An investigation of corneal integrity in recreational divers

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ABSTRACT

Objective: To compare the corneal integrity of recreational divers and non-divers.

Methods: The cross-sectional study was conducted at the St. Erik's Eye Hospital, Stockholm, Sweden, between September 2003 and February 2004. Questionnaires were randomly distributed to determine the potential diving and non-diving participants. After filling the questionnaires and giving informed consent, corneal endothelial photographs were obtained from the right eyes of the study participants (age range, 20-42 years). Aided and unaided visual acuities were obtained using the Snellen acuity chart.

Results: One of the divers reported temporary blurred vision immediately after a diving session, which resolved 2 days later. The average median corneal endothelial cell size for the recreational divers was 14.3 μm^2 larger than that of the non-divers (p=0.43), and the mean endothelial cell density was 95.7 cells/mm^2 less than the non-divers (p=0.51).

Conclusion: There are no significant adverse permanent effect of diving on vision amongst the recreational divers. There is an indication of polymegethism and pleomorphism among the divers, however, no significant difference in the corneal morphology of the recreational divers and the non-divers. However, a further investigation with a larger sample size is needed to confirm this.

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Underwater diving has become popular due to the availability of easy-to-use life-support equipment. Decompression, a consequence of bubble formation that often happens when the partial pressure of body tissues exceeds the ambient pressure is commonly encountered in diving.[1] Factors including tissue perfusion and surface tension of the gas-medium interface, account for the high incidence of bubble formation in veins, joints, the spinal white matter, and ocular surface tissue.[2,3] Health concerns in recreational sport diving include diseases of the lung, heart, brain, and the endocrine system.[3] Symptoms may range from unconsciousness to fatigue, personality changes, poor concentration, irritability, and changes in vision.[3] As a guide to safety, the clinical standards of practice in the United States do not support diving for persons with asthma and insulin-dependent diabetes.[3,4] For example, decompression sickness was first associated with submarine escape training where rapid ascent forced air into the pulmonary veins, causing cerebral air embolism and rapid unconsciousness.[5,6] Reduction of gas-filled spaces within the body when descending underwater and overexpansion during ascent cause considerable physiologic changes in the body tissues ranging from ocular, tympanic membrane injury to lung damage, and entry of air into the arterial circulation.[3,4] At sea level, the ambient pressure is described as one atmosphere absolute (1 ATA). This pressure increases by 1 ATA for every 33 feet of descent in sea water.[3] The human eye normally exists in a world where it is exposed to ambient pressure that is the result of the combined and equally distributed weight of all the gases in the Earth's atmosphere. The ophthalmic aspects of diving have received less attention in the literature. Cases of ocular manifestations of diving documented include that of a 39-year-old diver who had painful blurred vision in the right eye immediately after scuba diving several inches from a red coral reef.[7] The diver had multiple superficial corneal foreign bodies with infiltrates that gradually resolved after 3 months of topical

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corticosteroids treatment. This type of keratitis might have resulted from the release of vasoactive substances by the red coral's toxin-releasing organelles.[7] Another report presented a case of a 41-year-old recreational diver who suffered an orbital hemorrhage following face-mask barotraumas.[8] Recompression is usually the mainstay of treatment for decompression sickness.[9] In a survey by Taylor et al[10] comprising 709 divers from Australia (n=346), and United States (n=363), 16 of the 709 divers reported permanent disabilities including hearing loss, tinnitus, and balance disorder, and the findings warrant further research.[10,11] Regarding the impact of refractive surgery on diver's cornea, it may be argued that divers who have had radial keratotomy, Laser assisted in situ keratomileusis (LASIK) should not dive due to the risk of a trauma with rupture along the lines of the corneal incision.[12] However, a study by Huang et al[12] reported that acute hyperbaric stress did not alter refractive power after corneal surgery. Concerning contact lens wear, soft lenses have been found safe with diving except for possible lens loss or displacement.[13,14] Hard contact lens wear causes corneal edema after diving,[15] probably by the formation of nitrogen bubbles in the pre-corneal tear film. However, fenestration of 0.4 mm in the center of a hard contact lens has been reported to prevent bubble trapping and corneal edema.[15,16] There are various diving concerns, however, the focus of the present study is to investigate any subtle subclinical effect in the corneal morphology of recreational divers.

