty in clearing minus lenses in AI.[2,8,18–20]

The amplitude scaled facility[61] is considered to have better sensitivity over the standard ±2.00 DS in differentiating symptomatic and asymptomatic adult subjects. In the amplitude scaled facility testing, the magnitude of the accommodative flippers and the testing distance are scaled based on the accommodative amplitudes. Based on an experiment conducted with 19 healthy adults using 36 different combinations, the 45% distance demand and 30% power range showed the highest correlation with symptom scores and was recommended over the standard ±2.00 DS testing at 40 cm.

Diagnostic Criteria

Duane's classification is one of the earliest classification systems used to group non-strabismic binocular vision anomalies based on phoria and the accommodative convergence to accommodation ratio (AC/A).[6,31] This classification system categorizes accommodative dysfunctions into accommodative insufficiency, accommodation excess, ill-sustained accommodation, inertia of accommodation, inequality of accommodation and paralysis of accommodation. Many authors have adopted this classification system with minor modifications (Table 1).

Diagnostic Signs and Complementary Signs

In a study that evaluated the frequency of AI with different diagnostic criteria, a prevalence of 41.95% was reported when only AA was used a single criterion compared with 6.34% when both AA and MAF ≤6 cpm were considered, 2.93% when AA, MAF ≤6 cpm and BAF ≤3 cpm were taken into account, and 1.95% when AA, MAF=0 cpm and BAF=0 cpm were considered.[13] This points to the fact that using AA as the sole criterion results in overestimation of the prevalence. Therefore, using both diagnostic and complementary signs results in better sensitivity in the estimation of AI prevalence. In summary, the vast majority of studies have utilized the following approach of definite and complementary signs to diagnose AI. The confirmatory diagnostic sign is AA 2 D less than the Hofstetter's minimum expected amplitudes for a given age. Other complementary signs include reduced monocular (≤6 cpm) and binocular (≤3 cpm) accommodative facility with minus lens difficulty, increased lag of accommodation (MEM ≥+0.75 DS) and reduced PRA ≤−1.25 DS.

Differential Diagnosis of AI

Differential diagnosis of AI is immanent to the clinical decision-making process. AI can occur in certain primary ocular diseases (eg Adie's tonic pupil, iris sphincter tear), generalized systemic (eg anemia, mumps, measles) and neurological disorders (eg syphilis, meningitis), and lesions disrupting the parasympathetic innervation of the ciliary body.[31] A few systemic and ocular drugs are also known to impair accommodation.[3] Thus, a detailed history taking eliciting the possible etiological associations is important before clinical management options pertinent to AI are proposed.

What Can Trigger Accommodative Dysfunctions?

The etiology behind AI is poorly understood.[63] Additional inhibitory mechanisms related to the sympathetic pathway are considered as a possible hypothesis,[62] while phasic dysfunction of the accommodative system is another commonly accepted hypothesis for accommodative dysfunctions.[63–65] This hypothesis also explains the additional tonic dysfunction in accommodation anomalies.[64] Some studies that have shown improvements in phasic accommodation with treatment for AI add evidence to the phasic hypothesis.[65]

Smartphone and laptop use almost tripled from the 1990s to 2010. Studies have shown that mobile phone use for more than 20 minutes results in reduced AA and accommodative facility, and increased lag of accommodation.[66–68] Accommodative parameters tend to show more reduction with gadgets compared with paper work at comparable working distances.[68] Digital eye strain and associated accommodative dysfunctions with increased gadget use remain potential areas for further exploration.[69,70]

Efficacy of Treatment Options in AI

AI, being a condition affecting the ability of the eyes to stimulate accommodation, is prone to cause symptoms pertaining predominantly to reading and near work. The sequential management approach to treating AI includes correction of ametropia, added lenses and vision therapy.[3,31]

Any amounts of uncorrected hyperopia can potentially impact the accommodation system, inducing accommodative fatigue. The primary management consideration in any accommodative dysfunction would be to address the role of uncorrected ametropia. Near addition plus lenses, vision therapy and accommodative facility training are the most commonly recommended and practiced treatment options.[71]

