

USAARL Report No. 93-19



Military Research with Contact Lenses

By

Roger W. Wiley

Visual Sciences Branch

Sensory Research Division

March 1993

Approved for public release; distribution unlimited.

**United States Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-5292**

Notice

Qualified requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), Cameron Station, Alexandria, Virginia 22314. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

Change of address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

Disposition

Destroy this report when it is no longer needed. Do not return to the originator.

Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

Reviewed:


RICHARD R. LEVINE
LTC, MS
Director, Sensory Research
Division


ROGER W. WILEY, O.D., Ph.D.
Chairman, Scientific
Review Committee

Released for publication:


DAVID H. KARNEY
Colonel, MC, SFS
Commanding

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified				1b. RESTRICTIVE MARKINGS			
2a. SECURITY CLASSIFICATION AUTHORITY				3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited			
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE							
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 93-19				5. MONITORING ORGANIZATION REPORT NUMBER(S)			
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromedical Research Laboratory		6b. OFFICE SYMBOL (If applicable) SGRD-UAS-VS		7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Development Command			
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 620577 Fort Rucker, AL 36362-5292				7b. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21702-5012			
8a. NAME OF FUNDING / SPONSORING ORGANIZATION		8b. OFFICE SYMBOL (If applicable)		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER			
8c. ADDRESS (City, State, and ZIP Code)				10. SOURCE OF FUNDING NUMBERS			
				PROGRAM ELEMENT NO. 62787A	PROJECT NO. 3M162 787A879	TASK NO. BG	WORK UNIT ACCESSION NO. 168
11. TITLE (Include Security Classification) (U) Military Research with Contact Lenses							
12. PERSONAL AUTHOR(S) Roger W. Wiley							
13a. TYPE OF REPORT Final		13b. TIME COVERED FROM _____ TO _____		14. DATE OF REPORT (Year, Month, Day) 1993 March		15. PAGE COUNT 24	
16. SUPPLEMENTARY NOTATION							
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) contact lenses, reduced field-of-view, lens reflections				
FIELD	GROUP	SUB-GROUP					
20	06						
19. ABSTRACT (Continue on reverse if necessary and identify by block number) Although all military air services have strict vision standards to select only the most physically qualified candidates, the prevalence of refractive errors among aviators is quite significant. Recent advances in helmet mounted displays and other cockpit equipment have raised compatibility issues with spectacle corrections. Because of these compatibility problems, many military services are considering contact lenses as a possible refractive error correction option. In this paper, the numerous military laboratory-based and field tests of contact lenses are reviewed. Military contact lens research has a history of almost 50 years. In general, the results from these investigations have supported the adoption of positive contact lens policies and several military departments have recently modified their policies to allow use of contact lenses by aviation personnel. Different lens materials and wearing regimens have been recommended, and the data fail to strongly support a particular lens type over all others. Clearly, some lens types are more appropriate for different military requirements and environments.							
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS				21. ABSTRACT SECURITY CLASSIFICATION Unclassified			
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Scientific Information Center				22b. TELEPHONE (Include Area Code) (205) 255-6907		22c. OFFICE SYMBOL SGRD-UAX-SI	

Table of contents

Introduction..... 3

Military research with contact lenses..... 4

 Early studies with PMMA lenses..... 5

 Contact lenses for tanker/transport/
 patrol missions..... 7

 Contact lenses for the fighter/attack missions..... 9

 Contact lenses for rotary-wing aircraft..... 12

 Contact lenses in unique military environments..... 13

Recent issues..... 15

Summary.....18

References.....19

This page intentionally left blank.

Introduction

Good visual acuity is essential for pilots and other aircrew members. When selecting flying personnel, aeromedical authorities have traditionally insisted on strict visual standards for cockpit crew, and, until recently, most NATO air forces have had little need for visual refractive correction among aircrew. This may change as pilot recruitment and training procedures undergo modifications. In the USAF for example, 10 percent of pilots are spectacle wearers at intake, but 27 percent of pilots and 51 percent of navigators are currently flying with some form of refractive correction.

The use of contact lenses (CL) by military aircrew potentially could eliminate many of the problems associated with spectacles, e.g., reduced field-of-view, lens reflections, fogging, displacement under high Gs, vibration, and discomfort on extended missions. Spectacles also are proving difficult to integrate with chemical defense gear, as well as night vision goggles and future helmet mounted display systems. Moreover, recent technical developments in lens materials and production/fitting procedures have given soft contact lenses a very widespread acceptability in civilian life. Consequently, a demand for the sanctioning of contact lenses in the military cockpit is to be expected, and indeed most air forces have already encountered such challenge to current rules.

However, aircrew use of CLs during military missions raises problems very different from those in most other occupations and leisure time activities. Field use makes routine hygienic and cleansing procedures impractical, or impossible, and the military cockpit poses special risks such as low humidity, high levels of air particulates, and extreme G-conditions, to name only a few. Also, the prevalence of complications from CL use in the civilian domain is not sufficiently well known to be simply extrapolated to military conditions.

The use of CLs under adverse conditions, with particular application to military aviation, has recently been examined by the Committee on Vision under the Commission on Behavioral and Social Sciences and Education of the National Research Council (USA). The current Working Group 16, set up by AGARD AMP in 1990, has profited from this material, as well as from examining the recent U.S. experiences in the use of CLs in selected flight personnel both in peacetime conditions and during the Persian Gulf conflict.

Military research with contact lenses

Since the beginning of military aviation, vision has been recognized as the critical sensory mode by which a pilot acquires necessary information to fly an aircraft. All military services have medical standards, including demanding vision requirements, to select only the best physically qualified candidates for aviation training. However, now most military air services permit entry of pilot candidates having relatively minor refractive errors. These candidates, combined with nonpilots and those pilots who develop refractive errors during their flying careers, represent a significant percentage of the active aviator population who require optical correction.

Spectacles, usually of special design, are the conventional means for correcting refractive errors of aviators. While corrective spectacles have proven effective over many years, there are recent unique cockpit environments and equipment requirements for which spectacles are inadequate. Because of these, the military operational communities have increasingly asked their supporting medical departments to allow the use of contact lenses to correct refractive errors. A major influence behind these frequent requests is the enormous increase in the use of contact lenses by the civilian community over the last 20 years. With the development of more physiologically compatible materials to fabricate the lenses, there also has been a concurrent greater acceptance of contact lenses among eyecare professionals.

