



Measures of accommodative function in secondary school year 9 and year 13: a 4-year longitudinal study

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Abstract

Purpose To characterize accommodative function in secondary school children in year 9 and year 13 and assess the possible relationship between daily working conditions (number of near work hours and distances) and accommodation variables related to accommodative excess.

Methods This was a prospective study. Participants were 43 subjects who were first examined in year 9 and then again when they were in year 13. The accommodation variables measured in each session were as follows: accommodation amplitude (AA), accommodative response (AR), monocular and binocular accommodation flexibility (MAF and BAF), negative relative accommodation (NRA), and positive relative accommodation (PRA). Other data recorded were the number of hours spent working at near vision tasks and the distances used for these tasks. Participants were classified as those with accommodation variables within the normal range (NA) and those with variables suggesting accommodative excess (AE).

Results Several accommodative function variables were below normative values in both year 9 and year 13. The number of subjects classified as having AE went from 27.9% in year 9 to 58.1% in year 13 according to AR ($p < 0.005$) and from 23.3 to 46.5% according to MAF ($p = 0.024$). More near work was reported in year 13 (44.6 h/week) than year 9 (32.7 h/week) ($p < 0.001$). It emerged that subjects in year 13 spent more hours working at near if they had AE than if they were assigned to the NA group. No differences were detected in near work distances used by subjects in the NA and AE groups in both years.

Conclusions In both school years, values outside the norm were detected in several accommodative function measures. Also, devoting more hours to near work was linked to a greater extent of accommodative excess. We would therefore recommend regular accommodative function assessment in secondary school children.

Keywords Near vision · Working hours · Working distance · Accommodative excess · Secondary school students

Key messages

What is known

- Accommodative dysfunctions in young people are frequent and may cause symptoms of asthenopia affecting near vision and, consequently, learning.

What is new

- Secondary school children were found to show an almost double incidence of accommodative excess in Year 13 compared to Year 9.
- This study relates accommodation excess to more hours spent on near vision tasks rather than closer distances used for these tasks.

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Introduction

Accommodation is the ability of the visual system to change its optical power in an effort to maintain a clear retinal image or focus as the distance of the object viewed varies. Accommodation is achieved by changing the shape of the lens through a series of dynamic changes mediated by the ciliary muscles.

Currently, many of the daily activities of children and adolescents involve near distance work including a large proportion of free time spent on mobile phones, computers, and tablets rather than on outdoor activities [1]. The repercussions of this increase in hours dedicated to near vision tasks has been examined in many studies [1–5]. One consequence is overexertion of the eye's accommodation system [3, 6]. Accommodative anomalies have been linked to several symptoms when performing near vision tasks including headache, eye strain, blurred vision, difficulty in changing focus, excessive sensitivity to light, eye pain, and reading problems [7–12]. Because of the possible effects of these symptoms on different aspects of a child's education, research efforts have examined the relationship between accommodative behavior and academic performance [13], learning problems [14], or even attention deficit [15]. In these reports, nevertheless, working conditions or time employed in near work tasks are not usually specified.

In the study by Iribarren et al. [3] conducted in adults aged 18 to 31 years, significant yet weak correlation was detected between a greater number of cumulative near work hours and reduced accommodative flexibility and greater asthenopia symptoms. To date, however, no such study has focused on secondary school-aged subjects.

Given the possible relationship between long near work and the accommodative system of children and adolescents including symptoms affecting academic performance, the correlation between near work conditions (hours and distances) and accommodative anomalies needs to be examined in this age group. We hypothesized that more hours spent at near vision tasks and closer near working distances could be related to accommodative overexertion, in turn, causing difficulty in relaxing accommodation and, therefore, accommodation excess.

The objectives of this study were to (1) characterize accommodative function in individuals in year 9 and determine the changes produced over 4 years when these students were in year 13, and (2) assess the relationship between near work hours/distances and variables related to accommodative excess in both years.

Subjects, materials, and methods

This was a prospective study. Of the 143 subjects in year 9 enrolled, owing to home confinement during the Covid-19 pandemic, only 43 individuals completed the study in year

13. Thus, participants were 43 children, 25 female, and 18 male, from the secondary school CEU San Pablo, Madrid, Spain. These children completed a first test session in year 9 at a mean age of 13.3 ± 0.4 years, and a second session when they were in year 13 and aged 17.24 ± 0.4 years. In both sessions, tests, questionnaires, and measurements were undertaken in the same room and under the same conditions of light by three experienced optometrists.