Plus Lenses

Near addition plus lenseswork by reducing the near accommodative demand and restoring the accommodation amplitudes to normal ranges with the lenses in place. Abdi and Rydberg (2005) assessed the symptoms with plus lens additions (+0.75 DS and +1.00 DS) on 49 children aged 7–16 years, and found reduced symptoms among 98% of the study sample during the 12-week treatment period.[12] In a case series that evaluated the efficacy of +1.00 DS reading addition on reading speed, it was reported that plus lenses significantly restored the accommodation parameters to normal limits, but did not show any significant improvements in reading speed.[72]

Wahlberg et al (2010), in a similar study, measured AA, and accommodation response with +1.00 DS or +2.00 DS near addition randomized to 11 subjects each. During the 8-week follow-up, the +1.00 DS treatment group showed an increase in AA and reduction in symptoms score measured using a VAS, compared to the +2.00 DS addition, which did not improve the AA. This study recommended that minimum amounts of near addition would be beneficial in restoring accommodation amplitudes to a level enabling near visual activities with the therapeutic lenses, yet creating a small residual blur adequate enough to stimulate and exercise accommodation.[7]

It is important to note that the study samples were considerably small in all these studies, limiting the understanding of the true efficacy of plus lenses and whether they served as a treatment or a correction. What remains unclear in all these studies is the sustainability of the restoration of accommodation amplitudes after discontinuation of the therapeutic lenses, and the duration required for the continuation and cessation of treatment.

Vision Therapy

Vision therapy or orthoptic therapy remains the most recommended treatment option for AI. It involves purposeful manipulation of blur, proximity and disparity, with the objective of normalizing the accommodative system.[73] In his review of the effectiveness of vision therapy for accommodative dysfunctions, Rouse concluded that:[74,75]

- Vision therapy is an efficacious option to treat accommodation dysfunctions and the literature supports the same
- Vision therapy plays an important role in improving both the signs and symptoms, and these improvements are fairly stable following the discontinuation of treatment
- Vision therapy does modify the physiologic accommodative responses accounting for placebo effects.

Hoffman et al,[76] Weisz[77] and Wold et al,[78] in the 1970s, investigated the role of in-office vision therapy in improving accommodative dysfunctions, and suggested that vision therapy is efficacious in improving accommodative parameters. These studies included binocular vision dysfunctions in general and thus lacked the discrimination of subjects specifically with AI, and also gave few or no details regarding the in-office vision therapy protocol. Daum (1983), in a retrospective review of 114 subjects, studied AA, AC/A, stereopsis, fusional range, phoria, accommodative facility and lag of accommodation following 10–15 minutes of home-based vision therapy three times a day. This study reported that 96% of the study sample had partial improvements while 53% achieved complete resolution.[11] Similarly, Hung et al in 1986 studied tonic accommodation, facility, AC/A ratio, convergence accommodation to convergence ratio (CA/C) and fixation disparity with in-office vision therapy, and reported improvements in both accommodative facility and symptoms score.[79] This study included a total of 21 symptomatic subjects, of whom only six subjects had a pure accommodative dysfunction. The therapy sessions included training for accommodation facility with ±2.00DS lenses, jump focus and computer vergence training as 30-minute in-office vision therapy sessions weekly combined with daily 15-minute home-based vision therapy. Sterner et al (2001) compared the efficacy of accommodative facility training using a ±2.00 DS accommodative flippers group against a Plano flippers sham group. This study had just 13 children who were further randomized to one of these treatments, which reported that ±2.00 DS lens training has true efficacy in improving accommodative facility.[80]

As part of the CI treatment trial, Scheiman et al[81] compared the efficacy of in-office vision therapy combined with home reinforcement, home-based computer vision therapy, home-based pencil push-up and placebo treatment in improving accommodation parameters in a subgroup of 63 children aged 9–17 years who had reduced AA. At 12 weeks of treatment, the in-office vision therapy group showed significant improvements in accommodative amplitudes compared to the other treatment arms, which were both clinically and statistically significant. At completion of treatment after 1 year, 12.5% of the study sample showed regression of accommodation amplitudes. This is the only randomized clinical trial (RCT) that evaluated the treatment efficacy in AI, but it is important to note that the efficacy of near addition plus was not assessed as part of this study. Also, as study inclusion was based on AA as the only criterion, it cannot be extrapolated to subjects who have more severe symptoms.

