Keratoconus and Fitness to Fly

Maxime Delbarre; Pascale Crepy; Françoise Froussart-Maille

BACKGROUND: Of the body senses, vision is the most important for safe flight. Keratoconus causes progressive blurring and distortion of vision, which threatens the career of a civilian or military aviator. The goal of this retrospective study was to describe a series of keratoconus cases in a pilot population and to discuss decisions about their flight waivers.

METHODS: To assess the impact of keratoconus on flying careers, we reviewed the records of all aviators with keratoconus examined in an Aeromedical Center over the past 5 yr.

RESULTS: The files of 19 pilots [13 line pilots and 6 military pilots (3 fighter pilots)] were collected and analyzed. Of the 19 patients, 2 did not obtain flight fitness waivers. Among the 17 who received waivers, correction for defective distant vision (glasses or contact lenses) was imposed on 5 aviators.

DISCUSSION: Keratoconus is a medical condition with aeromedical significance that should be detected by aeromedical examiners. A flight license can only be considered if the disease is stable and with satisfactory visual quality. Double pass aberrometry may be helpful to determine flight fitness. This study shows that keratoconus is not always a disability for aviators. Most of them are able to continue their flying careers safely. However, it must be analyzed on a case-by-case basis.

KEYWORDS: expertise, flight fitness, pilots, keratoconus, vision, visual quality.

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Keratoconus is an ectatic corneal dystrophy characterized by noninflammatory, apical thinning and conical protrusion of the cornea. This condition usually manifests itself as a bilateral irregular astigmatism. The disease occurs in all races, bilaterally and asymmetrically. The prevalence of keratoconus in the whole population is 1.38 per 1000 population.[9] Keratoconus typically commences at puberty and progresses to the mid-30s, at which time progression slows and often stops. Between age 12 and 35 it can arrest or progress at any time and there is no way to predict how fast it will progress or if it will progress at all.[6] In general, young patients with advanced disease are more likely to progress to the point where they may ultimately require some form of surgical intervention. The disease stabilizes more after the fourth decade. Symptoms are highly variable and, in part, depend on the stage of progression of the disorder. Keratoconus may result in blurred vision, light sensitivity, nearsightedness, and double vision, leading to profound visual loss.

There are many keratoconus treatments options available today.[1,15] Treatment for keratoconus depends on the severity of the condition and how quickly the condition is progressing. Generally, there are two approaches to treating keratoconus: slowing the progression of the disease and improving vision. If keratoconus is progressing, corneal collagen cross-linking might be indicated to slow or stop the progression.[22] This procedure strengthens and stabilizes the cornea by creating new links between collagen fibers within the cornea. Corneal collagen cross-linking is effective at stabilizing corneal topography and visual acuity over the long term in patients with progressive keratoconus.[14] A small percentage of treated eyes may continue to progress.[20,21] However, this treatment does not reverse keratoconus.[18–20] Improving vision depends on the severity of the disease. Mild to moderate keratoconus can be treated with eyeglasses or rigid gas permeable contact lenses.[10] This will likely be a long-term treatment, especially if the cornea becomes stable with time or from cross-linking.

From the Percy Military Hospital, Clamart, France.

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Address correspondence to: Maxime Delbarre, M.D., Ophthalmology, Percy Military Training Hospital, 2 rue Lieutenant Raoul Batany, Clamart 92130, France; delbarremaxime@gmail.com.

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Intrastromal corneal ring segments are medical devices made of synthetic material designed to alter the morphology and refractive power of the cornea. Intrastromal corneal ring segment implantation is a safe and reversible technique that can achieve corneal flattening and improved visual outcomes.[3,11] In some people with keratoconus, the cornea becomes scarred with advanced disease or wearing contact lenses becomes difficult. In these people, cornea transplant surgery might be necessary.

Vision is probably the most important of the aviator's senses. Any decrease in visual acuity potentially poses a threat to flight safety. When a member of the aircrew is referred for keratoconus, flight fitness becomes questionable.