The study protocol adhered to the principles of the Declaration of Helsinki and was approved by the Ethics Committee of the Hospital San Carlos, Madrid, Spain. Written informed consent was obtained from the parents of the children who wished to participate in this study.

Exclusion criteria were any eye disease, strabismic and non-strabismic binocular vision anomalies, amblyopia, any medication that could influence the accommodative response, high ametropia (hyperopia $> +2.50$ D, myopia > -4 D, and cylinder > 1.50 D), near and distance visual acuity below 0.00 log MAR in each eye, and limited stereopsis.

In the initial test session, candidates were selected in an assessment including anamnesis, distance and near visual acuity (VA), cover test for distance vision and near vision, near point of convergence, distance and near phorias and vergences, AC/A ratio, stereopsis, and objective and subjective refraction depending on the criterion of maximum plus to maximum VA.

Weekly hours of near work questionnaire

For each subject, a questionnaire was completed by an examiner in which participant's replies indicated the number of hours per day they spent doing different near work tasks (specifying which tasks). The examiner instructed each individual to describe all the activities they practiced in a typical school day and during the weekend.

Next, weekly hours dedicated to each near task were calculated by multiplying by five the hours for each daily task and adding the corresponding hours reported for the weekend.

Measurement of the distance employed in near work

We also recorded the distances used for three near work tasks: reading, writing, and phone screen use. For reading and writing, the subjects were asked to adjust the distance of the chair and the table where the text was placed, so that the position adopted was as similar as possible to the one that they habitually used. Besides, the optometrists instructed participants to behave naturally. The distance was measured

between the forehead and the stimulus of the task conducted. The stimulus was as follows:

- Reading: PROLEC-SE test with a VA demand corresponding to 6/12.
- Writing: subjects had to complete a series of questions referring to the text they had just read.
- Smartphone: students had to send a WhatsApp message (VA demand corresponding to 6/15).

Accommodative variables

The accommodation measurements made were accommodation amplitude (AA), accommodative response (AR), monocular accommodative facility (MAF), binocular accommodation facility (BAF), negative relative accommodation (NRA), and positive relative accommodation (PRA).

Subjects wore their subjective refractive correction and measurements were taken mainly following the baseline criteria of Mitchell Scheimann and Bruce Wick [10]. Room and column lights were kept on (500 lx) for all measurements except for the monocular estimated method (MEM) retinoscopy, for which room lights were turned down so that the retinoscopic reflex could be seen (300 lx).

For AA, we used the minus lens method [10]. The methods fused cross-cylinder (FCC) and (MEM) were used to determine AR [10]. MAF and BAF were measured using a ± 2.00 D flipper and the subject asked to focus on line number five of No. 9 Bernell's vectogram at 40 cm [10]. NRA and PRA were measured at 40 cm using 6/9 stimuli and introducing lenses binocularly in 0.25 D steps [10].

Sample stratification according to whether accommodation variables were within normal reference values or outside reference values suggesting accommodative excess

To explore possible differences in accommodative excess depending on the factors number of near work hours and distance, the sample was divided into a normal reference values (NA) group and normal reference values (AE) group for each of the accommodative variables. For stratification, the following results were considered AE [10–12]:

- AR = 0.00 or negative in cases in which results were obtained by MEM retinoscopy and negative values in the FCC examination.
- MAF ≤ 5 cpm, BAF ≤ 2 cpm (both with plus lens failure).
- NRA $\leq +1.25$ D.

Any subjects not returning these results were classified as NA.

Statistical analysis

All statistical tests were performed using IBM SPSS software version 27. Descriptive data are provided as means and their standard deviations. Ocular variables were obtained for both eyes. The normality of data was confirmed using the Shapiro Wilk's test. Data were compared between the right and left eye and between the first and the second test sessions using a Student's *t*-test for paired samples. To compare accommodative variables with standard values, a single-sample *t*-test was used. The Mann–Whitney *U* test was used to assess differences between the NA and AE groups in the number of near work hours and distances. To assess relationships among qualitative variables, we used the chi-square test or Fisher's exact test depending on the sample size. Significance was set at $p < 0.05$.

