• Clinical Research •

The role of clinical diagnosis criteria on the frequency of accommodative insufficiency

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Abstract

• AIM: To estimate and compare the frequency of accommodative insufficiency (AI) within the same clinical population sample depending on the type of clinical criteria used for diagnosis. Comparing the frequency within the same population would help to minimize bias due to sampling or methodological variability.

• METHODS: Retrospective study of 205 medical records of symptomatic subjects free of any organic cause and symptoms persisting despite optical compensation evaluated. Based on the most commonly clinical diagnostics criteria found in the literature, four diagnostics criteria were established for AI (I, II, III and IV) based on subjective accommodative tests: monocular accommodative amplitude two or more diopters below Hofstetter's minimum value [15-(0.25×age)] (I, II, III, IV); failing monocular accommodative facility with minus lens, establishing the cut-off in 0 cycles per minute (cpm) (I) and in 6 cpm (II, III); failing binocular accommodative facility with minus lens, establishing the cut-off in 0 cpm (I) and in 3 cpm (II).

• RESULTS: The proportion of AI (95%CI) for criteria I, II, III and IV were 1.95% (0.04%-3.86%), 2.93% (0.31%-4.57%), 6.34% (1.90%-7.85%) and 41.95% (35.14%-48.76%) respectively, with a statistically significant difference shown between these values (χ^2=226.7, P<0.001). A pairwise multiple comparison revealed that the proportion of AI detected for criterion IV was significantly greater than the proportion for the rest of the criteria (P-adjusted<0.05 in all cases).

• CONCLUSION: The prevalence of cases of AI within the same clinical population varies with the clinical diagnostic criteria selected. The variation is statistically significant when considering the monocular accommodative amplitude as the only clinical diagnostic sign.

• KEYWORDS: epidemiology; amplitude of accommodation; accommodative facility

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INTRODUCTION

Accommodation is a variation of clear vision with modification in lens power that is affected by age-related changes. Several studies have focused on the loss of amplitude of accommodation (AA) with age[1-4]. The normal values for the AA as a function of age were determined by Moore and Donders[4] towards the end of the 19th century and by Duane[5] in the early 20th century. In 1950, Hofstetter[6] created mathematical formulas to calculate the minimal, average and maximal AA (AA=15-0.25×age; AA=18.5-0.3×age; AA=25-0.4×age) based on the Donder's age-expected norms and Duane's studies.

Accommodative insufficiency (AI) is a condition in which the AA is chronically below the lower limits of the expected AA for the patient's age[3]. Generally has a non pathological or functional aetiology, but it may occur in association with primary ocular disease, generalized systemic and neurologic disorders, as well as with lesions that produce focal interruption of the parasympathetic innervations of the ciliary body[7]. Many medications can also cause accommodative dysfunction[8]. Patients with AI usually present asthenopia associated with sustained near work. Symptoms begin almost simultaneously with an increase in near work demand and is characterized by an inability to focus or sustain focus at near[9]. Clinically and experimentally, AA is often measured with the subjective push-up method, where accommodation is stimulated by moving the test chart towards the patient's

Table 1 Evaluation protocol performed at the Visual Training Department

Clinical test	Material and method
Near visual acuity	Radner-Vissum test[20]
Monocular UNVA and CNVA	
Binocular UNVA and CNVA	
Ocular motor function	Fixation stimulus in the different positions of gaze
Near and distance cover testing	Prism bar in free space using an accommodative target[a]
Near point of convergence	Accommodative target[a]
Near and distance FV	Prism bar in free space using an accommodative target[a]
Stereopsis	Randot or Titmus Stereo test
Monocular AA	Minus lens method in phoropter using an accommodative target at 33 cm
MAF	Flipper ±2.00 D lens (starting with lenses +2.00 D) using an accommodative target[a] at 40 cm Register cpm and the position where exist difficult
BAF	Flipper ±2.00 D lens (starting with lenses +2.00 D) using an accommodative target[a] at 40 cm and polaroid bar readers to checking suppression. Register cpm and the position where are more difficult. In case of suppression, annoted eye and position.