Military medical authorities have been hesitant to allow the use of contact lenses because of the exceptional conditions in which military personnel must operate. Research directed toward civilian use of contact lenses doubtless is not completely applicable for military situations. However, there is a growing body of information, from civilian and military research studies, which should be considered in assisting the development of recommendations regarding the use of contact lenses by military personnel.

Two recent publications (Committee on Vision, National Research Council, 1990, and Lattimore, 1990a) provided insight into some of the information relevant to contact lenses in aviation. The Committee on Vision, U.S. National Research Council, published a report (1990) which detailed the deliberations and recommendations prepared by a civilian committee of contact lens experts. Based upon a literature review and input from military ophthalmic experts, the committee recommended that contact lenses be worn only for mission essential duties and further recommended that, except for unusual

medical indications, only soft contact lenses be allowed. This latter recommendation was based on a perceived problem with foreign body entrapment by rigid lenses or dislodgement of the lenses during flight. In his review, Lattimore (1990b) discussed the published information which served as basis for the decision by the U.S. Army to pursue a large-scale study of contact lenses worn by rotary-wing aviators. Lattimore concluded that, although the currently available information indicated that contact lenses could be worn safely in aviation environments, they represented only a partial solution since they could not provide satisfactory correction for all of the younger aviators and could not satisfactorily correct the more experienced, presbyopic aviator.

Early studies with PMMA lenses

Military contact lens research has a history of almost 50 years. In 1944, Jaeckle reported the results of his investigation of what were unspecified but are presumed to be glass scleral lenses. In his study, he subjected 10 volunteers to various simulated altitudes in a hypobaric chamber and examined the subjects with a biomicroscope. At altitude, most of his subjects had bubbles trapped underneath the lenses and suffered some loss in visual acuity. He concluded that bubble formation should be expected at altitudes of 18,000 feet or greater. Somewhat surprisingly, he did not think his results should serve as a contraindication to the use of these lenses at ordinary altitudes. In 1958, De Vries and Hoogerheide published the results of a similar study. They reported the results from a single fighter pilot who successfully wore polymethyl methacrylate (PMMA) corneal lenses for all phases of flight. They studied the pilot in the controlled environment of a hypobaric chamber and noted bubble formation underneath the lenses which began at 20,000 feet simulated altitude and which increased in size and number with further ascent. This was not accompanied by a measured decrease in acuity, and the bubbles disappeared at about the same altitude during descent, although some corneal staining was observed for 30 minutes following the simulated flight.

Turnour (1960) and Turnour and McCulloch (1962) expanded our knowledge of operational exposures in their studies of personnel wearing PMMA lenses. Of the 22 subjects initially fitted with PMMA lenses, 16 (73 percent) were successful. Various numbers of these subjects then were studied in the following different controlled operational environments: explosive decompression (ground level to 10,000 feet); heat (55°C and 30 percent humidity); cold (-45°C); acceleration (+6 Gz); swimming; pressure breathing; altitude chamber (27,000 feet). Their results indicated that the lenses performed acceptably although the

investigators did note bubble formation under the lenses of three subjects at a simulated altitude of 10,000 feet. Questionnaire data indicated that subject acceptance of the lenses was quite positive. McCulloch (1962) reexamined these same subjects after a period of 18 months during which they had no professional eyecare support available. At that time, one additional subject had discontinued wearing the lenses. Three of the contact lens subjects, one of whom had corneal stippling near the lower limbus, had increased conjunctival injection because of overwear of the PMMA lenses. This cleared promptly with corneal rest. McCulloch also repeated some of the simulated altitude tests in the hypobaric chamber and again reported the observation of gas bubbles, which he attributed to nitrogen, at approximately 18,000 feet. From these studies, the authors concluded that there were no medical reasons to deny use of contact lenses in aviation, but they should be considered a supplement rather than an alternative to conventional spectacles.

In a similar investigation, Newsom, Tredici, and Noble (1969) exposed 16 subjects fitted with PMMA contact lenses to simulated altitudes up to 40,000 feet. They found bubble formation underneath 21 of the 32 lenses and noted that the bubbles increased in size and number with increasing altitudes and a decrease in size and number with decreasing altitudes. Two of their subjects having large central bubbles under their lenses reported blurred vision.

The USAF fitted 167 pilots and navigators with PMMA CLs from 1950-1965. All, except three, discontinued wear due to discomfort, loss of interest, inconvenience, distracting movement, etc., (Tredici and Flynn, 1987). Morris, in 1964, provided early information concerning the issue of long-term wear of PMMA corneal contact lenses by aviation personnel. He obtained follow-up questionnaire data from some of the 82 aviation personnel who had been fitted with PMMA lenses 3-4 years earlier. Of those responding, about 50 percent reported that they were either full or occasional wearers of the lenses, but only 20 percent were full-time wearers (defined as 10 or more hours per day, 7 days per week). He could not decide what determined success or nonsuccess, but inability to obtain regular eyecare was a major reason. There were no reports of dislodgement with G forces and no reports of the formation of bubbles under the lenses at altitude.

During this same period, some consideration was given to allowing the use of PMMA contact lenses in commercial aviation. In 1962, Diamond discussed advantages and disadvantages of correction with contact lenses and concluded that the lenses for aircrew were of questionable safety in the cockpit. A few years later, Wick (1965) revisited the argument and concluded that the

safety level was acceptable. At that time, 2600 pilots, both commercial transport and passenger airline, were wearing PMMA contact lenses with waivers. These pilots represented 0.57 percent of the pilot population, and they accounted for 0.43 percent of the accidents. Wick also thought that the risk of lens decentering or loss was quite minimal in commercial aviation.

