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# Long-term Effects of Diving on Corneal Tomography, Anterior Chamber Depth, and Axial Length of the Eye

## Sualtı Dalışın Kornea Tomografisi, Ön Kamara Derinliği ve Gözün Aksiyal Uzunluğu Üzerindeki Uzun Dönem Etkileri

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ABSTRACT

**Background:** The aim of the study was to investigate the effects of long-term SCUBA and deep diving on corneal tomographic parameters, anterior chamber depth, and axial length of the eye in professional divers.

**Materials and Methods:** This cross-sectional, comparative study comprised military divers and non-diver military personnel. The diver group was divided into two groups, the SCUBA group, which dives up to 40 m with half-face masks, and the deep diver group, which dives deeper than 40 m with diving helmets. Healthy military personnel who didn't dive constituted the control group. A complete ophthalmological examination, corneal tomography, pachymetry, anterior chamber depth, and axial length measurements were made in all participants with a Scheimpflug camera and IOLMaster 500 partial coherence interferometry device.

**Results:** The SCUBA diver group consisted of 30 eyes of 15 participants, the deep diver group consisted of 60 eyes of 30 participants, and the control group consisted of 80 eyes of 40 participants. The median diving time was 10.00 years in the SCUBA diver group, while in the deep diver group, it was 10.50 years. The anterior chamber depth value showed a statistically significant decrease in the SCUBA diver group compared to the control group (p=0.018). The y-coordinate of the corneal thinnest point to the corneal apex showed a statistically significant increase in the SCUBA diver group compared to both the control group and the deep diver group (p=0.019). The differences in corneal keratometry, Q value, astigmatism, thinnest pachymetry, and axial length measurements were not statistically significant between the groups (p>0.05).

**Conclusion:** The significant decrease in the anterior chamber depth, together with the increase in the y-coordinate of the thinnest point suggested a positive pressure effect on the cornea in diving groups, especially in the SCUBA group. However, none of the eyes showed loss of visual acuity and/or abnormal findings on the ophthalmological examination.

**Keywords:** Anterior chamber depth, anterior ophthalmic parameters, cornea, deep diving, eye, SCUBA

ÖZ

**Amaç:** Bu çalışmanın amacı, profesyonel dalgıçlarda uzun süreli SCUBA ve derin dalışın kornea tomografik parametreler, ön kamara derinliği ve gözün aksiyel uzunluğu üzerindeki etkilerini araştırmaktı.

**Gereç ve Yöntemler:** Bu kesitsel, karşılaştırmalı çalışma, askeri dalgıçlar ve dalgıç olmayan askeri personeli içermekteydi. Dalgıç grubu, yarım yüz maskeleri ile 40 metreye kadar dalan SCUBA grubu ve kasklarla 40 metreden daha derine dalan derin dalgıç grubu olarak iki gruba ayrıldı. Dalış yapmayan sağlıklı askeri personel kontrol grubunu oluşturdu. Tüm katılımcılara tam göz muayenesi, Scheimpflug kamera ve IOLMaster 500 parsiyel koherens interferometri cihazı ile, kornea tomografisi, pakimetri, ön kamara derinliği ve aksiyal uzunluk ölçümleri yapıldı.

**Bulgular:** SCUBA dalgıç grubu 15 katılımcının 30 gözünden, derin dalış grubu 30 katılımcının 60 gözünden ve kontrol grubu 40 katılımcının 80 gözünden oluştu. SCUBA dalgıç grubunda ortanca dalış süresi 10,00 yıl iken, derin dalgıç grubunda ortanca dalış süresi 10,50 yıl oldu. Ön kamara derinlik değeri SCUBA dalgıç grubunda kontrol grubuna göre istatistiksel olarak anlamlı bir azalma gösterdi (p=0,018). Kornea en ince noktasının kornea apeksine olan y-koordinatı, SCUBA dalgıç grubunda hem kontrol grubu hem de derin dalgıç grubuna göre istatistiksel olarak anlamlı bir artış gösterdi (p=0,019). Gruplar arasında korneal keratometri, Q değeri, astigmatizma, en ince pakimetri ve aksiyel uzunluk ölçümlerindeki fark istatistiksel olarak anlamlı değildi (p>0,05).