Results

No significant differences ($p < 0.05$) were detected between the right and left eye in all the ocular measurements made, so data are presented only for the right eye. Mean age, spherical equivalent refractive error, and VA were 13.3 ± 0.4 years, 0.01 ± 1.12 D, and 0.00 log MAR respectively in year 9, and 17.2 ± 0.4 years, -0.13 ± 1.31 D, and 0.00 log MAR respectively in year 13.

Number of hours and distance of near work

School hours for both years 9 and 13 were 9 a.m. to 4 p.m. The time outside school spent on near tasks was 32.7 ± 11.7 h (weekly mean) in year 9 and $44.6 \text{ h} \pm 12.9$ in year 13 (daily mean of 4.6 h and 6.3 h respectively). Our *t*-test for paired samples revealed that the mean number of near work hours was significantly higher in year 13 compared to year 9 with a mean difference of 11.8 ± 16.5 h ($t = -4.709$, $p < 0.001$).

The distances employed for near vision tasks were also significantly higher in the second test session, and went from 31.7 ± 7.3 in year 9 to 34.4 ± 5.8 cm in year 13 for reading distance ($t = -2.141$, $p = 0.038$), from 24.8 ± 7.7 to 30.3 ± 6.1 cm for writing distance ($t = -4.284$, $p < 0.001$), and from 21.1 ± 6.7 to 31.8 ± 6.3 cm for phone use distance ($t = -3.762$, $p < 0.001$).

Accommodative variables

Table 1 shows the accommodation variables determined in the participants in year 9 (session 1) and then 4 years later when they were in year 13 (session 2).

The results of our analysis of variables related to accommodative excess (AR, MAF, BAF, and NRA), which was our second study objective, are shown in Figs. 1, 2, and 3. These figures illustrate the number of subjects returning accommodative excess variables within normal reference values (NA group) or outside reference values suggesting accommodative excess (AE group) at the two time points.

Table 1 Mean accommodation variables measured in the study participants in sessions 1 and 2 and *p*-values of the difference between means for the whole sample and normative data

Accommodation variable	Mean	Standard deviation	Normative data [10]	<i>p</i> -value
AAML 1 (D)	10.4	2.2	12.0	<0.001
AAML 2 (D)	7.9	1.9	10.7	<0.001
MEM 1 (D)	0.4	0.2	0.5	0.437
MEM 2 (D)	0.4	0.2	0.5	0.086
FCC 1 (D)	−0.0	0.4	0.5	<0.001
FCC 2 (D)	−0.2	0.4	0.5	<0.001
MAF 1 (cpm)	8.0	4.0	11	<0.001
MAF 2 (cpm)	7.0	4.9	11	<0.001
BAF 1 (cpm)	6.6	4.4	8	0.055
BAF 2 (cpm)	5.1	4.9	8	<0.001
PRA 1 (D)	−2.0	0.9	−2.3	0.026
PRA 2 (D)	−2.1	1.0	−2.3	0.135
NRA 1 (D)	1.8	0.5	2.0	0.036
NRA 2 (D)	1.6	0.4	2.0	<0.001

AAML accommodative amplitude measured using minus lenses, MEM accommodative response measured using retinoscopy, FCC accommodative response measured using fused cross-cylinder, MAF monocular accommodative facility, BAF binocular accommodative facility, PRA positive relative accommodation, NRA negative relative accommodation

Effect of the number of near work hours on accommodation excess-related variables

Tables 2 and 3 provide the results of our analysis of hours of near vision work in the groups NA and AE according to each of the accommodative variables and each of the time points.

The data presented in Table 2 indicate no significant differences in year 9 between the NA and AE groups in the number of hours spent on near vision tasks.

The data presented in Table 3 indicate that subjects in year 13 in the AE group undertook more hours of near work ($p < 0.05$) than those in the NA group for the variables related to accommodation relaxation using plus lenses (MAF and NRA).

Effects of the distances used for different near tasks on accommodation variables

No differences in working distances were found between the AE and NA groups for any of the accommodative variables (AR, MAF, BAF, and NRA) or near tasks analyzed (writing, reading, or phone use).

Discussion

Our study provides data for secondary school children regarding the hours spent and distances employed in near vision tasks, their accommodative function profiles, and assesses accommodation function profiles at two time points 4 years apart. Also explored here was the possible association between more near work hours or shorter working distances and values of accommodative variables suggesting accommodative excess.