These early investigations of contact lenses in aviation provided clear evidence of a significant problem with trapped gas bubbles underneath the gas impermeable PMMA material at simulated altitudes of about 20,000 feet. Curiously, the majority of the authors thought that PMMA contact lenses were acceptable in military aviation. Only Morris (1964) concluded that the disadvantages of contact lenses were greater than the potential advantages. Morris had access to a large number of aviators who had flown a variety of flight profiles while wearing PMMA lenses. The aviators reported that lens loss, lens decentering, and bubble formation had not occurred. Therefore, his recommendation was based on resource considerations rather than physiological effects.

From that point up to the present, laboratory and operational tests have principally used soft contact lenses or rigid lenses made from gas permeable materials. Three broad categories of military operational flight have been identified. These are the the tanker/transport/patrol (maritime) mission, fighter/attack profile of high performance aircraft, and rotary-wing (helicopter) flight. While there are contact lens concerns which are common to all three categories, the environments presented by each are sufficiently unique to deserve separate consideration. Therefore, these same three categories will be used to group the more recent scientific reports where possible.

Contact lenses for tanker/transport/patrol missions

The tanker/transport/patrol mission profile is probably the most benign among military operations for contact lens wear. Cabin altitude is maintained at less than 10,000 feet, usually between 5,000 and 8,000 feet. The primary concern is extended exposure to these slightly reduced oxygen partial pressures and to low humidity, usually between 10 percent and 15 percent. For these conditions, experiences in civilian commercial aviation are directly applicable. Boissin (1973, 1979) provided early information concerning contact lens comfort under these wearing conditions. Using both anonymous questionnaires and some direct examination of cabin and cockpit crew, he concluded that contact lenses were tolerated for flights of 4 hours or less. However, for longer flights, they were uncomfortable. Similarly, Eng (1979) collected questionnaire data from 744 commercial

flight attendants. Almost all reported some eye discomfort which, for almost 50 percent, started less than 2 hours into the flight. Most attributed the discomfort to smoke. However, there were no reported differences between attendants wearing contact lenses and those not wearing lenses. Runge and Friedrich (1979), from their theoretical calculations of the corneal oxygen requirements and availability of oxygen at reduced partial pressures, concluded that none of the lens materials available at that time (1979) would provide sufficient oxygen, and that flight crews should not wear contact lenses for high altitude flights of greater than 2 hours duration. They also recommended that passengers should be warned to remove their lenses prior to flying.

In a study directed specifically toward military aviation, Draeger, Schroder, and Vogt (1980) exposed subjects wearing soft or rigid lenses to simulated altitudes of slightly greater than 8000 feet with a humidity between 12 percent to 15 percent. No findings were made that indicated any deterioration in the fit of the lenses, acuity, or compatibility. In comparison, Punt and coworkers (Punt et al., 1985; Punt et al., 1988) studied various rigid lens materials having oxygen transmission properties ranging from none to high. When their subjects wore these various lenses in simulated altitudes of 8000 feet and less than 20 percent humidity for periods up to 6 hours daily, they observed punctate keratitis with all lens types. They noted a possible relationship with oxygen permeability in that lenses having higher permeability seemed to result in complaints of a milder degree and usually after a longer symptom-free period. There were no changes in acuity.

Other military studies have used soft contact lenses to address similar concerns. Forgie and Meek (1980) fitted soft lenses to their subjects who were then exposed to simulated altitudes of 9000 feet for 6 hours. After 6 hours, their two control subjects not wearing lenses complained of dry eyes along with one of eight soft lens wearing subjects. They observed minimal corneal staining and no changes in visual function. Flynn et al., (1985a, 1985b, 1986a, 1988) used low- and high-water content soft lenses on eight subjects exposed to 10,000 feet simulated altitude and on four additional subjects having similar exposure but with lower (5 percent) humidity. There were indicators of physiologic stress such as increased tear debris, injection, and corneal staining. However, because of the lack of visual degradation and what they considered insignificant symptoms with the lenses, even when low atmospheric pressure was combined with dry air, the authors concluded that soft contact lenses could be worn during flight duties. A similar conclusion was reached by Tinning (1990). He fitted disposable soft lenses to seven subjects exposed to a simulated altitude of 8000 feet over a period of 2.5 hours. Most of his contact lens subjects

showed minor increased perilimbal injection. Rose-Bengal staining of devitalized corneal epithelial cells was increased significantly in those eyes wearing contact lenses. There were no changes in contrast sensitivity and only minor fluctuations in visual acuity for both contact lens eyes and control eyes. He thought that these changes would not interfere with flight duties.

Dennis et al., (1988) conducted a field study aboard a C-5 aircraft performing a routine operation requiring long daily flights on a 5-day mission. Ten subjects wearing soft contact lenses of different water content and six control subjects were examined daily at various times into the flights. Among the contact lens wearers, there was no loss of visual acuity or contrast sensitivity. Some indications of physiological stress (conjunctival injection and tear debris) were noted in both the lens wearers and the controls. One CL wearer who slept briefly while wearing his lenses developed a corneal abrasion which required patching. From their results, the authors concluded that, although there were some indicators of stress, there was insufficient degradation in visual performance or lens comfort to preclude the use of soft contact lenses in military transport aircraft.

These laboratory and field studies have provided a basis for allowing the wear of soft contact lenses on military tanker/transport aircraft. The evidence supporting the use of rigid lenses is less clear, since several published reports indicate the occurrence of punctate keratitis with all rigid lens types, although the severity decreases as lens oxygen permeability increases.

Contact lenses for the fighter/attack missions

The in-flight environment presented by fighter/attack aircraft, perhaps, is potentially the most hostile for the contact lens wearer and, based on the number of scientific publications, has received the greatest attention. Major concerns have continued to be the possibility of bubbles trapped underneath the lenses at higher altitudes, the associated visual changes, physiological responses to the corneal hypoxia created by the reduced oxygen partial pressures at altitude, the oxygen transmission capabilities of the various lens materials, and lens decentering with +Gz. Although many reports have addressed these problems, the results have been mixed and difficult to synthesize because of the differing oxygen transmission properties of the lenses used and differing fitting characteristics of the lenses.