**Sonuç:** Ön kamara derinliğindeki belirgin azalma, en ince noktanın y-koordinatındaki artışla birlikte dalış gruplarında, özellikle SCUBA grubunda kornea üzerinde pozitif bir basınç etkisi olduğunu gösterdi. Ancak hiçbir gözde görme keskinliği kaybı ve/veya oftalmolojik muayenede anormal bulgular saptanmadı.

**Anahtar Kelimeler:** Ön kamara derinliği, ön oftalmik parametreler, kornea, derin sualtı dalışı, göz, SCUBA

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## Introduction

Diving is a profession practiced in fields such as military, scientific, search and rescue. It is also an activity done as underwater photography and sports. The number of professional and amateur divers is increasing all over the world and in Türkiye.

During diving activity, exposure to increased ambient pressure at an undersea level can cause medical problems in many organs, especially in the respiratory system and the eye (1,2,3,4). Ocular barotrauma is one of the main diving issues in ophthalmology (5,6,7,8). According to Boyle's law, the volume of a certain quantity of gas is inversely proportional to the absolute pressure (9). Air-filled organs and tissues decrease in volume as the pressure increases. The aqueous liquid and vitreous gel protect the eye against barotrauma in the absence of any mask in front of the eye. With a mask, an air-filled chamber forms in front of the eyes. This chamber is susceptible to pressure changes under the sea level. As the depth increases under the sea, the exposed pressure to the mask will also increase (9). Thus, the volume and pressure of the chamber formed by the mask will also change. It is expected that these changes will also affect the eyeballs forming a wall of the chamber. This effect results in ocular barotrauma.

Equipment technology is also being improved day by day to protect divers from both life-threatening decompression sickness and potential adverse effects on the eyes and other organs. In SCUBA diving, which is up to 40 m deep, half-face masks that cover the eyes and nose or full-face masks where the whole breathing is done inside the mask are used. However, in deeper dives, only full-face masks or diving helmets are used. Because they have different designs, they will be affected by pressure and the gas content differently. This study aimed to investigate the effects of long-term SCUBA and deep diving on corneal tomographic parameters, anterior chamber depth (ACD), and axial length (AL) of the eye in professional divers.

## Material and Methods

This cross-sectional study was approved by the Ethical Committee of the University of Health Sciences Türkiye (date: 16.02.2023, number: 23-13) and conducted according to the criteria of Helsinki Declaration. Written informed consent was obtained from all participants.

The study consisted of military divers and non-diver military personnel referred to the outpatient clinic of the ophthalmology department for routine periodic eye examinations. The diver group was divided into two groups as the SCUBA group, which dives up to 40 m, and the deep diver group, which dives deeper than 40 m. Healthy military personnel who didn't dive constituted the control group. According to the criteria for being military personnel, all participants were individuals with less than 1 D of a refractive error and no other ophthalmological disorders. Individuals who had undergone any procedure including refractive surgery on the cornea and had any history of intraocular surgery were excluded from the study. Other exclusion criteria were smoking and presence or history of any systemic disease, including hypertension.

Visual acuity and intraocular pressure measurements, slit-lamp and fundus examinations were performed on each participant. Corneal tomography, pachymetry, and anterior chamber measurements were made with a Scheimpflug tomography device (Pentacam, Oculus®, Germany). IOLMaster 500 device (Carl Zeiss Meditec AG, Jena, Germany) was used for the AL measurement Keratometry (K) 1, K 2, K mean, astigmatism, maximal K (within 6 mm diameter), Q value (corneal asphericity value), thinnest pachymetry, and the y-coordinate of the thinnest point to the corneal apex were recorded from the corneal tomographic measurements (Figure 1). ACD was another parameter obtained from the Scheimpflug device (Figure 1). Corneal tomography parameters evaluated in the study are described in Table 1.