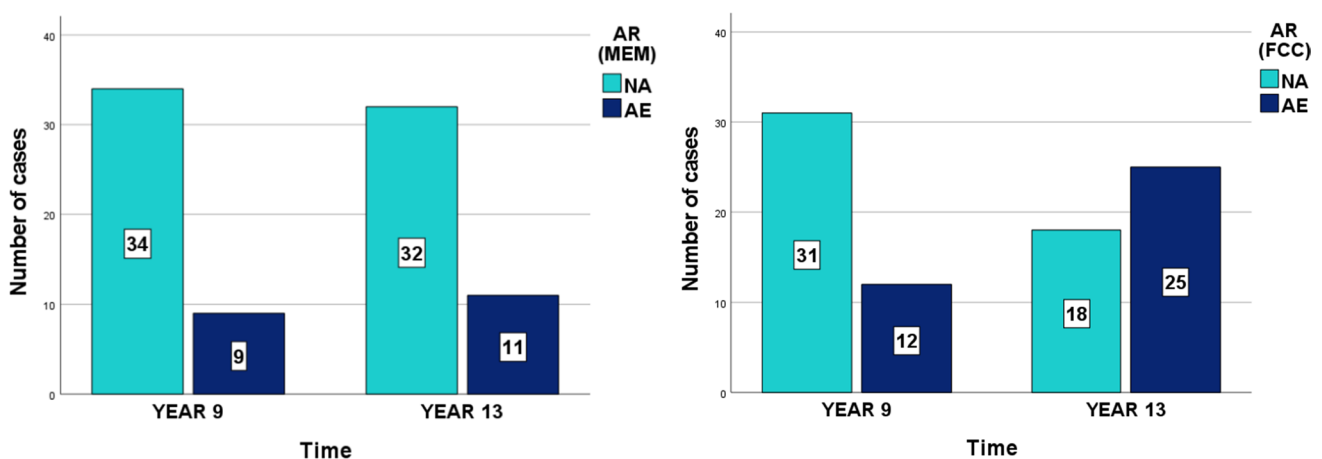


Fig. 1 Subjects showing accommodative responses (AR) measured through MEM (left) and FCC (right) within and outside reference standards in years 9 and 13

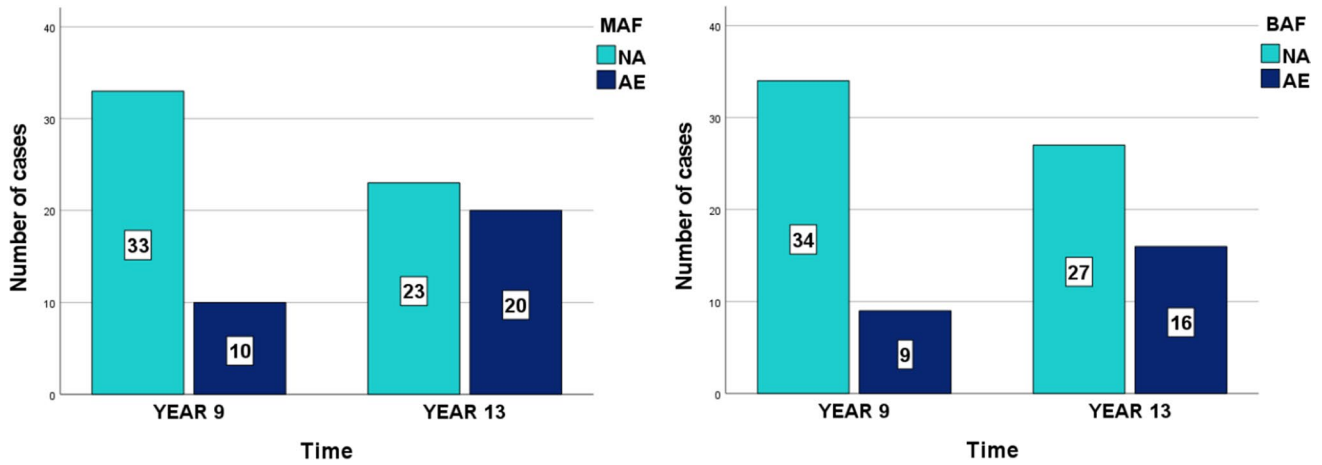


Fig. 2 Subjects showing MAF (left) and BAF (right) values within and outside reference standards in years 9 and 13

