·Clinical Research·

Objective evaluation of the changes in the crystalline lens during accommodation in young and presbyopic populations using Pentacam HR system

Yao Ni, Xia-Lin Liu, Ming-Xing Wu, Ying Lin, Yu-Ying Sun, Chang He, Yi-Zhi Liu

Foundation items: Supported by National Natural Science Foundation of China (No. 81070747) and Research Award for New Century Excellent Talents in University (No. NCET08-0586) in China; and Science and Technology Planning Project of Guangdong Province, China (No.2010B090400416)
Zhongshan Ophthalmic Center, State Key Laboratory of Ophthalmology, Sun Yat-sen University, Guangzhou 510060, Guangdong Province, China
The first two authors (Yao Ni and Xia-Lin Liu) contributed to this study equally
Correspondence to: Yi-Zhi Liu. Zhongshan Ophthalmic Center, State Key Laboratory of Ophthalmology, Sun Yat-sen University, Guangzhou 510060, Guangdong Province, China. yizhi_liu@yahoo.cn
Received: 2011-09-22 Accepted: 2011-10-31

Abstract

• AIM: To quantify the changes in the lens profile with accommodation in different age groups.

• METHODS: The Pentacam HR system was used to obtain the images of the anterior eye segment from 23 young and 15 presbyopic emmetropic subjects in unaccommodated (with an accommodation stimulus of 0.0D) and accommodated (with an accommodation stimulus of 5.0D for the young group and 1.0D for the presbyopic group) states. The phakic crystalline lens shape, including curvature of crystalline lens and central lens thickness (CLT), and the measurements of anterior segment length (ASL), central anterior chamber depth (CACD) were investigated. The anterior chamber volume (ACV) was also measured.

• RESULTS: The reduction of CACD and ACV were significant in both groups after accommodation stimulus. From the profile of anterior eye segment, a significant decrease in anterior crystalline lens radii of curvature (-2.52mm) and a mean increase in CLT (0.222mm) and ASL (0.108mm) were found in the young group with an accommodation stimulus of 5.0D. However, no statistically significant changes of CLT, ASL, or crystalline lens radii of curvature were found in the presbyopic group.

• CONCLUSION: Our data showed that the shallowing of anterior chamber during accommodation was caused by the forward bulging of the anterior lens surface, rather than by anterior shifting of lens position in either young or presbyopic subjects.

• KEYWORDS: accommodation; crystalline lens; Pentacam HR; anterior eye segment
DOI:10.3980/j.issn.2222-3959.2011.06.07

Ni Y, Liu XL, Wu MX, Lin Y, Sun YY, He C, Liu YZ. Objective evaluation of the changes in the crystalline lens during accommodation in young and presbyopic populations using Pentacam HR system. *Int J Ophthalmol* 2011;4(6):611-615

INTRODUCTION

The ultimate goal of intraocular lens (IOLs) implantation is to restore natural accommodation in the pseudophakic eye. As yet, we do not understand the mechanism of accommodation completely, and the theory or hypothesis regarding the physiological mechanism of human accommodation is still not entirely established [1-3], although it seems to depend on the contraction of ciliary muscle, the tension of zonules, and elasticity of the crystalline lens.

Accommodation, the adjustment of the focal length of the lens of the eye to the distance of objects in the visual field, is usually achieved by a dynamic change of the total refractive power of the eye. As the most important refractive component of accommodation, crystalline lens naturally became the focus of the study. Since some imaging devices can obtain images of the anterior eye segment during accommodation, several predecessors have reported the changes in the crystalline lens with accommodation stimulation such as lens thickness and diameter, anterior and posterior curvature, refractive index, volume and position [4-8]. However, there are still different views based on the findings produced through different imaging devices.