UNVA: Uncorrected near visual acuity; CNVA: Corrected near visual acuity; FV: Fusional vergence; AA: Amplitude of accommodation; MAF: Monocular facility accommodation; cpm: Cycles per minute; BAF: Binocular facility accommodation. [a]Accommodative target: Accommodative stimulus with a visual acuity two lines above the baseline visual acuity of the patient.

eyes and as a consequence there is an increase of the angular size at higher accommodative demands. However, several studies shown that this method overestimated the true value of AA due to the depth-of-field of the eye and errors when taking measurement at close working distance[10-13]. Sheard[14] found that using the subjective minus-lens method, where the test chart is placed at a distance of 40 cm and minus power is gradually added, yielded less AA than the data reported by Moore and Donders[4] and Duane[1] using a near point method. Some authors have reported a difference in the AA when comparing both methods[2,11,15-16] and minus lens method exhibited the best repeatability[11].

In addition to AA, there are additional tests that evaluate clinical accommodative skills: monocular accommodative facility (MAF), binocular accommodative facility (BAF), accommodative response [monocular estimate method (MEM) and fused cross cylinder (FCC)] and positive relative amplitude (PRA).

There is no common clinical diagnostic criterion for the detection of AI. All diagnostic criteria incorporate the push-up monocular accommodative amplitude at least 2 D below Hofstetter's calculation for minimum amplitude: 15-(0.25×age). The additional tests evaluating clinical accommodative skills are considered by some diagnostic criteria, but there is no homogeneity in the selected tests and diagnostic cut-off points.

Literature-reported prevalence of AI greatly varies, from 2%[17] to 61.7%[18] due to the lack of standardization in the type of subjects enrolled and clinical diagnostic tests employed[19]. Besides, it is important to compare the prevalence of AI within the same clinical sample to minimize bias caused by the sampling and methodological variability.

The main objective of this study was to estimate the frequency of AI within the same population sample using different diagnostic criteria based on subjective minus-lens method and to reveal the existence of diagnostic discrepancies according to the criteria used.

SUBJECTS AND METHODS

Ethical Approval The research followed the tenets of the Declaration of Helsinki and was approved by the Ethics Committee.

Population Sample Data from the medical records of patients of the Visual Training Department in a Private Ophthalmologic Hospital of Madrid were retrospectively reviewed between September, 2010 and February, 2012. Symptomatic subjects with no evidence of any organic cause and symptoms persisting despite optical compensation were referred to the Visual Training Department after ophthalmic examination.

The inclusion criteria were: patients under 46y, previous ophthalmologic examination, no signs or symptoms of amblyopia, and registered accommodative tests (monocular AA, MAF and BAF). Sample size calculation was based on the assumption of 5% prevalence, an accuracy of ±3% and a 95% confidence interval (CI).

Visual Examination Sequence All subjects had a previous comprehensive ophthalmic examination including: patient history, uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), subjective and cycloplegic refraction, slit-lamp examination of the anterior segment and funduscopy. Subjects were always evaluated by the same optometrist and only one measure was made of each test. The evaluation protocol followed at the Visual Training Department is summarized in Table 1.

Table 2 Clinical diagnosis criteria to classify AI in our study

Criteria	Diagnostic signs		
	AA	MAF	BAF
Criterion IV	AA<$AA_{norm\ min}$ -2 D		
Criterion III	AA<$AA_{norm\ min}$ -2 D	MAF≤6 cpm, failing minus lens	
Criterion II	AA<$AA_{norm\ min}$ -2 D	MAF≤6 cpm, failing minus lens	BAF≤3 cpm, failing minus lens
Criterion I	AA<$AA_{norm\ min}$ -2 D	MAF=0 cpm, failing minus lens	BAF=0 cpm, failing minus lens

AA: Amplitude of accommodation; $AA_{norm\ min}$: Hofstetter's minimum age formula (AA=15-0.25×age); D: Diopters; MAF: Monocular accommodative facility; BAF: Binocular accommodative facility; cpm: Cycles per minute.