Methods. The participants were recruited through personal contacts, study recruitment posters, and local Internet network. The study took place at the St. Erik's Eye Hospital, Stockholm, Sweden. Altogether, 35 divers and 10 non-divers, all residents in the Stockholm area were recruited in the present study. Only 16 of the 35 divers fulfilled the study requirement according to the questionnaire and screening eye examination. After filling the questionnaires and giving their informed consent, corneal endothelial photographs were obtained from the right eyes of study participants between September 2003 and February 2004. The participants were in the age range of 20-42 years, with the mean of divers being 32 years, and the mean age of non-divers being 33 years. Of all the 16 divers included, 10 had refractive error correction with glasses and soft contact lenses, and the remaining 6 were emmetropic. Six of the 10 non-divers had refractive error correction, and the other 4 were emmetropic. The study protocol approval was obtained from the appropriate institutional ethical committee. The study was explained to all subjects, and consent obtained. Participants were recruited on the basis that they would be able to come for a screening

eye examination at the university eye hospital if they responded positively. The inclusion criterion for the recreational divers was at least 2 years diving with at least 40 dives per year. For the non-divers only subjects that had never been under any hyperbaric pressure conditions such as an oxygen chamber were included. The subjects were in good health, as self-reported, however, exclusions were made on the basis of any remarkable history of a systemic disease that could affect the cornea, such as diabetes type-1, multiple sclerosis, and lupus erythematosus. Subjects were subsequently invited to visit our clinic for an eye examination if they responded yes, and they provided suitable comment and clarification (sometimes through telephone or e-mail communication) on questions such as occupation, general health, eye disease, glasses or contact lens use, and if any diving experience. The subjects were asked to complete a questionnaire. The questionnaire included providing information on age, gender, visual correction requirements and whether they wear glasses or contact lenses. Questions in the study questionnaire are as contained in **Table 1**. Visual acuity (VA) was measured with a Snellen acuity chart under standard clinical conditions. Three images in the central part of the corneal endothelium on each of the subjects' right eyes were obtained with a Topcon non-contact specular microscope (model SP 1000P, Topcon, Japan) with a camera using the auto focus mode. At the time of the image capture, the corneal endothelial cells were assessed objectively for any anomalies, such as blebs, polymegethism, pleomorphism, guttae, and other signs of corneal edema. The corneal endothelium was then assessed objectively following the manufacturer's recommendation. To do this, a region of interest (ROI) was selected from the middle of the image. This ROI was enlarged to facilitate the marking of 21 contiguous cells on the displayed image using a mouse-based cursor. The software calculates an average median cell size (or area), and provides an estimate of the endothelial cell density (ECD). The calculation of the ECD is based on the average cell area of the 21 cells. The semi-automatic identification of cell borders and subsequent calculation of cell density and variation coefficient for cell size were repeated 3 times. The average of the 3 estimations for each subject was used as the subject data. To compare with the 10 non-divers, the data for 10 out of the 16 divers were randomly selected.

All data were entered into an Excel spreadsheet for generation of descriptive statistics. The student t test was utilized, with any *p* value less than 0.05 regarded as significant. The data were recorded as endothelial cell density (cells/mm^2); minimum, median, and maximum cell size (μm^2).

Table 1 - The study questions (questionnaire) and response as utilized in the survey.

Questions	Response		
Do you engage in any form of diving?	Yes ( )	No ( )	
Indicate your date of birth.	Day:	Month:	Yr:
If you engage in diving, how many years have you been diving?	( )	Stopped one yr ago	Still diving
If you engage in diving, how many dives do you perform in one year? Indicate how often?	( )	Every 3 months Every 6 months	Others
Do you wear spectacle glasses or contact lenses? If Yes, circle what type:	Yes ( ) No ( )	Spectacle glasses Contact lenses	
Indicate if your spectacle glasses or contact lenses have plus or minus signs.	Plus ( )	Minus ( )	
Do you have any visual change during diving? If Yes, circle what type of visual change.	Yes ( ) No ( )	Blurry Sharper Cannot describe	
When did you notice the visual change after diving? Circle the answer that applies to you.	1 day 2 days 7 days	2 weeks 4 weeks Never	
When did the noticed visual change after diving disappear? Circle the answer that applies to you.	1 day 2 days 7 days	2 weeks 4 weeks Never	