The development of new therapies and vision quality assessment devices currently allows assessing the fitness of an applicant with some flexibility in standards in some cases. In civilian aviation, applicants with keratoconus may be assessed as fit if visual requirements (hypermetropia not exceeding +5.0 diopters; myopia not exceeding −6.0 diopters; astigmatism not exceeding 2.0 diopters; anisometropia not exceeding 2.0 diopters) are met with the use of corrective lenses. Civilian pilots must meet refractive criteria and distance visual acuity, with or without correction, which must be at least 6/9 (0.7) for each eye separately, and at least 6/6 (1.0) with both eyes. Medical reports of the applicants shall be referred to the medical assessor of the licensing authority if the visual requirements are not met. The licensing authority can decide if a derogation from the medical standards can be obtained if the pilot does not meet the visual requirements (eye refraction or visual acuity).

At the initial examination, in French military aviation, the pathology is an absolute disabling condition. Even forme fruste keratoconus leads to an unfit to fly decision due to the risk of progression of the disease. No military pilot can start training if he has keratoconus. In revalidation and renewal examinations, in the case of keratoconus, the military pilot shall be referred to the defense aeronautics medical commission to obtain a derogation to fly. This commission decides on fitness to fly according to the medical files on a case-by-case basis.

In French (civilian and military) aviation, nearly 16,000 examinations are conducted on aircrew members (4000 pilots) in the Ophthalmology Department of the National Pilot Expertise Center (Clamart, France) each year. The mission of this center is to select and monitor aircrews. It is the main center for military personnel and supports many private pilots and those employed by commercial airlines.

When keratoconus is identified during a routine visit, the information is recorded in a register, allowing us to locate the records of these patients for analysis. A corneal topography is performed systematically during the first visit for all pilots and at the request of the ophthalmologist if it is necessary during a routine visit. If the visual requirements are met, a periodic evaluation is performed by an ophthalmologist.

The objective of this retrospective study is to describe a case series of keratoconus in an aircrew population and to discuss decisions about their flight fitness.

METHODS

Subjects enrolled in this study were flying aviators who demonstrated evidence of keratoconus on corneal imaging. Exclusion criteria were patients with low quality topographic maps that did not meet the minimal quality required by the system. The study was approved by the Ethics Committee of the Percy Army Training Hospital.

Our study focused on patients with expertise records examined between 2016 and 2021. It involved all aviators who presented with keratoconus responsible for unfitness to fly during systematic monitoring at the Ophthalmology Department of the National Pilot Expertise Center. Medical records were retrospectively examined, and the following data were analyzed:

- Age, gender, aeronautic specialty;
- Date of diagnosis, time of follow-up;
- Visual acuity (best corrected and uncorrected distance and near visual acuity);
- Corneal topography parameters (central corneal thickness, thinnest point pachymetry, flat k value, steep k value, mean k value, maximum keratometry) measured with a Scheimpflug camera (Oculus Pentacam Rotating Scheimpflug Camera; Oculus, Wetzlar, Germany);
- Objective scatter index (OSI) with HD Analyzer© (Visiometrics, Cerdanyola del Vallès, Espagne);
- Modulation transfer function cutoff frequency (MTF cutoff) with the HD Analyzer©. The intersection between the MTF curve and the abscissa axis corresponds to the cutoff frequency.[8] It is normally given that a cutoff frequency of 30 cpd in contrast sensitivity function corresponds to a visual acuity of 20/20;
- Pearson correlation coefficient was used to measure the strength of a linear association between MTF cutoff and best corrected distance visual acuity;
- Keratoconus stage classified into four stages according to the Amsler-Krumeich classification;[12] and
- Fitness-to-fly results.

RESULTS

The files of 19 pilots [13 line pilots and 6 military pilots (3 fighter pilots)] were collected and analyzed. The military pilots with keratoconus did not suffer from keratoconus on their initial examination. All these pilots began their pilot training with normal corneas. Keratoconus developed during their careers, unlike the civilian pilots, some of whom already had keratoconus.

All the pilots were men. Each patient presented with bilateral involvement. The candidates were on average 22.42 ± 2.03 yr of age at the time of diagnosis (**Table I**).