The SCUBA diver group used half-face masks that covered the nose and upper face area, but with a breathing apparatus in the mouth as a separate part from the mask. The deep diver group used diving helmets, with full breathing within the helmet, covering the entire face, including the mouth. Annual dive hours were recorded for each participant in both diver groups.

### Statistical Analysis

Data were analyzed with IBM SPSS V23. The Kolmogorov-Smirnov and Shapiro-Wilk tests for conformity to normal distribution were examined. Independent two-sample t-test was used to compare normally distributed data according to paired groups, and Mann-Whitney U test was used to compare non-normally distributed data. The Kruskal-Wallis test was used to compare the data that were not normally distributed according to groups of three or more, and multiple comparisons were examined with the Dunn test. One-Way Analysis of Variance was used to compare normally distributed data according to groups of three or more, and multiple comparisons were examined with Duncan's test. The relationship between non-normally distributed data was used with Spearman's rho correlation coefficient. Analysis results were presented as mean ± standard deviation and median (minimum-maximum) for quantitative data, and frequency (percent) for categorical data. Significance level was taken as p<0.05.

## Results

The study compared three groups; the SCUBA diver group, the deep diver group and the control group. The SCUBA diver group consisted of 30 eyes of 15 participants, the deep diver group consisted of 60 eyes of 30 participants, and the control group consisted of 80 eyes of 40 participants. All participants were male military personnel. The mean age was 33.40±6.32 years in the SCUBA diver group, 34.30±7.95 years in the deep diver group and 33.66±6.06 years in the control group. There was no statistical difference between the ages of the groups (p>0.05). All participants had 20/20 of uncorrected visual acuity. The median diving time as years was 10.00 (2.00-22.00) years in the SCUBA diver group, while in the deep diver group, the median was 10.50 (2.00-30.00) years. There was no statistical difference in the diving time as years between the groups (p=0.935). Consistently, there was no significant difference in the total diving time as hours between groups [400.00 (20.00-950.00) hours in the SCUBA diver group and 275.00 (50.00-2000.00) hours in the deep diver group as the median] (p=0.356).

When the corneal K 1, K 2, K mean and K max values were compared between the groups, no statistically significant difference was observed (p>0.05) (Table 2). There was no statistically significant difference between the groups in the comparison of astigmatism and Q value (p>0.05) (Table 2).

While there was no difference between the groups in the comparison of corneal thicknesses, the y-coordinate