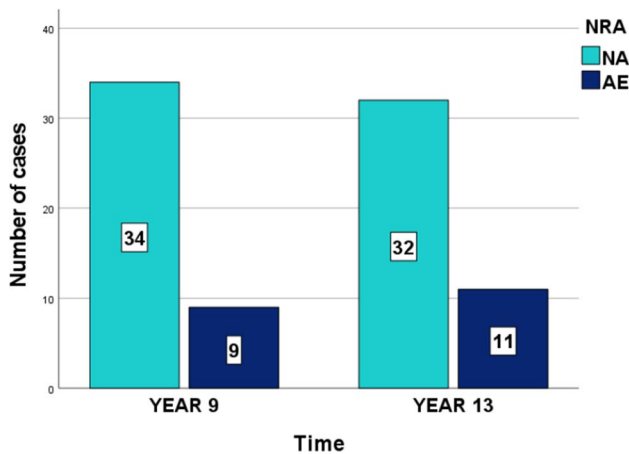


Fig. 3 Subjects showing NRA values within and outside reference standards in years 9 and 13

Number of near work hours and distances employed

The participants of this study dedicated many hours, besides to school work, and to near work tasks, and this number of hours was significantly higher in year 13 compared to year 9. Our data indicate that after school, these secondary school children spent most of their waking hours on near vision tasks.

The distances employed for three near tasks (writing, reading, and phone screen use) were also significantly higher in year 13 compared to year 9. This change that took place over time could be considered beneficial as shorter working distances are related to a greater accommodative effort. This lengthening of close work distance as children grow is consistent with the findings of Wang et al. [16]. These authors compared near work distances in different conditions (reading on a sofa, reading at a table, and both reading and writing at a table) and found that near work distance increased with age, along with height and Harmon distance.

Table 2 Mean number of hours dedicated to near work recorded in the two year 9 groups of subjects with accommodation variables suggestive of normal accommodation (NA) or accommodative excess (AE), and mean differences between the two groups

Accommodation variable	Measurement method	Criterion for suspected AE	Mean no. of NV hours	Mean difference (hours)	p-value (Mann–Whitney U)
AR	MEM	0.0 or lead	NA 32.5 AE 34.5	2.0	0.76
	FCC	Lead	NA 31.9 AE 34.9	3.0	0.30
FLEXIBILITY	MAF	≤ 5 cpm	NA 30.6 AE 39.5	8.9	0.34
	BAF	≤ 2 cpm	NA 31.8 AE 35.8	4.0	0.30
NRA	NRA	≤ 1.25 D	NA 32.1 AE 34.6	2.5	0.65

Table 3 Mean number of hours dedicated to near work recorded in the two year 13 groups of subjects with accommodation variables suggestive of normal accommodation (NA) or accommodative excess (AE), and mean differences between the two groups

Accommodation variable	Measurement method	Criterion for suspected AE	Mean no of NV hours	Mean difference (hours)	<i>p</i> -value (Mann–Whitney <i>U</i>)	<i>p</i> -value* (Bonferroni correction)	Power (1- β)
AR	MEM	0.00 or lead	NA 44.1 AE 54.0	9.9	0.34	1.36	N/A
	FCC	Lead	NA 39.8 AE 47.9	8.1	0.06	0.24	N/A
FLEXIBILITY	MAF	≤ 5 cpm	NA 37.8 AE 51.5	13.7	0.001	0.004	0.97
	BAF	≤ 2 cpm	NA 40.5 AE 50.1	9.6	0.02	0.08	0.72
NRA	NRA	≤ 1.25	NA 41.7 AE 52.9	11.2	0.009	0.03	0.84

**p*-value adjusted by Bonferroni correction by multiplying its value by four (number of variables assessed). N/A not applicable. Power calculated considering an alpha of 0.05

Accommodative variables (AA, AR, MAF, BAF, and NRA)

For the variable AA, results obtained were below normative values in both test sessions and also worsened over the 4-year period. As some authors indicate, such low values may be attributed to the Hoffsteter formula used to define normality, which could be overestimating the real value of accommodation [17]. The fact that AA was lower in our second examination was expected due to the decline in this ability with age.