Eight pilots were declared fit to fly without limitation. Nine pilots were declared fit to fly with optical correction limitation (valid only with correction for defective distant vision or correction by means of contact lenses). Two were declared unfit to fly.

Table I. Summary Table.

PILOT	BIRTH YEAR	JOB	AGE AT THE TIME OF DIAGNOSIS (yr)	CURRENT AGE (yr)	KERATOCONUS STAGE (INITIAL EXAM)	CURRENT KERATOCONUS STAGE	CURRENT BCVA (DECIMAL)	CURRENT CCT (μm)	CURRENT KERATOMETRY GREATER CURVATURE (D)	CURRENT MEAN KERATOMETRY	CURRENT ASTIGMATISM (D)	CURRENT OSI	CURRENT MTF CUTOFF (cpd)	FLIGHT APTITUDE	OPTICAL CORRECTION LIMITATION
1	1981	MP (FP)	25	40	0	1	1.0	482	47.7	44.7	1	0.6	36.5	Derogation	VDL
					0	2	0.9	495	47	45.6	1.75	1	34.7		
2	1979	MP (FP)	24	42	0	1	1.0	494	46.9	45.7	2	1.6	16.9	Derogation	None
					0	1	1.0	488	48.6	44.6	0.75	1.2	21.7		
3	1984	MP	22	37	0	2	0.8	485	47.2	45.8	1.75	1.9	21.7	Derogation	VDL
					0	1	1.0	478	46.8	45.4	1.25	1.8	23.8		
4	1992	MP	24	29	0	1	0.9	548	48.2	44.8	1.5	0.8	34.9	Derogation	None
					0	1	1.0	527	47.5	43.9	0.75	0.7	31.9		
5	1990	MP	22	31	0	2	0.8	482	49.7	43.7	2.25	1	32.2	Derogation	CCL
					0	2	0.8	507	50.6	44.4	1.75	1.4	23.8		
6	1996	MP	23	25	0	2	0.6	479	51.2	47.4	2.00	1.8	8.2	Unfit to fly	
					0	2	0.7	472	52	47	2.5	2	5.3		
7	1991	LP	25	30	0	2	0.7	499	49.8	47.9	2.75	2.6	11.7	Derogation	VDL
					0	2	0.7	485	51.6	47.3	2.25	2.8	12.8		
8	1997	LP	20	24	1	1	0.8	517	46.9	45.3	2.75	3.1	7.9	Derogation	VDL
					1	1	0.9	531	46.5	45.7	3.5	2.6	16.5		
9	1983	LP	21	38	1	1	1.0	505	48	43.3	2.25	2.2	21.6	Fit to fly	VDL
					1	1	0.9	510	49	43.9	2.75	2	24.8		
10	1985	LP	23	36	0	1	1.0	548	45.4	45.6	2.25	1.5	15.7	Fit to fly	None
					0	1	1.0	487	46.4	45.7	2.5	0.9	36.2		
11	1995	LP	19	26	1	3	0.6	513	52.8	49.6	2.75	3	10.8	Derogation	CCL
					1	2	0.7	532	50.6	48.7	3.5	2.4	12.8		
12	1986	LP	25	35	0	1	1.0	420	47.3	45.5	2.5	1.9	15.8	Fit to fly	None
					0	1	1.0	449	47.5	44.6	2	0.9	26.9		
13	1983	LP	21	38	2	3	0.6	451	52.2	48.6	2.75	3.6	6.3	Derogation	VDL
					2	2	0.8	487	51.7	48.9	3.5	3.4	4.9		
14	1995	LP	21	26	1	1	0.8	485	47.3	44.2	1.75	1.6	24.8	Derogation	VDL
					1	1	0.9	488	48	45.3	2	1.3	22.9		
15	1992	LP	25	29	0	2	1.0	448	50.8	46.7	2.75	2.3	9.7	Derogation	VDL
					0	3	0.6	536	51.1	47.2	2.5	2.9	15.5		
16	1991	LP	24	30	0	1	1.0	531	46.8	43.5	1.25	0.8	35.8	Fit to fly	VDL
					0	1	1.0	410	47.9	44.6	2	1.4	17.7		
17	1980	LP	23	41	0	1	1.0	503	47.8	45.2	1.5	0.8	23.9	Fit to fly	None
					0	1	1.0	520	49.1	44.9	1.75	1.1	22.6		
18	1990	LP	20	31	1	2	0.9	510	50.8	47.8	2.25	3.1	13.6	Fit to fly	VDL
					1	2	1.0	503	50.1	47.6	1.75	3.3	9.4		
19	1994	LP	19	27	1	3	0.6	481	52.9	48.1	2.5	3.8	7.5	Unfit to fly	
					1	3	0.5	476	53.5	49.1	2.75	4.2	6.2		