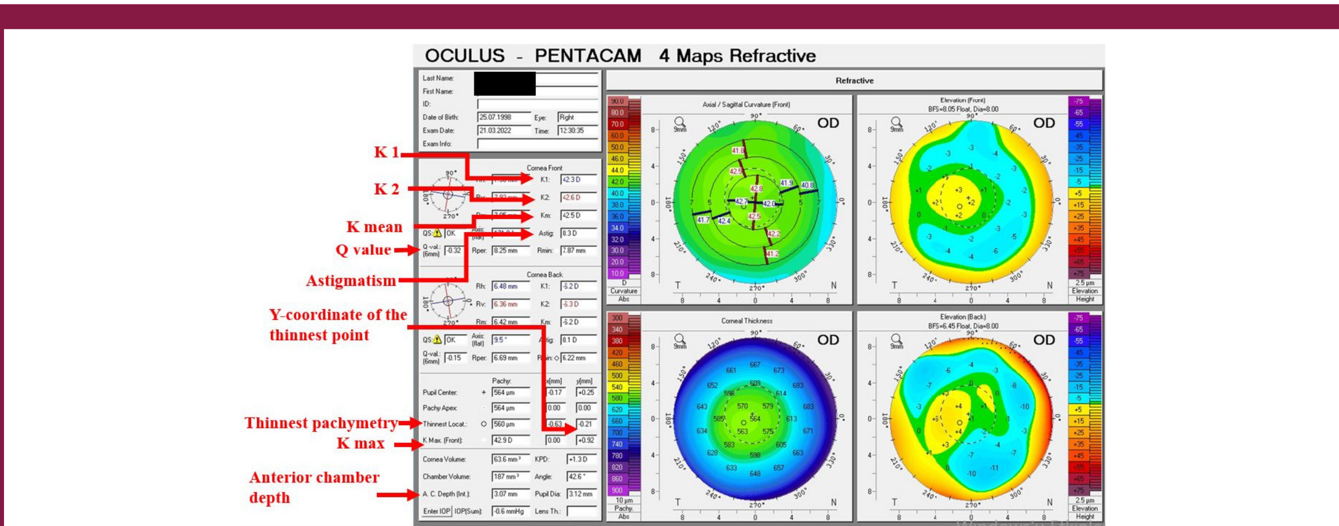


**Figure 1.** The image of the Pentacam 4-maps refractive screen. The data from the Pentacam measurement are displayed on the image

**Table 1. Parameters obtained from the corneal tomography measurements**

| Parameter | Description |
|---|---|
| Keratometry 1 (K 1) | The curvature-related refractive power of the major flat meridian in the central 3 mm of the anterior cornea. |
| Keratometry 2 (K 2) | The curvature-related refractive power of the major steep meridian in the central 3 mm of the anterior cornea. |
| Mean keratometry (K mean) | The arithmetic means of the K 1 and K 2 values. |
| Astigmatism | The value of astigmatism in the central 3 mm of the cornea. |
| Q value | The asphericity value of the central 6 mm of the cornea, between -0.25 and -0.50 in normal eyes. |
| Maximum K (K max) | The maximum curvature-related refractive power in the any point of the central 8 mm of the cornea. |
| Thinnest pachymetry | The minimum value of the corneal thickness within central 8 mm of the cornea. |
| Y-coordinate of the thinnest point | The vertical coordinate of the thinnest point relative to the corneal apex. |
| Anterior chamber depth | The distance from the posterior surface of the corneal apex to the center of the anterior surface of the crystalline lens. |

**Table 2. Comparisons of the SCUBA diver, deep diver and control groups**

| | SCUBA diver group n=30 | | Deep diver group n=60 | | Control group n=80 | | Test st. | p |
|---|---|---|---|---|---|---|---|---|
| | Mean ± SD | Median (min-max) | Mean ± SD | Median (min-max) | Mean ± SD | Median (min-max) | | |
| K 1 (D) | 42.53±1.37 | 41.95 (40.60-45.70) | 42.30±1.47 | 42.20 (38.50-45.10) | 42.47±1.78 | 42.15 (39.40-52.50) | 0.129[1] | 0.937 |
| K 2 (D) | 43.16±1.49 | 42.80 (41.10-46.60) | 43.10±1.57 | 42.80 (40.00-46.20) | 43.12±1.43 | 43.00 (40.30-46.50) | 0.003[2] | 0.958 |
| K mean (D) | 42.83±1.42 | 42.35 (40.90-46.10) | 42.68±1.53 | 42.40 (38.80-45.60) | 42.72±1.41 | 42.55 (38.90-45.70) | 0.074[2] | 0.786 |
| Q value | -0.23±0.09 | -0.24 [(-0.06) - (-0.48)] | -0.23±0.13 | -0.20 [(-0.04) - (-0.69)] | -0.26±0.12 | 0-.24 [(-0.03) - (- 0.61)] | 3.266[1] | 0.195 |
| Astigmatism (D) | 0.66±0.25 | 0.60 (0.40-1.30) | 0.77±0.41 | 0.70 (0.10-2.00) | 0.78±0.45 | 0.80 (0.10-2.10) | 1.821[1] | 0.402 |
| K max (D) | 43.66±1.73 | 43.25 (41.30-48.70) | 43.60±1.64 | 43.40 (40.10-46.70) | 43.67±1.48 | 43.40 (40.70-48.80) | 0.133[1] | 0.936 |
| Thinnest pachymetry (µm) | 547.03±37.21 | 545.00 (479.00-638.00) | 537.17±30.20 | 537.50 (476.00-605.00) | 537.35±37.19 | 534.00 (475.00-633.00) | 1.540[1] | 0.463 |
| Y-coordinate of TP (mm) | -0.62±0.25 | -0.61 [(-0.14) - (-1.19)][b] | -0.47±0.19 | -0.52 [(-0.12) - (-1.05)][a] | -0.48±0.22 | -0.48 [(0.00) - (-1.09)][a] | 7.935[1] | 0.019 |
| ACD (mm) | 3.03±0.28[b] | 2.94 (2.50-3.48) | 3.05±0.30[ab] | 3.10 (2.47-3.78) | 3.16±0.30[a] | 3.14 (2.35-3.82) | 5.707[2] | 0.018 |
| AL (mm) | 23.67±0.61 | 23.54 (22.88-25.22) | 23.86±0.69 | 23.76 (22.17-25.73) | 23.83±0.65 | 23.91 (22.50-25.43) | 3.280[1] | 0.194 |