Using both soft contact lenses and PMMA rigid lenses, Simon and Bradley (1980) reported that they observed bubbles underneath nonfenestrated PMMA lenses only at hypobaric altitudes of 37,000 feet, and that the bubbles disappeared within 10 minutes at that altitude. No bubbles were seen on subjects wearing soft lenses or fenestrated PMMA lenses. Eng, Rasco, and Marano (1978) examined subjects wearing soft lenses at hypobaric chamber altitudes of 20,000 feet and 30,000 feet. They did not observe any bubbles nor any changes in acuity, refraction, keratometry, or biomicroscopic findings. In comparison, Hapnes (1980) tested four subjects using daily wear soft contact lenses at a simulated altitude of 18,000 feet. He reported that 8 of the 10 eyes suffered "fogging" of vision after 4 hours at this altitude. Some discomfort also was noted along with lacrimal debris and ciliary injection. Among 6 subjects wearing both rigid and soft lenses, Draeger, Schroder, and Vogt (1980) found only one rigid lens wearer who had a small gas bubble with a simulated altitude of over 16,000 feet. Forgie and Meek (1980) reported that 2 of 10 soft lens subjects had small gas bubbles trapped at the limbal sulcus at a simulated altitude of 25,000 feet. These disappeared after 10 minutes. In a followup test, he had nine subjects wear soft lenses at 25,000 feet for 2.5 hours and noted no significant changes in vision, lens position, or corneal thickness. He observed no gas bubble formation. Significantly more adverse findings were reported by Castren (1983). Among seven subjects who wore soft lenses at a simulated altitude of 12,000 feet for 3 hours, he reported that all had some objective findings. The most serious observations were corneal erosions in 4 eyes and opacities of the corneal stroma in 10 eyes. Brennan and Girvin (1983, 1985) used medium- and high-water content soft lenses with 17 subjects at a simulated altitude of 27,000 feet. They reported no biomicroscopic changes. One of the 17 subjects did suffer slight reduction in acuity, although none of the subjects showed changes in measured contrast sensitivity. Similarly, using low- and medium-water content soft lenses, Flynn et al., (1985, 1986, 1988) reported no bubble formation or biomicroscopic changes other than increased lacrimal debris. No changes in visual acuity or contrast sensitivity were measured. In a second study using both rigid gas permeable lenses and soft lenses, Flynn et al., (1985, 1986) studied a large number of subjects at a variety of hypobaric chamber altitudes or on transport aircraft during flights. Central bubbles were observed at altitudes greater than 20,000 feet in 20 percent of the eyes wearing rigid lenses. With soft lenses, bubble formation only at the limbus was detected in 24 percent of the eyes tested, sometimes occurring at altitudes as low as 6000 feet. Acuity was not affected.

Punt and Heldens (1988) reported an original study in which spherical and aspherical rigid gas permeable lenses were used. They noted no changes in fit or function with gradual decompression up to 27,000 feet. However, with rapid decompression, gas bubbles formed and increased in size and number for several minutes, finally dissipating after 6 minutes at 27,000 feet. A clear picture of the corneal response to the hypoxic environment has not emerged from these studies. Obviously, gas bubbles are trapped underneath some contact lenses at altitude in some subjects. There is a suggestion that the location of the bubbles is central with rigid lenses and more peripheral at the limbal sulcus with soft lenses. Since few studies reported any corneal changes following exposure in hypobaric chambers, physiological changes likely are related to oxygen transmissibility of the lenses. The visual acuity reductions at altitude that were reported for several subjects probably were not sufficient to compromise flight safety.

The potential for contact lenses to decenter from the cornea with exposure to G forces also has been a concern receiving considerable attention. The possibility of this occurring would depend almost completely upon the fitting relationship of the lens to the cornea and the physical properties of the lens material. Therefore, the contact lens response to acceleration forces might depend upon the type of lens worn. Draeger, Schroder, and Vogt (1980) reported that both rigid and soft lenses remained centered during accelerations of 1 G per second up to 3 G. Investigators have used a variety of soft contact lenses to study lens behavior at a number of +Gz levels in centrifuges. Forgie (1981) and Forgie and Meek (1980) fitted 15 mm diameter, lathe-cut soft lenses to 6 subjects who were exposed to +6 Gz (+5.1 Gz at eye level) in a centrifuge. Depending on lid tightness, the lenses were displaced during the exposure, but never sufficiently to uncover the pupillary area. Similar results were found by Brennan and Girvin (1983, 1985) who exposed 13 subjects wearing soft lenses to +6 Gz in the centrifuge. Again, displacement was never sufficient to uncover the pupil. However, some of their subjects suffered significant acuity loss due to grayout or blackout from retinal ischemia. Flynn et al., (1987) increased centrifuge exposures of their soft lens wearers up to +8 Gz. They tested acuity with direction of gaze upward, lateral, and straight ahead during the exposures and found slightly reduced acuity, almost surely due to retinal ischemia, for their contact lens wearers, as well as for their spectacle

wearers and emmetropic control subjects. There have been anecdotal reports from USAF aviators flying fighter/attack aircraft while wearing SCLs which indicate that some lenses become dislodged when the aviator attempts to scan over his shoulder ("check six").

Several investigators have examined the behavior of rigid lenses with exposure to acceleration forces. Punt et al., (1985) compared spherical tricurve PMMA lenses to aspherical gas permeable lenses when they were worn by subjects exposed to high +Gz. Their results showed that the spherical rigid lenses started to decenter with exposures between +6 to +8.6 Gz, while the aspherical lenses remained centered when the subjects were exposed up to +9 Gz. In a separate study, Punt and Heldens (1988) compared spherical and aspherical rigid gas permeable lenses with similar results. The spherical design lenses started to decenter with exposures of +6 Gz, while the aspherical lenses remained centered at higher +Gz exposures. Dennis et al., (1989b) recently reported a similar study comparing aspherical rigid gas permeable lenses of two different diameters. Their subjects were exposed to a variety of accelerations while providing acuity measurements in different gaze positions. With exposures up to +8 Gz (two subjects), acuities with the contact lenses were similar to the spectacle control measurements. These investigators favored the response of the larger diameter lenses. There have been no reports, either from the limited centrifuge experiences or during flight, of rigid lens dislodgement or decentration due to G forces of sufficient magnitude to uncover the pupil.