BCVA: best corrected visual acuity; CCT: central corneal thickness; OSI: objective scatter index; MTF: modulation transfer function; MP: military pilot; FP: fighter pilot; LP: line pilot; VDL: valid only with correction for defective distance vision.

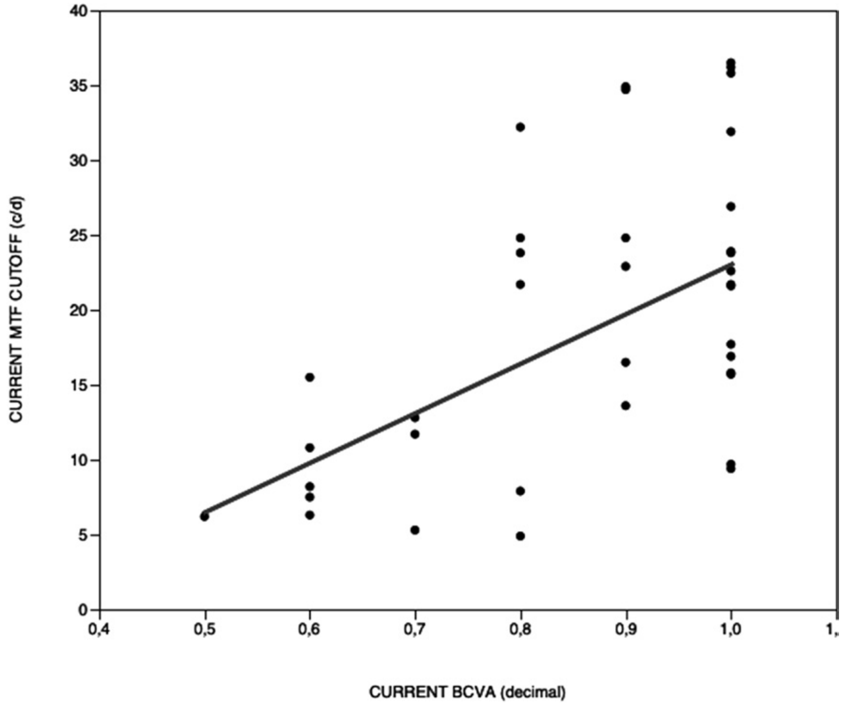

Fig. 1. Relationship between best corrected visual acuity (BCVA) and modulation transfer function cutoff frequency (MTF cutoff).

Six military pilots (three fighter pilots) with ages between 24 and 42 yr (mean age: 32.4 ± 5.7) presented with stage 1 keratoconus (N = 6 eyes) or stage 2 keratoconus (N = 6 eyes). The anterior and posterior corneal elevation maps were considered normal at the initial exam (not suspicious of keratoconus). All these pilots met the requirements for admission to pilot training during their first medical examination.

Using decimal notation, current best corrected visual acuity (BCVA) for all these military subjects was equal or better than 0.6. The average maximum keratometry was 48.6 ± 1.8 D, with a range of 46.8 to 52.0. Visual quality assessment was performed using a double pass aberrometry for each pilot; the mean OSI was 1.49 ± 0.80 and the MTF was 24.3 ± 10.3.