The Pentacam (Oculus, Wetzlar, Germany) is a non-contact device using a rotating Scheimpflug camera. It can generate precise and sharp images of the anterior segment of the eye in three-dimensions [9]. Therefore, in this study, the dynamic

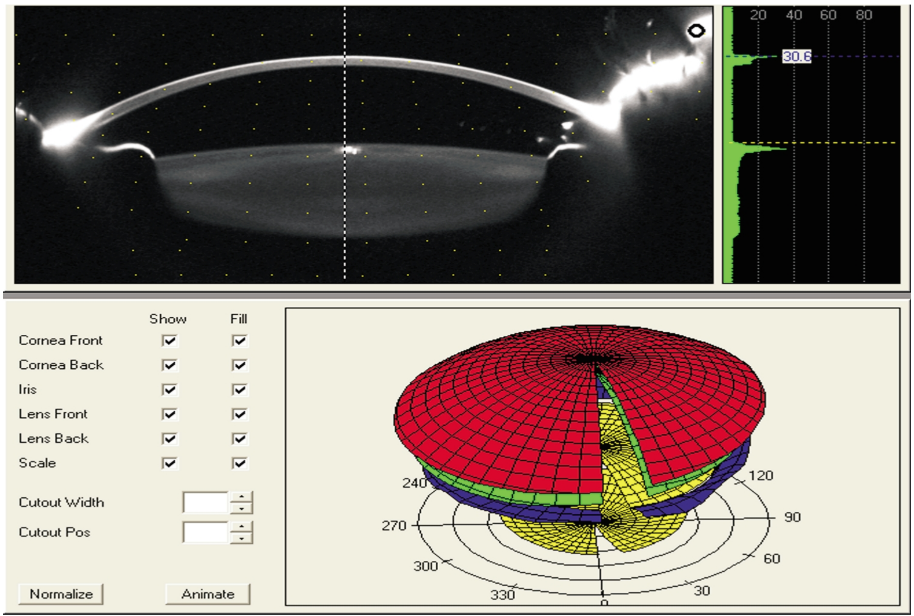

Figure 1 The anterior eye segment in a mydriatic eye is displayed by Pentacam HR system. The display in the upper half shows the individual Scheimpflug image. The virtual eye is shown in the lower half of diaplay. The anterior (red) and posterior surface (green) of the cornea, iris (blue) and lens (yellow) are dipicted as planes

changes of the refractive apparatus of the human eye, in particular, the phakic crystalline lens, was observed during physiological accommodation using Pentacam HR. Because accommodative amplitudes physiologically decrease with aging, both presbyopic people and young people were included in this study. Evaluating changes of the anterior eye segment with accommodation in young and older subjects will provide a better understanding of the relationship between the refractive apparatus and accommodative function. Such knowledge might be applied to the designing of accommodating IOLs.

PATIENTS AND METHODS

Patients In all, 23 young and 15 presbyopic subjects were recruited from Sun Yat-sen University, all of whom were East Asians. The young group had a mean age of 24.4±2.6 years (range: 18±29 years), and included 12 men and 11 women. Furthermore, the presbyopic group had a mean age of 55.7±5.1 years (range: 43-58 years), and included 6 men and 9 women. All subjects were emmetropic and free of ocular and systemic disease. No subjects had a history of refractive surgery. Only one eye of each subject was investigated (random sampling). All of the subjects had an uncorrected distance (5m) logMAR visual acuity (UCVA) of 0.00. The study was followed the tenets of the Declaration of Helsinki. And informed consent was obtained from each subject prior to study.

Methods

Pentacam anterior segment imaging system Pentacam images the anterior eye segment in three dimensions with a rotating Scheimpflug camera (Figure 1). Moreover, the system has a second camera to detect and correct for eye movement. The entire cornea and anterior chamber, including the crystalline lens, can be monitored synchronously. The Pentacam HR uniquely has a red blinking LED that serves as an active "Fixation Target". It can be moved in 0.5-dpt steps from +2dpt to -5dpt (Pentacam/Pentacam HR User Guide). With Pentacam HR, physiological accommodation can be induced and observed in the same eye for emmetropia [10].

Measurements In current study, monocular amplitude of accommodation was measured in presbyopic subjects firstly. Subjects were asked to read a 40cm near target with the selected eye, and the subjective minus lens method was used, which has been shown to have better repeatability [11]. Each eye was measured three times to obtain the average. Ultimately, all presbyopic subjects were confirmed to have more than 1.0D amplitude of accommodation.