Contact lenses for rotary-wing aircraft

The primary concerns with the use of contact lenses in rotary-wing environments are foreign body entrapment in flight and potential ocular pathology accompanying lens use in unsanitary field conditions. Relevant data concerning contact lens use in field operations are provided by reports about contact lens use among ground soldiers. Rouwen (1985) conducted clinical examinations for contact lens wearing soldiers just prior to and following a 3-week field exercise. At the end of 3 weeks, he reported that 21 percent of the 53 contact lens wearers receiving follow-up exams had switched back to combat spectacles. The remaining 79 percent wore their contact lenses and had few

complaints and no serious complications, although abnormal biomicroscopic findings had increased. There were reports of foreign bodies trapped underneath rigid lenses and cleaning difficulties with soft lenses. Van Norren (1984) obtained questionnaire data obtained from 87 contact lens wearers (46 rigid lens wearers and 41 soft lens wearers) following a 2-week field exercise. About 20 percent did not use their contact lenses from the start of field maneuvers. An additional 28 percent of rigid lens wearers and 17 percent of the soft lens wearers discontinued their contact lenses during the field exercise. Approximately 62 percent of the original contact lens wearers continued to use their lenses during the exercise.

Marquardt (1976) reviewed the various lens materials available and the advantages and disadvantages of each. Based upon the environment and potential problems which might be experienced, he concluded that contact lenses are not an acceptable alternative to spectacles for military field operations. In the earliest rotary-wing contact lens study, Crosley, Braun, and Bailey (1974) followed 18 aviator subjects fitted with soft lenses for 6 months. One of their primary concerns was foreign body involvement, but this proved not to be a problem. A more significant finding was variable acuity experienced by many of their subjects using these early soft contact lenses. Three of their subjects participated in a 72-hour continuous wear trial of these daily wear lenses without adverse clinical findings. Survey data concerning the use of rigid and soft contact lenses by operational aviators have been provided by Braithwaite (1983) and Burden (1988). These data are interesting for the lack of major problems among the aviators despite wearing histories of more than 10 years.

Bachman (1988, 1990) provided the results of a study of extended wear rigid and soft lenses fitted on 44 rotary-wing aviators. At the end of 6 months, his subjects showed some trends toward increased corneal edema, vascularization, and staining, but the subjects reported a large preference for contact lenses over spectacles for all aviation-related duties. He reported an 86 percent wearing success rate and no flight days lost due to the contact lenses during the 6-month trial period. Lattimore (1990b) recently published an interim report of an ongoing study of helicopter aviators fitted with disposable, extended wear lenses. To reduce the problems of field hygiene, these lenses were worn for variable periods up to 7 days and then were discarded. More than 200 aviators are participating in this study. While there have been no major complications, several adverse lens-related corneal responses (sterile ulcers) have been treated during this investigation and flight duty days have been lost.

Contact lenses in unique military environments

Several potential exposure environments are common to all military aviation profiles. Only Brennan and Girvin (1983, 1985) have provided information about vibration effects on visual acuity. They exposed their soft lens wearing subjects to discrete sinusoidal vibration frequencies and reported acuity decrements with vibrations of 6 and 8 hertz. However, the reductions were similar in magnitude to those found while wearing spectacles. The possibility of extreme temperatures affecting contact lens wear is also common to all flight profiles. As discussed earlier, Turnour (1960) and Turnour and McCulloch (1962) exposed PMMA lens wearing aviators to temperatures of -50°F and +130°F without demonstrating any functional loss. Brennan and Girvin (1983, 1985) exposed their soft lens wearing subjects to -15°F and 122°F without demonstrating any changes. No information is available concerning the wearing of contact lenses in warm, humid environments such as in the equatorial regions. Data concerning contact lenses worn in hot, dry environments was obtained in recent military operations in the Middle East, but is not yet available.

While not a significant concern to the tanker/transport mission, additional potential challenges to contact lens wear by rotary-wing and fighter/attack aviators are presented by noxious fumes and gases. This concern is shared by civilian police forces who are occasionally exposed to riot control gases. In an informative study, Kok-van Aalphen et al., (1985) reported that soft contact lenses appeared to protect the eyes from riot control gases and reduced related symptoms (lacrimation, burning), so that policemen wearing lenses remained more functional during exposure. Dennis et al., (1989a) using physostigmine bromine as a nerve agent simulant, monitored pupillary responses over 8 hours after exposure. Comparing the response of a contact lens eye with an uncovered eye, they concluded that the soft lenses acted as a barrier to the chemical during the first hour and then functioned as a sink, extending the time of the drug effects, after the first hour.

To study fume uptake, Sheeley and Hurst (1985) conducted gas chromatography-mass spectrometry analyses on soft lenses which had been worn by rotary-wing aviators and mechanics for periods ranging from 28 to 63 days. They reported that foreign

substances, primarily aldehydes and hydrocarbons, had been absorbed by the lenses but were present at minimal levels. Lenses worn by mechanics showed greater uptake. Taking a different approach, two studies (Brennan and Girvin, 1983; Levine, Lattimore, and Behar, 1990) investigated whether soft contact lenses could be worn underneath a protective mask. Their concern was the potential loss of hydration of the soft lenses and eye irritation caused by the forced air flow over the lens surface. They found no significant changes in physiological or visual functions after wearing protective masks for 4 hours and concluded that the lenses could be worn under protective masks without causing visual degradation.

Contact lenses also have been fitted to aviation personnel who, without the lenses, would be prohibited from flight duties. In 1972, Barry and Tredici reported results after fitting 11 keratoconic patients with rigid lenses. Nine of the 11 personnel were returned to flying duties. Tredici and Flynn (1986, 1987) published reviews of the medical histories of 55 aviators who had been referred to participate in a controlled lens fitting program because of various ocular conditions. Of the 55, 33 aviators had been unconditionally grounded prior to joining the program. Thirty-one were able to be returned to flight status using contact lenses. Finally, Rouwen et al., (1983) reported his experiences with refitting 28 soldiers with high water content soft lenses used for flexible wear. All but two of these soldiers had compromised anterior segments prior to entry into the study. He reported a successful wearing rate of 71 percent at the end of 3 months, which he considered acceptable given the state of corneal health at the beginning. He concluded that mixed extended/daily wear of soft lenses can be successful and safe, but emphasized the importance of regular follow-up care.