SD: Standard deviation, Test st.: Test statistics, K: Keratometry, D: Diopter, TP: Thinnest point, ACD: Anterior chamber depth, AL: Axial length, [1]Kruskal-Wallis H test, [2]One-Way Analysis of Variance, [a-b]There is no difference between groups with the same letter

of the thinnest point on the cornea showed a statistically significant increase in the SCUBA diver group compared to both the control group and the deep diver group (p=0.019) (Table 2).

The ACD value showed a statistically significant decrease in the SCUBA diver group compared to the control group (p=0.018). Although the ACD value in the deep diver group was much lower than the control group, there was no statistically significant difference between the deep diver group and either the control group or the SCUBA diver group (p>0.05) (Table 2).

When the AL of the eyes were compared, although they were shorter in the SCUBA diver group than in the deep diver and control groups, the differences were not statistically significant (p>0.05) (Table 2).

No significant correlation was found between the y-coordinate value of the thinnest point and the diving time (r=-0.164; p=0.122). However, a negative correlation was found significantly between diving time and ACD (r=-0.240; p=0.023).

## Discussion

To the best of our knowledge, this is the first study to examine the effects of diving on the anterior segment parameters of the eye in a long-term and real-life context. While human beings live on the earth, they are exposed to the ambient pressure created by the combined dispersed gases of equal weight in the atmosphere. At sea level, this exposed pressure is called one atmosphere absolute (ATA). This is natural and ideal for human life. In the environment where diving activity takes place, human are exposed to pressure above one ATA at the undersea level and this pressure increases as the depth increases. The body's response to pressure changes in the environment depends on the anatomy of the organ (10). The size of a liquid-filled or solid organ will not change with pressure. However, gas-filled, elastic-walled organs gradually compensate for pressure changes with volume changes, according to Boyle's law. Since the eyeballs contain aqueous and vitreous fluids, they will not be affected by changes in pressure below sea level. However, the use of masks, which is an indispensable equipment in diving, changes this situation. Masks create an air-filled space in front of the eyeballs, thus creating a new situation in which they will act from the changing pressure.

The study compared two groups of divers who dived at different depths and with different equipment to each other and to a control group of similar demographic and physiological characteristics who did not dive. The SCUBA diver group contained cases diving up to 40 m and used half-face masks covering upper half of the face with the nose and without the mouth. The deep diver group consisted of cases diving more than 40 m and used diving helmets covering the entire face including the nose and mouth. The two types of the masks form chambers with different physiological properties (11). In a half-face mask, a mouth breathing apparatus is used separately from the mask and the diver is only able to exhale into the mask (11). When the diver inhale and exhale through the separate mouthpiece during diving, negative pressure and related ocular barotrauma will occur inside the mask according to Boyle's law (11). With a diving helmet, the diver can both inhale and exhale into the helmet. Thus, it is easier to balance the gas pressure with the aid of a regulator, with a breathing environment close to normal conditions.