Five of these pilots were declared fit to fly after derogation by the French Military Authority, and two of them needed to wear correction for defective distant vision and carry a spare set of spectacles. One of them needed correction by means of rigid gas permeable contact lenses. Only one was not fit to fly.

There were 13 civil pilots with ages between 24 and 41 yr (mean age: 31.6 ± 5.3) who presented with keratoconus in different stages (Stage 1, N = 14 eyes; Stage 2, N = 7 eyes; Stage 3, N = 5 eyes). Seven of these pilots began their career with keratoconus; the corneal dystrophy was diagnosed during the selection visit.

Using decimal notation, BCVA was measured; all had equal or better than 0.5. The mean maximum keratometry was 49.3 +/2.3 D, with a range of 45.4 to 53.5 D. Among these cases, three pilots had undergone cross-linking therapy treatment. In this group, the mean OSI was 2.1 ± 0.85 and the mean MTF was 16.7 ± 8.6.

Six of these pilots have received an aviation medical certificate from the French Civil Aviation Authority. Correction for defective distant vision and a requirement to carry a spare set of spectacles (glasses) was imposed on eight aviators. One of them needed correction by means of rigid gas permeable contact lenses, another one was unfit to fly.

We found a significant positive correlation between MTF cutoff frequency and BCVA [Pearson correlation coefficient (ρ) = 0.5663 95%CI (0.3011, 0.7502)] (**Fig. 1**).

DISCUSSION

This study analyzed the career impact of keratoconus in aviation. We found that 17 of 19 aviators (89%) retained sufficiently corrected vision to remain able to fly at their last examination.

If pilots do not meet fitness standards, a civilian or military medical board may issue a flight waiver. These commissions rule according to a set of criteria ranging from the age of the pilot, the type of aircraft, the visual acuity, the stage of keratoconus, the evolution of the disease, and the vision quality.

The population of this study only includes men, which can be explained by the characteristics of the population studied. The percentage of female fighter and transport pilots in the French army is 2.3%[16] and approximately 10% in civilian aviation.

Due to careful initial medical selection, the number of pilots suffering from keratoconus is rare. The diagnosis of keratoconus is now facilitated by efficient topographers, which allows analysis of anterior and posterior corneal elevation. This probably explains why no military pilot has recently developed a keratoconus during their career.

With the development of computer processing, some new quantitative evaluation technology of vision quality is available.

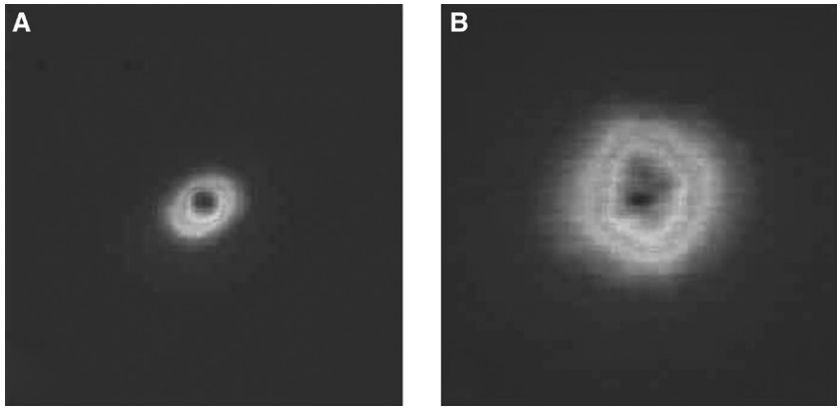

Fig. 2. Two-dimensional point-spread function plots derived from double-pass retinal imaging (HD Analyzer©). A) subject without keratoconus; B) subject with keratoconus.