The accommodation stimulus used for the young group in this study was 5.0D. Although it is not catching the maximum amplitude of accommodation that young adults can possess, it remains slightly larger than the amount of accommodation demand for most near works. Therefore, 5.0D is an appropriate option for observing physiological accommodation of young people. Besides, it is the maximum accommodation stimulus that can obtain from the Pentacam HR. In the presbyopic group, generally, the amounts of accommodation were too little to come up to the accommodation demand for most near tasks. However, all presbyopic subjects were confirmed to have more than 1.0D amplitude of accommodation firstly. Thus, 1.0D

Table 1 Anterior chamber parameters in two accommodated states

Parameter	Accommodation young group		P	Accommodation presbyopic group		P
	5.0D	0.0D		1.0D	0.0D	
CACD(mm)	2.83±0.30	2.94±0.30	<0.0001	2.54±0.25	2.55±0.26	<0.05
ACV(mm^3)	163.39±30.38	167.51±32.87	<0.01	117.70±26.53	119.76±26.80	<0.05

CACD= central anterior chamber depth; ACV=anterior chamber volume

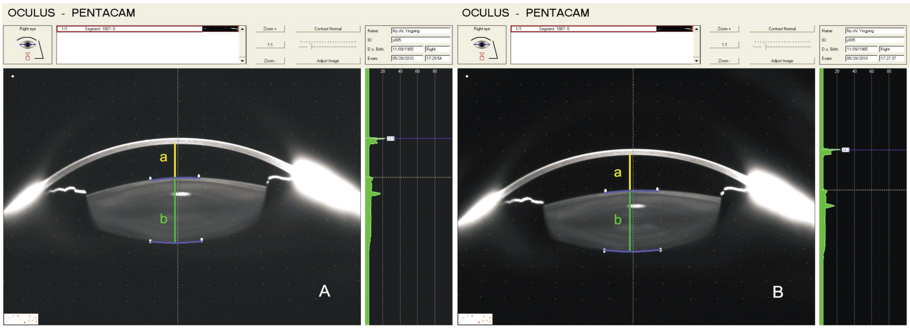

Figure 2 Representative images of crystalline lens evaluated by Pentacam HR in two accommodative states A：represents 5.0D accommodation stimulus；B：Represents 0.0D accommodation stimulus. In the images, the 3.0 mm area of anterior and posterior lens surfaces was delineated in blue curve for calculating lens curvature. Yellow line a: Central anterior chamber depth. Green line b: Central lens thickness. a+b=Anterior segment length

accommodation was chose to be accommodation stimulus for the presbyopic group.

The anterior segment measurement of each volunteer was performed by one examiner (Yao Ni) using the Pentacam HR system with automatic-release mode. All of the subjects were seated and were forced to fixate to on the target. Under 50-picture 3-dimensional (3D) scan mode, CACD and ACV were measured with built-in, movable target for physiologic accommodation stimulus. Previous studies have shown that the Pentacam has excellent repeatability and reliability for measurements CACD and ACV [12,13]. A mean of six measurements was recorded in unaccommodated state (0.0D accommodation stimulus) followed by 5.0D (1.0D for the presbyopic group) added to accommodation stimulus for accommodated state. The shift of CACD and ACV was calculated subtracting the two mean values.

After the pupil of selected eye was dilated with two drops of 5% phenylephrine, under the mode of enhanced dynamic Scheimpflug image, three images were obtained from the same eye in unaccommodated state (0.0D accommodation stimulus) first，followed by 3 images in the accommodated state (1.0D accommodation stimulus for the presbyopic group and 5.0D for the young group). Finally, these images were used for end-point analysis.

Pentacam HR provided good-quality images. The images of the anterior segment were obtained after mydriasis. Images were processed with mathematical software (MATLAB [The MathWorks Inc., Natick, Mass]). The edges of the crystalline lens were detected by a Canny filter program, then the least square data fitting method was applied to fit every edge to a circle. After this process, the anterior and posterior curvature of crystalline lens was calculated by using the fitted circles. In addition, the central anterior chamber depth (CACD) was calculated again from the enhanced dynamic Scheimpflug image using the same image software, as well as central lens thickness (CLT) and anterior segment length (ASL= CACD+ CLT).

Statistical Analysis The differences in CACD and ACV, which were automatic output parameters, were analyzed with two-sided Wilcoxon rank sum test. To compare the means of all parameters from the image, such as CACD, CLT, ASL and the anterior and posterior curvature of crystalline lens between unaccommodated and accommodated states, the Paired-Samples t test was used. Statistical analyses were performed with SPSS 16.0 software (SPSS, Chicago, IL). $P<0.05$ was considered significant.