Table 3 Descriptive statistics of age for total sample and the four group diagnostics criteria

Age	Total sample (*n*=205)	Criterion IV (*n*=86)	Criterion III (*n*=13)	Criterion II (*n*=6)	Criterion I (*n*=4)
UQ	44.00	43.00	43.00	43.00	36.00
Median	24.50	24.00	7.00	25.00	25.00
LQ	5.00	5.00	6.00	7.00	10.00
Mean	15.59	14.66	16.06	19.48	20.64
SD	11.01	9.22	13.59	15.71	12.08

UQ: Upper quartile; LQ: Lower quartile; SD: Standard deviation.

Accommodative tests were performed with the patient's best correction. The AA was measured by the subjective minus lens method in a phoropter using an accommodative target at 33 cm. The patient was instructed to look at a row of letters two lines larger than his best near visual acuity. Minus lenses of -0.25 D steps were added until the patient could no longer discriminate the target. To arrive at the AA, 2.50 D is added to the minus lens power necessary to blur the letters.

Clinical Diagnostic Criteria Diagnostic criteria were based on some of the criteria normally used to establish the prevalence of AI in the published literature. Articles meeting the following inclusion criteria were selected: showing data on the prevalence of AI, defined diagnostic criteria and reproducible clinical tests, defined clinical samples and subjects tested having an AA that fell more than 2 D below Hofstetter's minimum value. Four diagnostic criteria for AI (I, II, III and IV) were established based on subjective accommodative tests: monocular accommodative amplitude (AA) two or more diopters below Hofstetter's minimum value [15-(0.25×age)] (I, II, III, IV); failing MAF with minus lens, cut-off at 0 cycles per minute (cpm) (I) and 6 cpm (II, III); failing BAF with minus lens, cut-off at 0 cpm (I) and 3 cpm (II). Detailed requirements for each criterion are shown in Table 2.

Statistical Analysis Sample size calculation for the estimation of a proportion was determined considering an infinite population, a confidence level (1-α) of 95% and a precision (d) of 5%. The frequency rate of the studied alterations was considered of 15%. The formula applied was: $n=\frac{Z^2_{\alpha}\cdot p\cdot q}{d^2}$ (α=0.05, Z_{α}=1.96, p=0.15, q=1, d=0.05). Variables were described using absolute (*n*) and relative (%) frequency for qualitative variables, and the mean and standard deviation for quantitative variables. Based on these criteria, prevalence estimates were calculated and compared using the Cochran's *Q* test and the continuity-corrected Mc-Nemar tests with Bonferroni correction. *P*<0.05 were considered statistically significant. All the statistics and epidemiology analysis were performed using the statistical software IBM SPSS Statistics 22.

RESULTS

Demographic and Clinical Data Participants were 205 urban residents ranging from 5 to 44 years of age (15.59±11.01), 49.75% women (17±12) and 50.25% men (14±10). Descriptive statistics of age for the total sample and the four criteria (I, II, II, and IV) are summarized in Table 3.

The symptomatology distribution for the total sample revealed symptoms of asthenopia, headache and variable blurred near vision (90, 43.90%), (70, 34.14%) and (43, 20.97%) respectively. In addition , symptoms related to school environment were observed, such as poor school performance level and low reading speed, with values of (78, 38.04%) and (66, 32.19%) respectively. Occasional near diplopia and covering one eye when reading were reported symptoms in (29, 14.14%) and (16, 7.80%) respectively, this could reflect an association with some binocular dysfunction.

Subjects were referred to the Visual Training Department by different medical departments: General Ophthalmology Services (113, 55.12%), Paediatric Ophthalmology and Strabismus Services (29, 14.15%) and Anterior Chamber/ Segment Services (8, 3.90%). The rest were referred by Psychology and Counselling Departments of Educational Centres in the area (55, 26.83%).