Results. In total, 16 completed questionnaires were collected from the recreational divers, and 10 from non-divers. Aided and unaided VA was 20/20 in both groups. Slit-lamp biomicroscopy of anterior eye was unremarkable in both groups. Five out of 16 divers had, at least at one occasion, noticed a change in vision (such as blurring of sight) during diving. Four out of the 5 divers who noticed vision change, claimed to use their spectacle glasses daily and at diving, however, one of the divers would rarely wear their correction during diving (claiming not needing glasses for distance vision, wearing a hyperopic prescription). Out of the 4 divers who wear their corrections when diving, 2 reported sharper vision under water, while one reported blurry vision, and one cannot describe the visual change. Six out of the 11 divers, who reported no vision change during diving, also claimed to use their spectacle glasses daily and when diving. The question regarding any change in vision during diving was recorded as sharper, blurrier or cannot describe. One diver reported that the blurriness noticed immediately after one diving expedition resolved completely 2 days after the diving. The part of the study, which involved morphology of corneal endothelium, was undertaken to determine if there were any differences in the corneal endothelium of divers versus non-divers. As mentioned, this was carried out by taking corneal endothelial pictures with Topcon non-contact specular microscope (model SP 1000P, Topcon, Japan), on 16 divers and 10 non-divers.

Then the pictures were analyzed with the accompanying endothelial picture-analyzing program as described above. The literature indicates that the normal endothelial cell density value in the age range 20-40 years of the present study is approximately 2500-3000 cells per square mm (mm^2).[17] **Figures 1 and 2** show 2 samples of representative endothelial photographs, each from one diver and non-diver. Though the difference in the characteristic hexagonal appearance of the corneal endothelial cells in the photograph is not apparent, however, the statistical analysis showed a different trend in terms of the hexagonal morphology. The results of the analysis of the corneal endothelial cell density, sizes, and shapes are presented in **Tables 2 and 3**. The result of the cell density shows that non-divers have 95.7 cells per mm^2 higher mean value than in the divers, while that of the median cell size shows that the divers have 14.3 μm^2 larger values than the non-divers.

Discussion. The motivation for the present study was based on the theory that recreational divers could be at high risk of adverse stress to their ocular surface tissue such as the cornea and conjunctiva from the hyperbaric environment during diving. There are different types of diving such as recreational, military (navy), and commercial with the different degrees of risk, however, the sample size in the present study is too small to allow any categorization between the types of diving. Although a preponderance of polymegethism
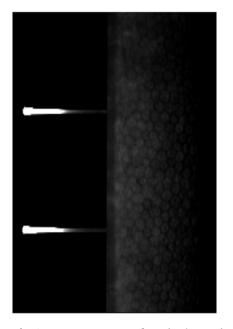
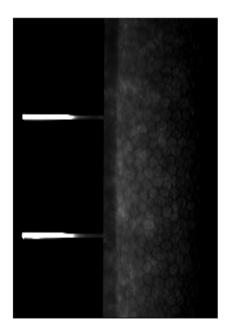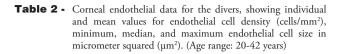**Figure 1** - A representative picture of non-diver's corneal endothelium.

Figure 2 - A representative picture of diver's corneal endothelium.

Table 2 - Corneal endothelial data for the divers, showing individual and mean values for endothelial cell density (cells/mm²), minimum, median, and maximum endothelial cell size in micrometer squared (µm²). (Age range: 20-42 years)

Subject	Cell density (cells/mm²)	Cell size (µm²)		
		Minimum	Maximum	Median
1	3338.4	159.0	501.7	299.5
2	2884.2	171.8	558.2	346.7
3	2557.5	177.0	886.7	391.0
4	2720.0	190.8	705.2	367.6
5	3178.3	108.8	685.5	314.6
6	2657.5	139.5	652.0	376.3
7	2253.0	143.2	674.0	443.8
8	3224.9	116.5	623.4	310.1
9	3412.6	125.2	613.5	293.0
10	2778.0	181.9	542.3	360.0
Mean value	**2900.4**	**151.4**	**664.3**	**350.3**

Table 3 - Corneal endothelial data for the non-divers, showing individual and mean values for endothelial cell density (cells/mm²), minimum, median and maximum endothelial cell size in micrometer squared (µm²).