RESULTS

Table 1 showed the data of CACD, obtained from 50-picture 3-dimensional(3D) scan mode in unaccommodated and accommodated states. In the young group, a significant reduction in CACD occurred with 5.0D accommodation stimulus ($P<0.0001$). In the presbyopic group, CACD appears significantly reduced with a lower accommodation stimulus (1.0D) ($P<0.05$).

ACV was presented in Table 1 too. ACV was an important anterior chamber parameter, which was used to investigate aqueous humor dynamics and glaucoma generally. It also diminished in both groups during accommodation($P<0.05$).

Figure 2 showed representative images of unaccommodated and accommodated states in a young subject (young subject

#6). The results of CACD, CLT and ASL were shown in Figure 3. The measurements of crystalline lens curvature were shown in Figure 4.

In the young group, a mean decrease in CACD (-0.114mm) and a mean increase in CLT(0.222mm) and ASL (0.108 mm) were found, with an accommodation stimulus of 5.0D. All the changes were highly statistically significant (P< 0.01). We also found a significant decrease in anterior radius of curvature during accommodation (mean-2.52mm) (P< 0.05), while the change of posterior radius of curvature was not considered statistically significant (mean -0.13mm). In the presbyopic group, the decrease in CACD (mean -0.025mm) was significant (P<0.05). CLT (mean 0.046 mm) and ASL (mean 0.021mm) showed a slight increase, but no statistical significance was found. The change in lens curvature also did not reach statistical significance.

DISCUSSION

As expected, a significant reduction in CACD was found in both young and presbyopic subjects with accommodation. Investigators suggested that the reduction was caused by the forward movement of the anterior lens surface [14,15]. There has been agreement regarding the changes in the thickness and surface curvatures of crystalline lens with accommodation, not only in rhesus monkeys [6,8], but also in humans [4,16-18]. However, the contribution of the forward movement of lens position to accommodation remains controversial [14,16,19]. Since the Pentacam rotating Scheimpflug camera, as a 3-dimensional anterior segment imaging system, was introduced to image the crystalline lens and measure lens thickness [20], in this study, we particularly used Pentacam HR to re-evaluate the lens profile in physical accommodation, although the curvatures of the anterior and posterior surfaces of lens required additional programs for further processing and analysis.

Generally, the changes in CACD, CLT, and surface curvatures during accommodation were correlated well with the previous findings [16]. Interestingly, we found that anterior segment length (ASL) increased distinctly with accommodation in the young group and the increase in ASL (mean 0.108mm) was almost equal to the decrease in CACD (mean -0.114mm). More important, the bulge in the anterior surface of crystalline lens was much greater than in the posterior surface with the 5.0D accommodation stimulus. These results implied that the decrease of CACD was derived from the bulge of the anterior lens surface and that the lens position did not shift forward in the young group. The increase of ASL (mean 0.025mm) in our presbyopes was still equivalent to the decrease in CACD (mean-0.022mm); however, the changes of ASL did not reach statistical significance, perhaps because of the low

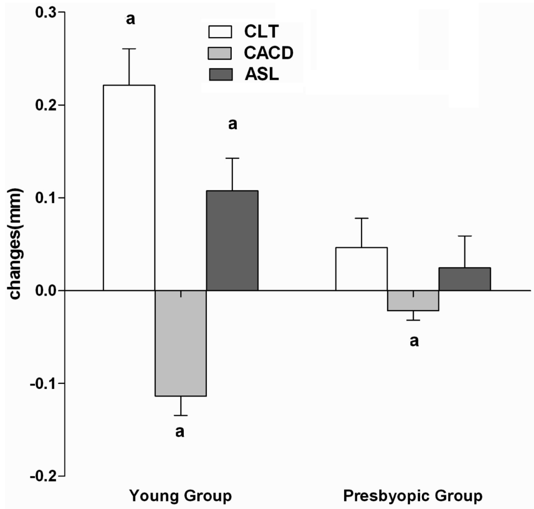

Figure 3 The mean change in measurements of central lens thickness (CLT), central anterior chamber depth (CACD), and anterior segment length (ASL) before and after accommodation in two groups ([a] P<0.05, Paired-Samples t Test, 5.0D accommodation stimulus for the young group and 1.0D accommodation stimulus for the presbyopic group)