The optical quality analysis system (HD-Analyzer©) is a double-pass system that is a convenient and objective method for visual quality assessment, including the higher order aberrations and scattered light. OSI provides information on the relevant forward scatter that affects vision.[2] This index may represent a clinically significant parameter that can evaluate quality of vision. OSI for normal eyes would range around 1, while values greater than 5 would represent highly scattered systems. Leonard et al. indicate that OSI may be useful in the diagnosis and staging of keratoconus given the significant increases observed at mild and moderate severity of keratoconus.[13] They did not show any significant differences between the OSI values of normal subjects and those with mildly atypical topography [early keratoconus (Stage 1) and moderate keratoconus (Stage 2)], suggesting that the quality of the retinal image in these patients is relatively normal. These results are similar in our study. We included moderate forms of the disease, which is probably why OSI values are low. On the contrary, Ren et al. reported that vision quality in the forme fruste, mild, or moderate keratoconus was inferior to that in normal vision.[19] The HD-Analyzer© gives important qualitative information, helping practitioners better understand the visual circumstances that pilots with keratoconus suffer from, particularly with more advanced forms of the disease.

The point spread function provides information on the overall optical performance of the human eye: it is the irradiance distribution of light from a point source projected onto the retina and it indicates the extent of blurring of the retinal image. This image is useful to easily evaluate vision quality (**Fig. 2**).

We found a significant positive correlation between MTF cutoff frequency and BCVA. The blurring of the retinal image reduces the subjective visual acuity, which is directly related to the MTF cutoff value, although it is not affected by retinal and neural factors. It is normally assumed that a cutoff frequency of 30 cpd in contrast sensitivity function corresponds to a visual acuity of 20/20.[17]

Most patients with keratoconus are managed with glasses or contact lenses for visual rehabilitation. However, although visual acuity may be improved, other aspects of visual function, such as contrast sensitivity or glare, may still be affected.[4] The residual aberrations significantly reduced contrast sensitivities at low and intermediate spatial frequencies for keratoconic eyes wearing rigid gas-permeable lenses.[23] Soft contacts have been proven to provide an operational advantage over the wear of spectacles in missions that require maneuvering flight, the use of night vision goggles, the wear of an oxygen mask, and the ability to quickly look to the far limits of lateral gaze, but some lenses have a high risk of inducing corneal hypoxia in flight due to poor oxygen transmissibility.

Contact lenses remain stable under load factors; Flynn et al. did not notice significant decentration of the contact lens during a test in a human centrifuge.[7] Dislodgement of a hard contact lens with acceleration, loss of the contact lens from the eye, and bubbles forming under the contact lenses during rapid decompression are possible. Hard contact lenses are even less stable on keratoconic eyes due to the abnormal shape. Dennis et al. showed a descent down the z-axis of 2–3 mm during a centrifuge test.[5] This type of contact lens seems not suitable for fighter pilots.

Military fighter pilots require perfect vision due to the nature of combat military aviation. The selection of these pilots is rigorous, so the detection of a keratoconus is a concern of ophthalmologists working at the National Pilot Expertise Center. The development of a keratoconus during a career would remove the fighter pilot from flight status. It is necessary to refer military pilots with keratoconus to the defense aeronautics medical commission. In some cases, derogations from medical standards can be obtained in order to fly again. The situation for airline pilots is different; keratoconus can be tolerated if the quality of vision does not deteriorate.

In conclusion, keratoconus is a medical condition of aeromedical importance and should be reported to aviation medical examiners upon diagnosis. At the initial examination in military aviation, the pathology is an absolute disabling condition. Certification in civil aviation is possible in cases where there is stable disease with a stable response to vision correction and correct visual quality. As the disease can potentially progress over a short period of time, the validity of medical aeronautical certification may be shortened accordingly (from 6 mo to 1 yr), especially in affected younger applicants, whose disease could advance more aggressively. Glare, distracting distortions, and monocular diplopia are symptoms that deserve special attention and make keratoconus a cause of incapacitation during flight. HD-Analyzer© images contain information about the vision quality of the eye. This device could be useful to decide whether or not the applicant is fit to fly in the case of keratoconus as it is not always a disability for aviators. Most of these pilots are able to continue their flying careers safely. However, it must be analyzed on a case-by-case basis.

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Authors and Affiliation: Maxime Delbarre, M.D., M.Sc., Pascale Crepy, M.D., and Françoise Froussart-Maille, M.D., M.Sc., Percy Military Hospital, Clamart, France.

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