The present study showed that ACD of the eye was significantly reduced in the SCUBA diver group compared to the control group. ACD in the deep diver group was also lower than in the control group, higher than the SCUBA diver group, but the differences were not statistically significant. The half-face mask is expected to create negative pressure inside the mask and a vacuum effect on the eyeballs. However, the decrease in ACD revealed by the study suggests the effect of positive pressure on the cornea. A previous study stated a reduction in ACD with swimming googles but that study showed a short-term change and reversibility after the removal of the googles (12). The diver groups in the present study consisted of professional divers. Because these divers were trained in exhaling through their noses to balance the undesirable negative pressure, a negative pressure effect could not be observed in the results of the study. It can even be thought that these divers exhale more and create positive pressure in the mask to avoid negative pressure during descent. The positive pressure with diving helmets complies with the laws of physics. Prolonged exposure to the positive pressure may cause flattening of the cornea and can reduce anterior chamber depth. The other finding in the study is that ACD values are negatively correlated with the diving hours. ACD value decreased as the diver's diving time increased.

Another finding in the study suggesting the flattening effect of positive pressure on the cornea is the decrease in central K values. The median values of K mean and astigmatism were the lowest in the SCUBA diving group, the deep diving group and the control group were followed it (K mean, 42.35 D, 42.40 D, 42.55 D; astigmatism, 0.60 D, 0.70 D, 0.80 D, respectively) although the differences were statistically insignificant.

A statistically significant variable in the study was the y-coordinate of the corneal thinnest point. This data shows the distance of the thinnest point of the cornea from the geometric center. In ectatic disorders of the cornea such as keratoconus, it is seen that the thinnest point moves away from the geometric apex and shifts towards the inferior and temporal (13,14). There are many studies showing that rubbing the eyeballs, thus pressing and flattening the cornea, plays an important role in the etiology of keratoconus (15,16,17). The current study found the lowest y-coordinate of the thinnest point in the control group (-0.48), but it increased to -0.52 in the deep diver group, and -0.61 in the SCUBA diver group, demonstrating the highest shift of the corneal vertex in the last group. This finding supports the theory of positive pressure on the eye in the SCUBA diver group, in line with the reduction in ACD.

AL measurements were parallel to ACD measurements, with the highest AL in the control group and the lowest AL in the SCUBA diver group, but the differences were not statistically significant.

The results of the present study showed that, although not statistically significant, the cornea was the thickest in the SCUBA diver group, followed by the deep diver group and the control group, respectively. Deleu et al. (18) found an increase in corneal thickness after 30 and 60 min of SCUBA diving and they suggested that this may be due to ocular barotrauma. On the contrary, Maverick et al. (19) reported that although they detected a minimal decrease in corneal thickness in their measurements after 20 minutes of SCUBA diving in 12 eyes, there was no significant change. Jiménez et al. (20) in their experimental study with swimming goggles, did not detect a significant change in corneal thickness in their measurements about 5 minutes with the goggles and 2 minutes after taking them off. All these studies are on the short-term effects of SCUBA diving or swimming goggles and are not based on long-term and real-life data like the current study.

## Conclusion

The results of the study revealed a significant difference in ACD and the y-coordinate of the thinnest point, with the highest difference in the SCUBA diver group. The decrease in ACD correlated with the increase in diving time. The decrease in ACD, together with the increase in the y-coordinate of the thinnest point and the decrease in the K mean values, suggest a positive pressure effect on the cornea. Because the participants in the study group were professional and well-trained, they managed to protect their eyes from the possible side effects of diving. Despite the significant differences in some variables obtained in the study, none of the participants had any visual symptoms. No abnormal findings were detected in the ophthalmologic examinations. For this reason, it is thought that the good training of divers and the use of advanced equipment minimize the effect of diving activity on the cornea and other anterior segment parameters in real-life practice.

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### Ethics

**Ethics Committee Approval:** This cross-sectional study was approved by the Ethical Committee of the University of Health Sciences Türkiye (date: 16.02.2023, number: 23-13) and conducted according to the criteria of Helsinki Declaration.

**Informed Consent:** Written informed consent was obtained from all participants.

**Peer-review:** Internally and externally peer-reviewed.

### Authorship Contributions

Surgical and Medical Practices: B.K., N.D., Concept: B.K., N.D., Design: B.K., N.D., Data Collection or Processing: B.K., N.D., Analysis or Interpretation: B.K., Literature Search: B.K., Writing: B.K., N.D.

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