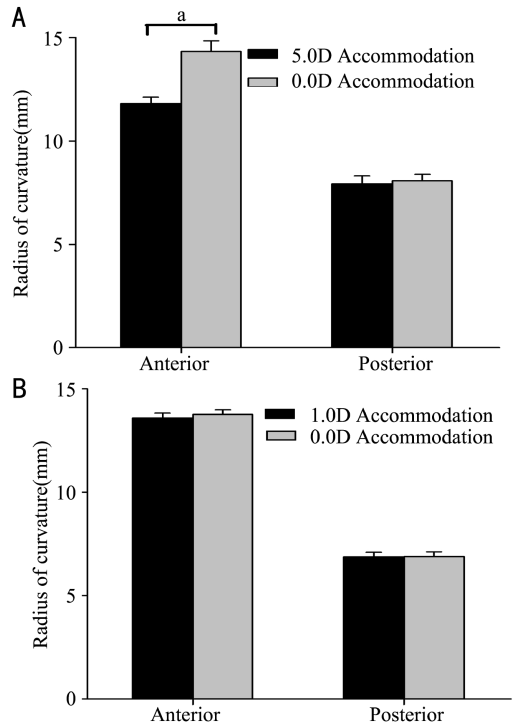

Figure 4 Anterior and posterior crystalline lens radii of curvature with accommodation.There is a significant decrease in anterior radius of curvature during 5.0D accommodation stimulus (mean-2.52mm) ([a] P<0.05, Paired-Samples t Test)
A: Young group; B:Presbyopic group

accommodation stimulus (1.0D) and small sample size. Furthermore, the anterior curvature change(mean-0.1775mm) were greater than the posterior curvature changes (mean -0.005mm) in the presbyopic group. Therefore, the forward movement of lens position could not occur in the presbyopic group with less than 1.0D accommodation stimulus. Apparently, the lens position did not move forward with accommodation in either the young group or the presbyopic group. Pentacam HR is a useful tool for evaluating changes of the entire anterior segment, and it can provide the lens profile. However, it still has several limitations. For example, it cannot capture the ciliary muscle and zonules. In addition, crystalline lens measurements cannot be obtained in some presbyopes, because phenylephrine does not always dilate the pupil sufficiently, limiting the imaging of lens.

As we knew, accommodating IOLs have been designed to mimic the natural process of accommodation in recent years. In designing truly ideal or perfect accommodating IOLs, it is necessary to understand the mechanisms of human lenticular accommodation. Although several studies have suggested that a forward movement of the lens position occurs [14,16], this slight movement is most likely a consequence of the bulge of the anterior lens surface and not an integral aspect of the accommodative mechanism [19]. No axial shift of accommodating IOLs was seen under physiological near-point stimulation, although a slight movement of IOLs can be clinically observed with drug-induced stimulation [21,22]. These observations agree with our finding that ciliary muscle did not drive the anterior movement of lens during natural accommodation. Consequently, a lens design that depends on the displacement of IOLs does not mimic the natural accommodative process, i.e., the theory of focus-shift accommodating IOLs is based on ciliary muscle forces that can generate forward optic-flat shift with near visual stimulation. Lens capsular refilling with new materials may be more accordance with physiological condition than the focus-shift accommodating IOLs. In the future, the development of lens refilling techniques, including surgical procedures and injectable materials, may result in truly accommodating IOLs that can work as a natural crystalline lens.

In summary, this study is the first time to use Pentacam HR system to evaluate the lens changes during physiological accommodation. The CACD was significantly reduced with accommodation both in young and presbyopic groups. The lens thickness and anterior and posterior curvature of crystalline lens changed with accommodation, however, the crystalline lens did not move forward during accommodation in either young or presbyopic subjects. Therefore, the physiological accommodation did not involve the forward shift of lens position.