A novel optical dichoptic vision therapy software which works on the principle of purposeful manipulation of the optical and vergence system was proposed and tested on 14 female university students aged 19–22 years. The authors measured accommodation contraction and relaxation times with 90 seconds of optical training compared to a closed eye rest control group, and reported that the accommodation contraction, relaxation times and eye fatigues scores were improved in the intervention group. The clinical application and feasibility of this novel protocol are yet to be explored.[35]

Vision Therapy with Combined Plus Lens

In a small sample of 19 children with a mean age of 10 years randomized to home-based ±1.50 DS accommodative flipper training and +1.00 DS reading addition, improvements in accommodative amplitudes and symptoms were reported in both the treatment arms, with better improvements in the facility group.[82] Again, interpretation of the results of the study is limited owing to the small sample and the large number of dropouts in the accommodative facility group, potentially indicating issues with compliance. Another case series reported near addition to be more beneficial than vision therapy in improving accommodative amplitudes and symptoms in a pre-presbyopic sample with AI.[71]

Except for one RCT,[81] the rest of the studies had potential issues related to study design, and all studies had issues with limited sample size. This therefore remains a potential area for further investigation and understanding.

Discussion

AI is a non-strabismic binocular vision anomaly that is characterized by an inability to focus or sustain focus for near vision in the pre-presbyopic age group. The prevalence of AI ranges between <1% and 61.7%[8,12] in various studies, and this wide range could be attributed to differences in study methodology and sample characteristics, including age, diagnostic criteria used, sample size, varied near work demand and ethnicity.

The diagnostic criteria used to define a particular dysfunction remain the key aspect to studies that are focused at characterizing the disease and arriving at the prevalence estimates. This seems to be the key issue in studies that provide the prevalence data for AI. Another confounding factor could be the subjective nature of the tests, bringing in variability to the accuracy of the diagnosis. The confounding factors affecting the prevalence estimates can be broadly classified as related to the sample size and sampling-related concerns, criteria for clinical tests, standardized diagnostic criteria and/or related to subjective factors. All these are potential methodological concerns that need to be addressed when the study protocol is planned.

Sample size concerns in these studies were related to issues with lack of information related to sample size calculation, which ideally should be done before the execution of the study. Only three studies[2,8,19] mentioned an a-priori sample size calculation, and in general studies that provided prevalence estimates had sample sizes ranging between 65[11] and 2023[16] subjects, resulting in a wide range of prevalence. Among the epidemiological studies, it was also surprising to see really low sample sizes in a few studies,[10,11] which again could have potentially inflated the prevalence measures. Addressing the sampling-related issues, it is important to align the sampling strategy with the proposed objectives of the study. Unfortunately, not many studies provided the sampling strategy, and one study[2] focused on a symptomatic clinical sample, which is known to influence the prevalence measures. Differences in the educational background, socio-economic status, rural–urban differences and age range included are potential factors that were not addressed in detail in most of the studies. These factors would result in a gap in the understanding of the prevalence estimates, limiting the ability to extrapolate the results to samples with similar characteristics.

In the standard diagnostic criteria, using a symptom questionnaire to characterize the symptoms, definition of the number of tests included in the diagnostic criteria and the cut-off point used will influence the prevalence. Only five studies used a questionnaire (Table 1) to characterize the symptoms, and the majority of studies relied upon the general clinical symptom of reporting blur.[4,5,9,20,29] Moreover, the presence of uncorrected refractive errors is known to influence the estimation of accommodation and vergence parameters. This again explains the considerable variability in the studies (Table 1), limiting the understanding of the true prevalence estimates. The number of diagnostic criteria and their respective cut-off points will have great implications for improving the diagnostic accuracy, and this has to be explored in detail in future studies.

There seems to be a huge gap in the availability of normative data for accommodation parameters for various ethnicities. There is a question as to the requirement for specific normative data sets for individual ethnic groups. Although there is a gap in the understanding of what could potentially influence the parameters across ethnicities, beyond the impact of humidity, climate, altitude, etc,[8,83] it could be argued that epigenetics plays a role in modulating the development of vision and thus impacting the functional characteristics. The varying range of myopia prevalence, for example,[84] is a potential clue that drives the need to address these concerns. It is equally important to reinvestigate certain aspects of structure and function every decade, to be able to understand the rapidly changing landscape of urbanization and its impact on lifestyle. With pandemics such as the coronavirus disease-2019 (COVID-19), there are increasing concerns of a spike in digital eyestrain and an increased prevalence of myopia.[85] Accommodation-related issues are nonetheless no exception in this regard, and need attention and investigation.