Recent Issues

General enthusiasm and positive support for contact lenses by subjects participating in the many different investigations are recurring themes throughout the diverse publications on military aviation contact lens research. Similar enthusiasm is apparent in several less structured operational aviation reports. Polishuk and Raz (1975) reported successful contact lens wear among 10 of 12 aviators fitted with contact lenses. These aviators performed all types of day and night mission profiles without incident or adverse contact lens response during a study

period of 6 months. Nilsson and Rengstorff (1979) discussed the success of a single Swedish fighter pilot who, at the time of their report in 1979, had worn soft contact lenses for extended periods over 4 years without incident and had experienced all potential environmental exposures which might be expected on a fighter mission. Cresswell, (1989) a flight surgeon and rated aviator, presented strong arguments for allowing the use of contact lenses in high performance aircraft based upon his extensive experience in that environment while wearing contact lenses. He advocates the use of contact lenses rather than spectacles in the fighter environment to enhance safety and effectiveness.

In 1981, Perdriel discussed the different materials used in fabricating contact lenses and reviewed the advantages and disadvantages of each of them in the cockpit. While he urged further research, he recommended continued caution in allowing the use of contact lenses by aviators. In the decade since that discussion, many new materials have been developed for contact lenses. These new materials provide better oxygen transmission properties and increase the fitting options available. During this same period, new electro-optical displays and other head-borne equipment have been incorporated into the cockpit. This new equipment is increasingly incompatible with spectacles and have forced renewed emphasis to consider contact lenses as an alternative to spectacles for refractive error correction. Almost all of the military-relevant contact lens studies published in recent years have concluded that, with appropriate selection, fitting, medical surveillance, and conservative wearing schedules, optional contact lens use would be acceptable in the aviation environment. Only Tressler (1988) recommended against the use of soft lenses in field conditions because of hygiene difficulties. However, his position was based on professional opinion after reviewing 21 patients suffering corneal ulcers. Of these, five were from active duty military patients wearing soft contact lenses. No information was available concerning possible predisposing conditions, and the data may not be entirely relevant to a well-controlled aviation contact lens policy.

Based upon successes from the laboratory and limited field investigations reported here, several military departments have modified their policies concerning the use of contact lenses by aviation personnel, and others have embarked on large scale operational experiments. With appropriate controls, recruits for

the Dutch Army and Air Force are allowed to wear contact lenses. Building from a foundation of their data comparing various lens materials, (Polishuk and Raz 1975; Punt et al., 1985; Punt et al., 1988; and Rouwen, 1985) the Dutch military medical authorities principally recommend the use of rigid gas permeable lenses with aspheric designs. In 1989, the U.S. Air Force approved the use of soft lenses of low- and medium-water content worn on a daily basis. The most recent data compiled from this large scale fitting program (Maffet 1990) indicates continued enthusiasm and success with a grounding rate for medical causes equal to 108 days per 1000 aviator-years. Total grounding rate, including administrative actions, is much higher. Cloherty (1985) reported data from ongoing contact lens trials in the Royal Air Force. He has personally monitored 70 aircrew who have been fitted with high water content soft lenses over a 12-year period; they flew more than 40,000 flying hours without incident. Initially they were allowed to wear lenses for 14 days continuous wear and out one night. After 5 years, this regime was changed to 7 days continuous wear and out one night. He now recommends the same high water content soft contact lenses, but they are to be used as daily wear and can be used as continuous wear for up to 7 days only when operational reasons demand such use, and only then. He also recommends no massaging of lenses in the palm of the hand during the cleaning/disinfecting process. New lenses are supplied every 6 months. His report is the longest continued observation of the same individuals by the same person to date.

The U.S. Army currently is conducting large scale contact lens trials in helicopter environments (Lattimore 1990b). For these tests, disposable low and medium water content lenses are used. Approximately 600 aviators now have participated in the trials for more than 24 months, including recent military operations in the Persian Gulf. The most serious incidents were six sterile ulcers which resolved without complications. Results also have been reported by Siegel (1990) from U.S. Navy experiments with Navy and Marine aviators. Using mostly soft contact lenses, but some rigid gas permeable lenses, worn either in a daily or extended wear regimen, Siegel (1990) reported that no adverse medical or operational events have occurred and acceptance of the lenses by the aviators has been quite positive.

Summary

A review of the many military laboratory and field tests demonstrates that a universal policy concerning contact lenses has not been considered and probably is not necessary. Different lens materials and wearing regimens have been recommended, and the data fail to strongly support a particular lens type over all others. Clearly, some lens types are more appropriate for certain situations and environments. It is reasonable to provide the clinician with the flexibility of a small variety of fitting options to best meet the physiological and occupational requirements of an individual aviator in spite of the obvious logistical advantages of dealing with only one type of lens and support system.

Perhaps the greatest environmental challenge to successful lens wear is presented by the hot and dusty desert environment. Aviators have been wearing contact lenses in the recent large scale military operations in the Middle East. While structured data collection and analyses are incomplete, anecdotal and preliminary reports from some aviators and supporting medical resources indicate continued enthusiasm and minimal medical problems with soft contact lens wear, although some operational problems were encountered.

Several ocular complications are strongly linked to use of contact lenses and should be expected to occur with aviators as the number of users and length of wear continues to increase. No information is available concerning a probable incidence rate of ocular complications, since military environments are sufficiently unique, and probably more physiologically harsh, to invalidate rates based on civilian experiences. Lens-related ocular complications will affect aviator availability and impact tactical plans and medical resource requirements. Perhaps some of the answers for these and other medical and nonmedical issues related to contact lenses which remain unresolved will be forthcoming from the ongoing field experiments. Ultimately, the rate of complications (visual, medical, operational) will determine whether the military services continue to use contact lenses.