Descriptive data of AA, FAM and FAB for the total sample and diagnostic groups (I, II, II, and IV) are summarized in Table 4. AA values for the total population decreased with age. MAF and BAF values as shown in Table 4 did not differentiate in which position (positive lens, negative lens or both) the

Table 4 Descriptive statistics for AA, FAM and FAB for the total sample and diagnostic groups (I, II, II, and IV)

Age range (y)	AA (D)					MAF (cpm)					BAF (cpm)				
	TS	IV	III	II	I	TS	IV	III	II	I	TS	IV	III	II	I
	n=205	*n*=86	*n*=13	*n*=6	*n*=4	*n*=205	*n*=86	*n*=13	*n*=6	*n*=4	*n*=149	*n*=56	*n*=11	*n*=6	*n*=4
5-10	*n*=102	*n*=50	*n*=8	*n*=2	*n*=1	*n*=102	*n*=50	*n*=8	*n*=2	*n*=1	*n*=75	*n*=32	*n*=7	*n*=2	*n*=2
UQ	15.50	11.25	11.00	5.00	2.00	17.00	16.00	4.00	4.00	0	16.00	15.00	7.00	2.00	0.00
Median	10.75	8.50	5.50	3.50	2.00	7.25	6.00	3.00	2	0	8.75	8.00	3.00	1.00	0.00
LQ	2	8.00	2.00	2.00	2.00	0.00	2.00	2.00	0.00	0	0.00	8.00	0.00	0.00	0.00
Mean	10.60	8.49	4.24	3.16	2.00	5.00	4.47	2.83	2.00	0	8.72	8.00	4.58	1.00	0.00
SD	2.48	0.71	4.95	2.12	a	7.42	5.66	1.41	2.83	a	1.06	3.72	2.09	1.41	a
11-28	*n*=66	*n*=28	*n*=1	*n*=1	*n*=1	*n*=66	*n*=28	*n*=1	*n*=1	*n*=1	*n*=50	*n*=20	*n*=1	*n*=1	*n*=1
UQ	16	9.50	6.25	6.25	6.25	16.00	12.50	0	0	0	14.00	14.00	1.00	1.00	0.00
Median	9.38	6.25	6.25	6.25	6.25	8.00	3.50	0	0	0	4.00	3.50	1.00	1.00	0.00
LQ	3.25	3.25	6.25	6.25	6.25	0.00	0.00	0	0	0	0.00	0.00	1.00	1.00	0.00
Mean	8.20	6.22	6.25	6.25	6.25	6.75	3.94	0	0	0	4.12	3.80	1.00	1.00	0.00
SD	3.20	1.70	a	a	a	5.05	4.48	a	a	a	4.34	3.76	a	a	a
29-45	*n*=37	*n*=8	*n*=4	*n*=3	*n*=2	*n*=37	*n*=8	*n*=4	*n*=3	*n*=2	*n*=24	*n*=4	*n*=3	*n*=3	*n*=1
UQ	9.50	4.50	3.00	3.00	3.00	12.00	6.00	1.00	1.00	0	16.00	10.00	1.00	1.00	0.00
LQ	2	2.00	3.00	3.00	2.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
Mean	4.77	3.08	2.62	2.62	2.45	2.91	2.25	0.33	0.33	0	5.33	1.75	0.50	0.50	0.00
SD	1.68	1.05	0.58	0.58	0.70	3.35	2.54	0.58	0.58	0	4.85	4.14	0.71	0.71	a

AA: Amplitude of accommodation; MAF: Monocular accommodative facility; BAF: Binocular accommodative facility; SD: Standard deviation; TS: Total sample; UQ: Upper quartile; LQ: Lower quartile; D: Diopter; cpm: Cycles per minute; a: Only one value.

subject had more difficulty to do the test. The 27.31% (56/205) of the total population presented sensorial suppression in the BAF test. For groups IV, III, II and I, there were a sensorial suppression rate of 34.88% (30/86), 19.69% (2/13), 0 (0/6) and 0 (0/4) respectively.

Accommodative Insufficiency Frequency

Comparison between clinical diagnostic criteria Frequency of AI (95%CI) by clinical diagnosis for I, II, III and IV criteria were 1.95% (0.04%-3.86%), 2.93% (0.31%-4.57%), 6.34% (1.90%-7.85%) and 41.95% (35.14%-48.76%) respectively. The results of the algorithm to classify the subjects are represented in Figure 1. The figure represents the distribution of subjects according to the value acquired by each of the clinical signs considered: AA, MFA and BAF. First, the variable AA classified 86 subjects as IA according to criterion IV. Of these 86 subjects, 58 showed MAF≤6 cpm, but only 13 failed in negative lens, with these 13 subjects classified as IA according to criterion III. Of these 13 subjects, 8 showed BAF≤3 cpm, although only 6 failed in negative lens (criterion II).

