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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARDograph 334

AMP Working Group 16

Operational Use of Contact Lenses by Military Aircrew

(L'Utilisation Opérationnelle des Lentilles de Contact)

The material in this publication was assembled to report the results of AGARD Aerospace Medical Panel Working Group 16 under the sponsorship of the Aerospace Medical Panel.

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Operational Use of Contact Lenses by Military Aircrew

(L'Utilisation Opérationnelle des Lentilles de Contact)

Edited by

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The material in this publication was assembled to report the results of AGARD Aerospace Medical Panel Working Group 16 under the sponsorship of the Aerospace Medical Panel.

North Atlantic Treaty Organization
Organisation du Traité de l'Atlantique Nord

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Preface

AGARD Aerospace Medical Panel (AMP) Working Group 16 was tasked in 1990 to consolidate the available information from practical experience in the use of contact lenses by flying personnel, and to offer guidelines for the eventual operational use of CLs by various categories of military aircrew. The need for such clarification was felt to be based both on changing demands in modern cockpits and on improvements in the manufacture and fitting of CLs, — but also from a gradual change within the population of NATO's military fliers. Many of these pilots now require some form of visual correction, and a substantial number will have encountered CL-use in civilian sports or other leisure time activities.

It has been my pleasure to work with NATO's foremost experts in the field of military ophthalmology during the preparation of this report, and the recommendations and guidelines given, and the result of thorough deliberations and discussions. During our mandate we were also given access to much new and useful information of interest to the military physician, inasmuch as the Gulf conflict saw some use of CLs both on the ground and in the air.

The collation we give of previous CL experiments within military aviation, and our recommendations for future use of lenses under operational circumstances, will — I think — also prove useful to military medical officers responsible for non-flying personnel.

I want to thank all my collaborators in the working group for their excellent service, and in particular Dr Roger Wiley who took on the demanding job as group secretary. The assistance given by US Naval Air Station, Pensacola; RAF Institute of Aviation Medicine, Farnborough; US Army Aeromedical Research Laboratory, Fort Rucker; and the German Air Force Institute of Aerospace Medicine, Furstenfeldbruck, is also much appreciated.

Préface

En 1990, il a été demandé au groupe de travail No. 16 du Panel AGARD de médecine aérospatiale (AMP) de compléter les informations disponibles sur l'utilisation des lentilles de contact par le personnel opérationnel en faisant appel à l'expérience pratique, et de proposer des directives pour l'utilisation opérationnelle éventuelle des lentilles de contact par différentes catégories de personnels navigants.

Le besoin d'une telle mise au point s'explique en partie par les contraintes imposées par le cockpit moderne et les progrès réalisés dans l'élaboration et l'ajustement des lentilles de contact, mais aussi par un changement graduel qui s'est opéré au sein de la population des pilotes de l'OTAN. Bon nombre de ces pilotes sont maintenant obligés d'avoir recours à des moyens de correction visuelle, et beaucoup d'entre eux utilisent des lentilles de contact dans un contexte de sports et loisirs.

J'ai eu le plaisir de travailler avec les principaux experts de l'OTAN dans le domaine de l'ophtalmologie militaire lors de la rédaction de ce rapport, et les recommandations et directives qu'il contient sont le résultat de délibérations et de discussions approfondies.

Pendant la période de l'étude, il nous a été communiqué un grand nombre d'informations nouvelles intéressant les médecins militaires, telles que l'utilisation des lentilles de contact pendant la guerre du Golfe, tant pour le combat aérien que pour les opérations terrestres.

La collation de rapports concernant les expériences effectuées sur les lentilles de contact dans le milieu militaire et nos recommandations, qui figurent dans ce rapport, concernant le futur emploi de lentilles dans des situations opérationnelles, devraient également s'avérer utiles aux médecins militaires responsables du personnel non-navigant.

Je tiens à remercier l'ensemble de mes collègues du groupe de travail pour la qualité des services qu'ils ont bien voulu rendre, et, en particulier, le docteur Roger Wiley qui a assumé de lourdes responsabilités en tant que secrétaire du groupe. L'assistance, apportée par l'US Naval Air Station, Pensacola, le RAF Institute of Aviation Medicine, Farnborough, l'US Army Aeromedical Research Laboratory, Fort Rucker et le German Air Force Institute of Aerospace Medicine, Furstenfeldbruck, a été également trés appréciée.

Egil Alnaes
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EXECUTIVE SUMMARY

Historically, military aviation candidates have been rigorously screened to ensure that only those with the best vision are selected to become pilots. For that reason, the correction of ametropia never has been a subject of major concern in the past. For various reasons, most military services have reduced uncorrected visual acuity standards in recent years so that the number of ametropic aviators has increased. These ametropic pilots have amply demonstrated that safe and efficient military flight profiles can be conducted while wearing a moderate visual correction.