References

- Bachman, W. G. 1988. Extended-wear soft and rigid contact lenses: Operational evaluation among Army aviators. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 88-17.
- Bachman, W. G. 1990. Evaluation of extended wear soft and rigid contact lens use by Army aviators. Journal of the American optometric association. 61:203-210.
- Barry, W. E., and Tredici, T. J. 1972. Keratoconus in USAF flying personnel. Aerospace medicine. 43:1027-1030.
- Boissin, J. P. 1973. A propos de la tolerance des protheses de contact chez le personnel navigant commercial. Revue de medecine aeronautique et spatiale. 12:568-569.
- Boissin, J. P. 1979. A propos de tolerance des protheses de contact chez le personnel navigant. Aeronautic and spatiale medecine. Subaquatic and Hyperbaric Medecine. 18:198-200.
- Braithwaite, M. G. 1983. The use of contact lenses by Army aircrew. Journal of the Royal Army Medical Corps. 129:43-45.
- Brennan, D. H., and Girvin, J. K. 1983. The suitability of soft contact lenses for aircrew. Farnborough, Hampshire, U.K.: Royal Air Force Institute of Aviation Medicine. IAM Report No. 626.
- Brennan, D. H., and Girvin, J. K. 1985. The flight acceptability of soft contact lenses: An environmental trial. Aviation, space, and environmental medicine. 56: 43-48.
- Burden, C. A. 1988. Contact lens use in aircrew. Letter and data provided to LCR David Still by Director of Preventive Medicine, National Defence Headquarters, Ottawa, Canada.
- Castren, J. 1983. The significance of low atmospheric pressure on the eyes with reference to soft contact lenses. 1984. Acta ophthalmologica supplement. 161:123-127.
- Cloherly, J. K. 1985. Contact lenses for pilots and aircrew in the services. In: Visual protection and enhancement. conference proceedings No. 379. 15.1 - 15.13. Advisory Group for Aerospace Research and Development. Neuilly-sur-Seine, France.

- Committee on Vision, National Research Council. 1990. Contact lens use under adverse conditions. Washington, DC: National Academy Press.
- Cresswell, G. J. 1989. 1000 hours in contact lenses. Unpublished manuscript, The Royal Air Force Institute of Aviation Medicine. Farnborough, U.K.
- Crosley, J. K., Braun, E. G., and Bailey, R. W. 1974. Soft (hydrophilic) contact lenses in U.S. Army Aviation. An investigative study of the Bausch and Lomb Soflens. American journal of optometry and physiological optics. 51:470-477.
- De Vries, E., and Hoogerheide, J. 1958. Contactglazen bij een straaljagervlieger (Contact lenses worn by a jet pilot). Aeromedica acta. 6:141-153.
- Dennis, R. J., Flynn, W. J., Oakley, C. J., and Tredici, T.J. 1988. A field study on soft contact lens wear in USAF military transport aircraft. Brooks Air Force Base, TX: USAF School of Aerospace Medicine. USAFSAM-TR-88-4.
- Dennis, R. J., Flynn, W. J., Oakley, C. J., and Block, M. G. 1989a. Soft contact lenses: Sink or barrier to chemical warfare agents? Brooks Air Force Base, TX: USAF School of Aerospace Medicine. USAFSAM-TR-89-2.
- Dennis, R. J., Woessner, W. M., Miller, R. E., and Gillingham, K.K. 1989b. The effect of fluctuating +Gz exposure on rigid gas-permeable contact lens wear. Brooks Air Force Base, TX: USAF School of Aerospace Medicine. USAFSAM-TR-89-23.
- Diamond, S. 1962. Contact lenses in aviation. Aerospace medicine. 33:1361-1366.
- Draeger, J., Schroder, U., and Vogt, L. 1980 Untersuchungen uber die vertraglichkeit und zulassungigkeit von kontaktlinsen in der luft- und raumfahrt. Klinische monatsblaetter fuer augenheilkunde und augenarztliche fortbildung. 176: 421-426.
- Eng, W. G. 1979. Survey on eye confort in aircraft: I. Flight attendants. Aviation, space, and environmental medicine. 50:401-404.
- Eng, W. G., Rasco, J. L., and Marano, J. A. 1978. Low atmospheric pressure effects on wearing soft contact lenses. Aviation, space, and environmental medicine. 49:73-75.

- Flynn, W. J., Block, M. G., Provines, W. F., Tredici, T. J., and Kullmann, R. D. 1985a. Soft contact lens wear during +Gz acceleration. Brooks Air Force Base, TX: USAF School of Aerospace Medicine. USAFSAM-TR-85-84.
- Flynn, W. J., Miller, R. R., Block, M. G., and Tredici, T. J. 1985b. The effects of hypoxia induced by low atmospheric pressure on soft contact lens wear. Brooks Air Force Base, TX: USAF School of Aerospace Medicine. USAFSAM-TR-85-30.
- Flynn, W. J., Miller, R. E., Tredici, T. J., and Block, M. G. 1986a. Effects on aviation altitudes on soft contact lens wear. Brooks Air Force Base, TX: USAF School of Aerospace Medicine. USAFSAM-TR-86-20.
- Flynn, W. J., Miller, R. E., Tredici, T. J., and Block, M. G. 1988. Soft contact lens wear at altitude: Effects of hypoxia. Aviation, space, and environmental medicine. 59: 44-48.
- Flynn, W. J., Miller, R. E., Tredici, T. J., Block, M. G., Kirby, E.E., and Provines, W. F. 1986b. Subcontact lens bubble formation under low atmospheric pressure conditions. Brooks Air Force Base, TX: USAF School of Aerospace Medicine. USAFSAM-TR-86-21.
- Flynn, W. J., Miller, R. E., Tredici, T. J., Block, M. G., Kirby, E.E., and Provines, W. F. 1987. Contact lens wear at altitude: Subcontact lens bubble formation. Aviation, space, and environmental medicine. 58:1115-1118.
- Forgie, R. E. 1981. Problems arising from the wearing of head equipment. In: Personal visual aides for aircrew. Lectures series no. 115. 4.1-4.7. Advisory Group for Aerospace Research and Development. Neuilly-sur-Seine, France.
- Forgie, R. E., and Meek, L. F. 1980. The movement of soft contact lenses on the human eye exposed to Gz acceleration. Downsview, Ontario, Canada: Defense and Civil Institute of Environmental Medicine. DCIEM Report No 80-R-49.
- Hapnes, R. 1980. Soft contact lenses worn at a simulated altitude of 18,000 feet. Acta ophthalmological. 58: 90-95.
- Jaeckle, C. E. 1944. Practicability of use of contact lenses at low atmospheric pressures. Archives of ophthalmology. 31:326-328.