Cochran's *Q* test showed a significant difference among these four frequency (χ^2=226.7, *P*<0.001). A pairwise revealed differences (*P*-adjusted<0.05) between criterion I and IV, II and IV and, III and IV. However, we did not find any significant difference when comparing the rates of frequency of AI according to criteria I, II and III (Figure 2A). Because the frequency obtained for criterion IV was increased over the rest,

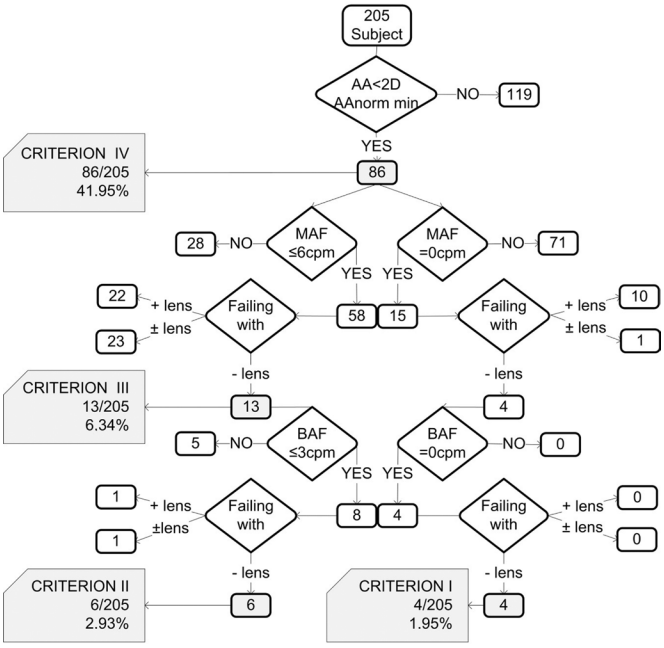

Figure 1 Results of the algorithms applied using the AA, MAF and BAF variables for each clinical diagnostics criteria.

we repeated the same analysis excluding this criterion. With Cochran's *Q* test, we found a significant difference among the three frequency of criteria I, II and III (χ^2=10.333, *P*=0.006). A pairwise comparison revealed differences (*P*-adjusted<0.05) between criterion I and III, II and III. We did not find significant differences when comparing the rates of frequency of AI according to criteria I and II (Figure 2B).

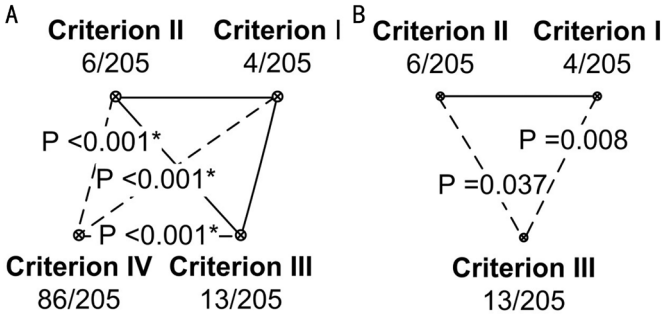

Figure 2 Comparison of the prevalence of AI for each clinical diagnostic criterion Full lines represent pairs of criteria in which no statistically significant differences were observed between the prevalence of these criteria. Dotted lines represent pairs of criteria with significant differences. The numbers on the segment indicates the *P*-adjusted value for each pairs of criteria with significant differences (*P*-adjusted<0.05). The number in each node represents the rate of subjects diagnosed with AI from total sample. A: Pairwise comparison criteria I-II, I-IV, I-III, II-III, II-IV, III-IV. Statistically significant differences were found for the criterion IV. B: Pairwise comparison criteria I-II, I-III, II-III, to eliminate the comparative analysis with criterion IV. Statistically significant differences were found for criterion III.

DISCUSSION

The clinical recognition of AI is important in recognizing a significant impact on accommodative function in disabilities[21] and low vision population[22] and in the study of the mechanism of accommodation to develop new ways to improve the results of presbyopia surgery[13]. The discriminate ability of the diagnosis test is highly dependent upon how prevalent the condition is. Therefore, it is necessary to know the prevalence of the condition to evaluate the validity of clinical tests[23]. Also to study the accuracy of the diagnosis, that which will serve to establish a reference standard.