Subject	Cell density (cells/mm²)	Cell size (µm²)		
		Minimum	Maximum	Median
1	2981.4	157.1	561.0	335.4
2	2729.4	110.4	618.9	366.4
3	3401.0	152.4	586.1	294.0
4	3282.8	135.5	518.8	304.6
5	2899.7	169.7	634.9	344.9
6	3248.9	126.6	570.6	307.8
7	2677.6	172.6	577.9	373.5
8	2879.3	153.6	588.7	347.3
9	3139.8	127.5	579.3	318.5
10	2721.5	224.6	565.2	367.4
Mean value	**2996.1**	**153.0**	**580.1**	**336.0**

and pleomorphism was observed among the divers' data, the present study did not show a significant difference in the corneal integrity of the recreational divers as compared to the non-divers. Given the likely possibility that there is a small physiologic stress in the cornea under hyperbaric conditions, a very large number of subjects would be required to conclusively show any between-group clinical difference.

The result of the present study from the questionnaire analysis indicated that one diver reported experiencing temporary blurring of vision immediately after a dive, which resolved 2 days after the diving. A probable explanation for this temporary blurry vision could be a myopic shift (a changed refraction in the direction of myopia) that occurred during the dive, which resolved 2 days after completing the particular diving

expedition. A similar experience has been reported in a closed-circuit mixed-gas scuba diver, which took one month to resolve.[18] In terms of similar hyperbaric oxygen exposure, another previous study also observed a reversible myopic shift after exposing 25 patients to a series of approximately 150 hyperbaric oxygen therapy sessions.[19] In terms of high altitude, it has been argued that pressure alone cannot be responsible for the visual changes noticed in the hypobaric environment, and it is hypoxic rather than hypobaric environment that is responsible for visual changes at certain altitude.[12] In that regard, if pressure alone were responsible for visual changes, the 4-fold increase in pressure moving from sea level to 99 feet sea water, (equivalent to 4 ATA) should have a more obvious effect than the two-thirds decrease in pressure from sea level to 29000 feet (0.3 ATA).[12] Apart from the concern on the cornea as an external ocular tissue, it has been shown that chronic exposure to a hyperbaric environment can result in hyperbaric oculo-visual changes such as myopia, and fundus lesions.[20,21] It is still unclear if hyperbaric myopia is caused by changes in the lens alone, or both in lens and cornea.[22,23] The focus of the present study is on the cornea. Huang et al[12] investigated the effect of recreational diving on corneal thickness and other parameters, post-refractive surgery, and found no statistically significant change in corneal pachymetry or keratometry between pre-hyperbaric and post-hyperbaric measurements. It is generally acknowledged that the underwater environment places a few conditions on the divers that are not experienced at sea levels. It should be noted that mask squeeze, an uncommon complication seen primarily in novice divers can create a pressure across the cornea. In the 1980s, studies of corneal integrity after radial keratotomy (RK) showed that the surgical incision might rupture at lower pressure than in non-surgical eyes.[24] At higher pressure, Peters et al[25] found no change in cornea pachymetry in 2 control and 2 radial keratotomy patients, and concluded that radial keratotomy was not a contraindication to recreational diving. Regarding a more recent refractive surgery method, Stratas and Peterson[26] reported that LASIK is safe for a recreational diver, although with no objective measurement. One of the concerns in the underwater environment is the immediate postoperative period, when exposure to seawater may introduce a higher risk of infection or mechanical dislodgement of the corneal flap after LASIK. A prominent researcher in diving, Butler[4] has recommended a 3-month healing period after RK, however, does not have specific recommendations after LASIK. The advent of newer refractive surgery methods demands continuous investigations on the impact on the corneas of individuals who engage in

diving. Guidelines for diving after ocular surgery, and suggestions on glasses and contact lens wear and diving, need to be developed and regularly revised.

A longitudinal study is needed to address if diving has a long-term impact on divers' cornea. To enhance the availability of data, the study of the effect of diving on the eye should be prospective. Divers should be advised on wearing the appropriate general body gear when diving. Based on the findings in the present study, it does not appear that recreational diving presents any adverse effects to cornea integrity as a consequence of underwater hyperbaric environment. While no substantial clinical changes in corneal endothelium are evident in the present study, it should not be taken that absolutely no changes to the cornea can occur due to diving. If divers go on repeated diving expeditions without adherence to reasonable health and safety guidelines, then subclinical damage to corneal integrity must be considered as a possibility that can serve to indicate any impending assault on the anterior eye. Recreational diving is a growing exercise activity that requires a thorough knowledge of the physics and physiology of the sport.

In conclusion, although there appears to be a preponderance of polymegethism and pleomorphism in the divers' cornea, the results did not show any significant difference in the corneal morphology of the recreational divers and non-divers. However, further investigation with a larger sample size is needed to confirm this.

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Related topics

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