Accommodative response values varied according to the measurement method used. Thus, mean MEM retinoscopy AR values were close to reference standards in both the first and second sessions and there were no significant differences between them. In contrast, FCC-determined AR differed significantly from normality values, and the mean accommodative lead response was significantly greater in the second session. Other authors [18–20] have reported significant differences between AR measurements depending on the method used. The different studies designed to assess AR seem to coincide in the fact that MEM retinoscopy leads to greater accommodation lags in the range +0.50 to 0.69 D. Because of this difference between the two methods, more work is needed to clarify which clinical AR measurement is most reliable to diagnose accommodative anomalies. Antona et al. [18] recommend using FCC instead of MEM retinoscopy because of its greater repeatability.

Accommodation flexibility tests play an important role in the diagnosis of accommodative and binocular dysfunctions. MAF is used to define purely accommodative anomalies while BAF has proven useful to diagnose both accommodation and binocular abnormalities [9–11, 21]. Some authors [21] argue that MAF measurement is an

essential clinical test for the diagnosis of accommodative excess and infacility when a patient fails only with plus lenses (excess) or with both plus and minus lenses (infacility).

In the present study, MAF means varied significantly from normative values for both measurements and the same thing happened for BAF in year 13 (Table 1). The values obtained for NRA showed similar behavior to MAF and BAF. This parameter also tests accommodation relaxation capacity in response to plus lenses and means were once again below reference values in both the first and second test sessions (Table 1).

In other longitudinal studies like the one by Jorge et al. [22], significant changes in the accommodative parameters LAG and NRA, among others, were recorded over a 3-year period in 20-year-old students. For both LAG and NRA, means in the second session were more positive, with differences of +0.32D and +0.66D respectively. In our study, both variables became more negative. This could be explained by the difference in participant age and the effects of time at those ages. Hence, in the study by Jorge et al. [22], students probably had similar visual demands between test sessions. The change in academic demands and time spent doing near work produced from years 9 to 13 in our study was much greater.

Figures 1, 2, and 3 show the changes produced in accommodative excess-related variables (AR, MAF, BAF, and NRA) between the first and second test sessions in subjects with values indicating normal accommodation function (NA) and those with values suggestive of accommodative excess (AE). These figures show that the number of subjects with suspected AE according to their AR (measured using FCC), MAF, and BAF values was practically double ($p < 0.05$) in year 13.

Impacts of near work hours and distances on accommodative function

Our data reveal that participants featured AR (FCC-based), MAF, BAF, and NRA values far from normative values and a tendency towards accommodative excess in year 13, when more hours were spent executing near vision tasks, although working distances were also increased.

When our study population was divided into NA and AE according to the variables AR, MAF, BAF, and NRA, we found that the year 9 students in AE (Table 2) dedicated approximately 2 and 9 weekly hours more (depending on the variable assessed) to near vision tasks than those in NA, although differences were not significant. Four years later in year 13, participants assigned to the AE group according to the same variables (Table 3) spent approximately 8 to 14 h per week more executing close work tasks than those in NA. In the second test session, the difference in near work hours between the two accommodation function groups was significant ($p < 0.05$) for the variables related to accommodation relaxation (MAF and NRA).

No differences in the near work distances used by subjects in NA and AE were detected in both test sessions.

In conclusion, our findings indicate that more hours dedicated to near vision tasks rather than closer working distances could exert more stress on the accommodation system, producing difficulty in relaxation of accommodation in subjects devoting more time to near vision tasks. These dysfunctions have been linked to symptoms like headache, blurred vision at both near and far, eye strain, and movement or twitching of letters in a text. Indeed, all of these symptoms can affect academic performance and learning. The clinical implications of these findings are that special attention needs to be paid to routine working conditions and that accommodative function in school-aged children needs to be assessed on a regular basis and treated if necessary.

Limitations and future research

A main limitation of our study was that due to Covid-19, only 30% of the subjects (43/143) enrolled in year 9 were able to complete this study in year 13. However, we detected a large number of subjects with accommodative variables outside the norm, so we recommend reviewing normative accommodative function data.

Author contribution All authors contributed to the study conception and design. Material preparations were performed by Esther Mármol-Errasti, José Miguel Cárdenas-Rebollo, Antonio Rodán, Encarnación Pagán-Fernández, Laura C Jara-García, and Catalina Palomo-Álvarez. The first draft of the manuscript was written by Esther Mármol Errasti

and all authors commented on previous versions of the manuscript. All authors have read and approved the final manuscript.

Declarations

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the Ethics Committee of the Hospital San Carlos (Madrid, Spain) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

Conflict of interest The authors declare no competing interests.

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