With regard to subjective factors, aspects of the subjects' understanding of the tests carried out, and clarity regarding what is expected of them, need to be considered. The concept of blur has been adequately debated in the clinical context. There exist more sources of inherent errors in the measurement techniques used to evaluate accommodation.[86] This, compounded with subjective factors, can lead to erroneous results. In general, the nature of the tests, that is, what is expected from the subject in their response; the speed and repetition of the tests, which are relevant for most binocular vision dysfunctions; and the endpoint of the test, defined through a standard set of instructions regarding what indicates sustained blur, can potentially influence the endpoint of the test and therefore the diagnosis. A standard set of written instructions for the clinician in this regard would reduce the variability to a great extent. Using objective measures to characterize the dysfunction would also improve the quality and validity of the diagnostic process. The subjective symptom of blur needs to be given serious consideration in studies that evaluate accommodation dysfunctions.

Blur could result from various causes, such as uncorrected refractive error, compromised image quality due to poor contrast or legibility, glare, associated strabismus, and anomalies of binocular vision such as CI and other accommodative dysfunctions such as ill-sustained accommodation or infacility of accommodation.[30,31] Thus, determining the primary etiology of blur is a key component in ascertaining the diagnosis of AI. Increased smartphone or gadget use and digital eyestrain have been proposed as risk factors for accommodative dysfunctions[66–70] in general, and thus require attention. Children with special needs and Down syndrome are at high risk for AI and require mandatory assessment of accommodation functions.[23–28] The time of examination for assessing the accommodation amplitudes also needs to be standardized and documented, considering the diurnal variability aspect of accommodation;[56] however, this needs to be explored further.

The use of a standardized symptom questionnaire should be part of the standard diagnostic criteria to understand the true impact of these dysfunctions on the vision-related quality of life. The symptom survey should also consider documentation of digital device use, dry-eye related symptoms, ergonomic symptoms and other psychosocial concerns that could provide the clinician with a holistic approach to diagnosis and management. The use of a standardized symptom survey will also enable the assessment of change in symptom scores during longitudinal follow-ups and pre–post vision therapy. Another area that needs more research is the impact of these dysfunctions on academic performance in children. There is evidence showing a higher proportion of AI in children with special needs,[23–28] but this needs to be explored further through standardized assessment of academic and reading performance as part of the assessment and treatment process. A 2019 RCT by the Convergence Insufficiency Treatment Trial: Attention and Reading Trial (CITT-ART) study group showed that vision therapy for CI did not improve reading performance on standardized reading tests.[87] Therefore, this aspect needs further exploration in the field of AI.

Treatment of AI involves the use of near addition plus lenses, vision therapy and combined optical therapy with vision therapy. Based on the current review, there is no clear evidence on the best treatment protocol. Yet, near addition plus lenses, and in-office or home-based vision therapy have proven to be efficacious options in improving symptoms.[31,80–82] In-office vision therapy has shown improved efficacy over home-based vision therapy and placebo therapy.[81]

When it comes to evaluating the efficacy of a standard treatment option, a variety of confounding factors need to be taken care of. These include, but are not limited to, the effect of placebo treatment, the motivation levels of the clinician and patient, instructions provided during the treatment, implied expectations and attention effects. Unfortunately, there exists a huge gap in knowledge and there is no high-quality evidence suggesting the best possible treatment option in AI. Based on the current evidence, low plus lenses and vision therapy have been used as independent treatment options in various studies, with a lack of a control group. The small sample size and the narrow age range further limit the extrapolation of these results to a larger clinical sample (Table 3). Based on the current recommendations, the selection of near addition needs to be based on the baseline accommodation parameters, and a minimum addition is recommended to begin with. Appropriate follow-up is required to understand whether the near plus lenses work as a treatment or a correction. RCTs are shown to provide the highest quality of evidence to assess the efficacy of a treatment regimen. The only RCT[81] in this area compared the efficacy of vision therapy with a placebo treatment, and the efficacy of plus lenses was not part of the comparison group in this study. Although the use of near addition plus lenses is proposed as the primary treatment option in AI,[31] it is logical that the severity of AI, based on the clinical signs and symptoms, will drive the treatment options. A subject with significant near blur who is unable to cope with near visual demands may need added plus lenses before advancing to vision therapy. Thus, it is also important to categorize the severity to be able to propose appropriate treatment