AI prevalence rates found in the literature search vary from 61.7%[18] to 2%[17]. Study samples came from a clinical and non-clinical context and not all the studied populations were symptomatic. Although the absence of symptoms does not warrant a correct accommodative function, it is known that the clinical characteristics used in diagnosis are the presence of symptoms, clinical signs and positive results in diagnostic tests. To reinforce our results, the studied sample in our study was symptomatic.

According to the current study, criterion IV overestimated the prevalence of AI assuming sample and methodology homogeneity. The results of the present study suggest not using AA as the only clinical sign for the diagnosis of IA. In fact, when using AA as the only diagnostic sign (criterion IV), the high rates could not be compared with the rates obtained when applying other criteria (criterion III, II or I) in which more clinical sign was considered.

Regarding the methodology used to evaluate AA, all revised studies used push-up methods for AA measurement. It is well known that this method reports higher AA values than the minus-lens method[11-12,15-16] and particularly in young children the push-up test overestimates accommodation[10]. So, when the measurement used for AA gives an overestimated value, the prevalence of AI will be underestimated. However, the minus lens method has showed the best repeatability[11], so the intra-measure errors were minimized.

Prevalence rates published in the studies using AA as the only clinical sign for AI diagnostic were 33.3%[24], 17.3%[25], 8%[26] and 4.7%[9] while the current study showed rates of 41.95%. There are studies that selected clinical and symptomatic population as well as the current study and obtained rates of 61.7%[18], 38%[27] and 12.5%[28]

Adding plus clinical signs to the AA limits the distribution of the studied condition. The great majority of the studies added the MAF test as in the present study, except Rouse *et al*[29] used MEM test. The MAF test evaluate a monocular function of the eye, instead BAF test assesses accommodation capacity in binocular conditions. In fact, BAF test was used in several studies too[17,30-33]. From a theoretical point of view, the BAF variable (criteria I and II) assesses accommodation capacity in binocular vision, thus, its value is influenced by the vergence system capacity to activate the fusion reserves. As we can observe in the current study results showed in Table 4, the 27.31% (56/205) of the total population presents sensorial suppression in the BAF test. We believe that using indirect measurements of accommodation in the diagnosis of a monocular condition can distort results, so we recommended using clinical signs measuring the accommodative function in a direct manner and dismiss other measurements distorted by the vergence system. These aspects suggest to use criterion III ($AA<AA_{norm\ min}$ -2 D and MAF≤6 cpm) for a correct diagnostic of AI. That is in concordance with results of Cacho *et al*[28] where failling MAF with -2 D lenses seems to be the sign most associated with the AI. Using criterion III we have found an AI prevalence of (6.34%; 13/205) what it quite similar to the prevalence of Cacho *et al*[28] using AA and MAF (4.26%; 14/328).

Another important aspect is that an apparent accommodative problem could result from latent hyperopia, so a cycloplegic refraction is usually required. Patients with uncorrected hyperopia, especially latent hyperopia, often have accommodative dysfunction, because accommodation continuously compensate for the hyperopia[34]. We recommend the use of cycloplegic refraction to make a correct differential diagnosis between a real accommodative problem and a problem linked to a latent hyperopia.

One study limitation is that data came from the clinical setting, so the results should not be considered representative of the general population. The diagnostic methods used were subjective. Objective methods are more precise and reliable to measure the accommodation function[13,35-36], but the clinical reality make it difficult to incorporate these type of diagnostic methods to the day-to-day setting. Diagnostic criteria may change as diagnostic techniques improve. Further investigation to define actual normal values of amplitude accommodation is needed. Overlapping symptoms in subjects with accommodative deficiencies emphasize the importance of defining a diagnostic criteria based on tests with the best repeatability.

In conclusion, we propose the use of criterion III ($AA<AA_{norm\ min}$ -2 D and MAF≤6 cpm) as clinical diagnosis criteria of AI with a protocol that include the use of the minus-lens method to measure AA and cycloplegic refraction.

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