REFERENCES

1 Coleman DJ. On the hydraulic suspension theory of accommodation. *Trans Am Ophthalmol Soc* 1986;84:846-868

2 Schachar RA. The mechanism of accommodation and presbyopia. *Int Ophthalmol Clin* 2006;46(3):39-61

3 Atchison DA. New thinking about presbyopia. *Clin Exp Optom* 2008;91(3):205-206

4 Koretz JF, Cook CA, Kaufman PL. Accommodation and presbyopia in the human eye. Changes in the anterior segment and crystalline lens with focus. *Invest Ophthalmol Vis Sci* 1997;38(3):569-578

5 Richdale K, Bullimore MA, Zadnik K. Lens thickness with age and accommodation by optical coherence tomography. *Ophthalmic Physiol Opt* 2008;28(5):441-447

6 Rosales P, Wendt M, Marcos S, Glasser A. Changes in crystalline lens radii of curvature and lens tilt and decentration during dynamic accommodation in rhesus monkeys. *J Vis* 2008;8(1):18 11-12

7 Strenk SA, Strenk LM, Guo S. Magnetic resonance imaging of the anteroposterior position and thickness of the aging, accommodating, phakic, and pseudophakic ciliary muscle. *J Cataract Refract Surg* 2010;36(2):235-241

8 Wendt M, Croft MA, McDonald J, Kaufman PL, Glasser A. Lens diameter and thickness as a function of age and pharmacologically stimulated accommodation in rhesus monkeys. *Exp Eye Res* 2008;86(5):746-752

9 Pei X, Bao Y, Chen Y, Li X. Correlation of lens density measured using the Pentacam Scheimpflug system with the Lens Opacities Classification System III grading score and visual acuity in age-related nuclear cataract. *Br J Ophthalmol* 2008;92(11):1471-1475

10 Read SA, Buehren T, Collins MJ. Influence of accommodation on the anterior and posterior cornea. *J Cataract Refract Surg* 2007;33(11):1877-1885

11 Antona B, Barra F, Barrio A, Gonzalez E, Sanchez I. Repeatability intraexaminer and agreement in amplitude of accommodation measurements. *Graefes Arch Clin Exp Ophthalmol* 2009;247(1):121-127

12 Doors M, Cruysberg LP, Berendschot TT, de Brabander J, Verbakel F, Webers CA, Nuijts RM. Comparison of central corneal thickness and anterior chamber depth measurements using three imaging technologies in normal eyes and after phakic intraocular lens implantation. *Graefes Arch Clin Exp Ophthalmol* 2009;247(8):1139-1146

13 Fu J, Li SN, Wang XZ, Wu GW, Mu DP, Wang J, Wang NL. Measurement of anterior chamber volume with rotating scheimpflug camera and anterior segment optical coherence tomography. *Chin Med J (Engl)* 2010;123(2):203-207

14 Dubbelman M, Van der Heijde GL, Weeber HA. Change in shape of the aging human crystalline lens with accommodation. *Vision Res* 2005;45(1):117-132

15 Yan PS, Lin HT, Wang QL, Zhang ZP. Anterior Segment Variations with Age and Accommodation Demonstrated by Slit-Lamp-Adapted Optical Coherence Tomography. *Ophthalmology* 2010;117(12):2301-2307

16 Tsorbatzoglou A, Nemeth G, Szell N, Biro Z, Berta A. Anterior segment changes with age and during accommodation measured with partial coherence interferometry. *J Cataract Refract Surg* 2007;33(9):1597-1601

17 Strenk SA, Semmlow JL, Strenk LM, Munoz P, Gronlund-Jacob J, DeMarco JK. Age-related changes in human ciliary muscle and lens: a magnetic resonance imaging study. *Invest Ophthalmol Vis Sci* 1999;40(6):1162-1169

18 Koretz JF, Cook CA, Kaufman PL. Aging of the human lens: changes in lens shape upon accommodation and with accommodative loss. *J Opt Soc Am A Opt Image Sci Vis* 2002;19(1):144-151

19 Glasser A. Accommodation: mechanism and measurement. *Ophthalmol Clin North Am* 2006;19(1):1-12, v.

20 Chen Y, Bao YZ, Pei XT. Morphologic changes in the anterior chamber in patients with cortical or nuclear age-related cataract. *J Cataract Refract Surg* 2011;37(1):77-82

21 Schneider H, Stachs O, Gobel K, Guthoff R. Changes of the accommodative amplitude and the anterior chamber depth after implantation of an accommodative intraocular lens. *Graefes Arch Clin Exp Ophthalmol* 2006;244(3):322-329

22 Menapace R, Findl O, Kriechbaum K, Leydolt-Koeppl C. Accommodating intraocular lenses: a critical review of present and future concepts. *Graefes Arch Clin Exp Ophthalmol* 2007;245(4):473-489