Table 3 Studies Assessing the Efficacy of Interventions for AI

Authors (Year)	Sample Size	Age Group (Years)	Treatment Groups and Comparisons	Control/ Placebo Arm (Yes/No)	Treatment Period	Outcome Measures
Daum (1983)[11]	144	12–37	Monocular and binocular push-up accommodation training (3 times/day), accommodative flippers (± 1.50 DS) (3 times/day)	No	3–14 weeks	• 96% of subjects showed partial improvement in both symptom relief and AA • 53% showed complete improvement in AA and symptom relief
Hung et al (1986)[79]	21; Only 6 had an accommodative dysfunction	18–24	In-office (±2.00 D flipper; jump focus and computer vergence training); Home orthoptic training(±2.00 D flipper)	No	30 minutes in-office orthoptic training + 15 minutes home orthoptic training/week	• Increase in flipper rate (p<0.001) • Improvement in tonic accommodation (p=0.011) • Normalizing of near fixation disparity curve (p=0.0011)
Sterner et al (2001)[80]	13 (7 in orthoptic group and 6 in sham group)	6–17	Accommodative flippers (±2.00 D) (2 sessions of 9 minutes each day for each day for 3 weeks)	Yes	5 weeks	• Orthoptic group showed improvement in accommodative flipper speed and relief in symptoms when compared to placebo
Wahlberg et al (2005)[7]	22; (11 (+1.00 D) and 11 (+2.00 D))	7–17	Plus lens (+1.00 D vs +2.00 D)	No	8 weeks	• Improvement in AA by 3.28 D (+1.00 D group) and by +1.36 D (+2.00 D group) • Improvement in visual analogue scale (VAS) for symptoms by 3.21 units (+1.00 D group) and by 5.57 units (+2.00 D group)
Abdi and Rydberg (2005)[12]	49	6–16	Plus lens of +0.75 D and +1.00 D	No	12 weeks	• 48 subjects were symptom free (97.95%) • 1 subject had reduced symptoms
Abdi and Rydberg (2005)[12]	3 (AI with CI)	6–16	CI exercise (pencil push-up 5 times/day) with +0.75 D plus lens	No	12 weeks	• 2 subjects were symptom free • 1 subject had reduced symptoms
Abdi et al (2007)[72]	12	8–16	Plus lens (+1.00 D)	Yes (3 control)	8 weeks	• Significant improvement in AA in subjects when compared to controls (p<0.001) • No change in reading speed with +1.00 D lens (p=0.28)

(*Continued*)

Table 3 (Continued).

Authors (Year)	Sample Size	Age Group (Years)	Treatment Groups and Comparisons	Control/ Placebo Arm (Yes/No)	Treatment Period	Outcome Measures
Brautaset et al (2008)[82]	19 (10 in plus lens group and 9 in vision therapy group)	7–14	+1.00 DS plus lens and accommodative flippers (±1.50 D)	Plus lens vs accommodative flipper	8 weeks	• Both groups showed improved AA, accommodative flipper group showed greater improvement ($F_{2,34}$=6.97, p=0.003) • Both groups showed improvement in facility, with accommodative flipper group showing better results [$F_{1,17}$=3.96, p=0.06]
Scheiman et al (2011)[81]	121 with accommodation dysfunctions (63 had a diagnosis of AI) (30 into office-based orthoptic, 27 into home-based orthoptic and 28 into placebo)	9–17	Home-based orthoptic therapy (pencil push-up, accommodative rock, jump duction); Office-based orthoptic therapy	Yes (compared with office-based placebo)	12 weeks	• Improvement in AA by both office-based orthoptic (2.00 D, p=0.02) and home-based orthoptic (2.00 D, p=0.037) when compared to placebo • Improvement in facility was noted in office-based orthoptic (4.4 cpm, p=0.0001) after 8 weeks of treatment and home-based orthoptic (2 cpm, p=0.002) when compared to placebo

options. Also, the mode of refractive correction, such as spectacles versus contact lenses, and its impact on accommodative parameters in accommodation dysfunctions such as AI remains unexplored. In general, further RCTs and well-designed and well-conducted studies are required to provide high-quality evidence.

Conclusions

The prevalence of AI shows considerable variation across ethnicities and age groups. The understanding of AI prevalence is currently limited owing to the lack of a standard set of diagnostic criteria and wide variations in the study methodology. There is a lack of high-quality evidence suggesting the best possible treatment for AI.

Disclosure

The authors report no conflicts of interest in this work.

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