- Kok-van Aalphen, C. C., van der Linden, J. W., Visser, R., and Bol, A. H. 1985. Protection of the police against tear gas with soft lenses. Military medicine. 8:451-454.
- Lattimore, M. R. 1990a. Contact lenses in the U.S. Army attack helicopter environment: An interim report. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 91-3.
- Lattimore, M. R. 1990b. Military aviation: A contact lens review. Aviation, space, and environmental medicine. 61: 946-949.
- Levine, R. R., Lattimore, M. R., and Behar, I. 1990. Visual performance of contact lens-corrected ametropic aviators with the M43 protective mask. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 90-12.
- Maffet, C. K. 1990. USAF Aviator Contact Lens Quarterly Report, Jul-Sep 1990. Letter by Deputy Director, Professional Affairs and Quality Assurance, Office of The Surgeon General. Department of the Air Force. Washington, DC. 11 December.
- Marquardt, R. 1976. Kontaklinsen - Ihr für und wider. Wehrmedizinische Monatsschrift. 6:170-174.
- McCulloch, C. 1962. The acceptance of contact lenses in military personnel. In: Visual problems in aviation medicine. Agardograph 61. 26-33. Advisory Group for Aerospace Research and Development. Neuilly-sur-Seine, France.
- Morris, F. M. 1964. Contact lenses for flying personnel - A clinical investigation. Contacto. 8:12-15.
- Newsom, W. A., Tredici, T. J., and Noble, L. E. 1969. The danger of contact lenses at altitude. In: Proceedings of the XVII International Congress on Aviation and Space Medicine. 216-218. Oslo, Norway.
- Nilsson, K., and Rengstorff R. H. 1979. Continuous wearing of Duragel contact lenses by Swedish Air Force pilots. American journal of optometry and physiological optics. 56:356-358.

- Perdriel, G. F. 1981. Les indications des verres de contact dans la pratique aeronautique (Contact lens indications in aeronautiques). In: Personal visual aides for aircrew. Lecture series no. 115. 2.1-2.4. Advisory Group for Aerospace Research and Development. Neuilly-sur-Seine, France.
- Polishuk, A., and Raz, D. 1975. Soft hydrophilic contact lenses in civil and military aviation. Aviation, space, and environmental medicine. 46:1188-1190.
- Punt, H., and Heldens, D. J. J. 1988. Fields of vision. Aeromedical Conference on Man-machine Interaction in High Performance Aircraft. Gilze-Rijen, the Netherlands.
- Punt, H., Heldens, D. J. J., Valk, P. J. L., and Heigensbergen, P.v. 1988. The behaviour of hard contact lenses in conditions of low relative humidity and low atmospheric pressure. Soesterberg, Netherlands: National aerospace medical centre. Report OR-88-01/R.
- Punt, H., van den Heuvel, A. C. H., van den Biggelaar, H. H., Hoekstra, G. J., and Rouwen, A. J. P. 1985. Dynamic behaviour of spherical and aspherical contact lenses exposed to +Gz acceleration forces. In: Visual protection and enhancement. Conference proceedings no. 379. 16.1-16.5. Advisory Group for Aerospace Research and Development. Neuilly-sur-Seine, France.
- Rouwen, A. J. P. 1985. Vergelijkend onderzoek: de gas-doorlatende asferische contactlens voor de militair. Utrecht: Militair Hospitaal "Dr. J Mathijssen." Report No. A84/K/061.
- Rouwen, A. J. P., Pinckers, A. J. L. G., v't'Pad Bosch, A. A. I., Punt, H., Doesburg, W. H., and Lemmens, W. A. J. G. 1983. Visual acuity, spectacle blur and slit-lamp biomicroscopy on asymptomatic contact-lens-wearing recruits. Graefe's archive for clinical and experimental ophthalmology. 221: 73-77.
- Runge, J. W., and Friedrich, H. H. 1979. Wearing of contact lenses during flights - problems for crew members and passengers. Phillipine journal of ophthalmology. 2: 77-82.

- Sheeley, R. M., and Hurst, W. J. 1985. Analysis of Hydrocurve II (Bafilcon A) contact lenses for toxic fume uptake in rotating wing aircraft. Unpublished manuscript. PA: Dickinson College Carlisle.
- Siegel, B. S. 1990. Aviation contact lens program update. Unpublished presentation to the U.S. Naval Aeromedical Institute Contact Lens Policy Working Group, Pensacola, Florida.
- Simon, D. R., and Bradley, M. E. 1980. Adverse effects of contact lens wear during decompression. Journal of American medical association. 244:1213-1214.
- Tinning, S. 1990. Soft contact lens wear and aviation. Paper presented at symposium, Ocular Hazards in Flight and Remedial Measures. Aerospace Medical Panel, Advisory Group for Aerospace Research and Development, NATO, October, London, U.K.
- Tredici, T. J., and Flynn, W. J. 1986. Contact lens wear for visual disorders in USAF aviators. Brooks Air Force Base, TX: USAF School of Aerospace Medicine. USAFSAM-TR-86-23.
- Tredici, T. J., and Flynn, W. J. 1987. The use of contact lenses by USAF aviators. Aviation, space, and environmental medicine. 58:438-443.
- Tressler, C. S. 1988. The incidence of corneal ulcers in soft contact lens wearers among active duty military at Fort Stewart, GA. Military medicine. 153:247-249.
- Turnour, N. C. 1960. A functional investigation of corneal type contact lenses. Toronto, Ontario: Institute of Aviation Medicine, Royal Canadian Air Force. IAM #60/1.
- Turnour, N. C., and McCulloch, C. 1962. Eye protection in aviation. In: Visual problems in aviation medicine. Agardograph 61. 106-117. Advisory Group for Aerospace Research and Development. Neuilly-sur-Seine, France.
- Van Norren, D. 1984. Contact lenses in the military service. American journal of optometry and physiological Optics. 61:441-447.
- Wick, R. L. 1965. Civil aviation and contact lenses. Aerospace Medicine. 36:127-130.