The most common type of visual correction worn by military pilots has been spectacles. However, due to recent developments in helmet attached electro-optical visual displays and protective masks, it has, in some cases, become very difficult or impossible to wear glasses while flying military aircraft. For that reason, alternative techniques for providing refractive error correction have been studied. The most obvious alternative to spectacle correction is the contact lens. These have received very wide acceptance in the civilian community and are used frequently in civilian aviation, both commercial and private. When compared to spectacle use, contact lenses offer both advantages and disadvantages for the ametropic aviator. These are discussed in subsequent chapters.

There are many environmental and occupational demands which are unique to military aviation. These special challenges which might affect the military contact lens wearer were included in our deliberations. When determining the acceptability of contact lenses in military aviation and the improvement in compatibility with equipment, peacetime missions while wearing contact lenses must be distinguished from wartime operations. Although some information about the operational use of contact lenses in aviation was gained during recent hostilities in Southwest Asia, happily no information was obtained about the acceptability of contact lenses on a chemical battlefield.

In addition to issues related to quality of correction and compatibility, the potential of damage to the eyes must be considered. The possible damage depends upon a number of factors, such as type of material (soft lenses, rigid lenses), inherent properties (oxygen permeability, rigidity, etc.), lens wearing schedule (daily, extended), hygienic standards of lens care (cleaning and disinfection), physiological changes associated with long term wear, and the conditions under which the lenses are worn. The degree of risk is also very much dependent upon the quality and intensity of medical surveillance. The level of clinical support must be considered in fitting contact lenses. Medical support must be continuous and readily available. Even if an optimally fitted contact lens has achieved acceptable physiological equilibrium with an eye, it must be remembered that the lens is a foreign body and creates an element of risk of acute or long term ocular damage. Considerations of potential complications must include both medical and operational (e.g. incompacitation during flight due to foreign body, lens dislocation, etc.) aspects. Based on data presently available from the limited military experiences with contact lenses and data reported from civilian studies, the considered opinion among the Working Group members is that the military services should expect approximately a 1% incidence per year for corneal ulcers and 10% incidence per year for minor complications, both of which would be directly attributed to contact lens wear.

The issue of service-connected disability is very important. Even though equipment compatibility demands might dictate that contact lenses provide the best optical correction choice for ametropic aviators, the fitting and use of contact lenses should be on a voluntary basis.

While aspects of costs related to fitting, procuring, controlling and replacing the lenses are not medical issues, they were included in this report for completeness. Not included in the following discussions, but also of importance, are analyses of the impact on flight personnel who will be lost for duty due to medical examinations or ocular complications. These analyses are the responsibility of the operational community.

Contact lenses clearly offer only a partial solution to replace corrective spectacles. Only 60% to 70% of ametropic aviators will be able to be fitted and successfully wear contact lenses on a longterm or career basis. At this time there are no satisfactory contact lens options for presbyopic aviators. Spectacle compatibility should continue to be the goal for cockpit and equipment designers.

Recommendations

Based upon available information and extensive deliberations, the Working Group offers the following recommendations:

a. If contact lenses are prescribed, they should be worn on a regular basis and not be reserved only for flight.

b. Training in the wear and care of lenses should receive greater emphasis. Wearers must demonstrate acceptable dexterity.

c. Flexible wear lenses are the lenses of choice. They should be worn on a daily basis but have an extended wear capability. The maximum extended wear should not exceed six nights, and then only for exceptional reasons. Compliance with hygiene requirements, wearing schedules, clinical examination schedules, and lens replacement schedules should be rigorously followed and receive command emphasis.

d. Informed consent records should be maintained for all aviators fitted with contact lenses.

e. It should be mandatory that all aviators retain a pair of spectacles for back-up on their person (not just in the cockpit) at all times while performing flight duties.

f. For emergency re-supply, aviators wearing

spectacles or contact lenses should be given an identification card identifying them as spectacle/contact lens wearers and containing prescription information for both contact lenses and spectacles.

g. The recommended post-fitting examination schedule for contact lenses is 1 day, 1 week, 3 months, and every 6 months thereafter.

h. All contact lens fittings and examinations should be done by qualified ophthalmic specialists approved by the appropriate aeromedical authority. The fitters must have knowledge of the aviation environment and the visual demands of aviators.

i. Visual acuity with contact lenses and spectacles must be carefully monitored. Any refractive error changes, especially increases in myopia, must be viewed with suspicion because of the possibility of corneal decompensation.

j. The military services should provide the contact lenses and all necessary supplies. Only the contact lenses provided should be approved for wear.

k. A central clinical data registry for each military service should be maintained for all contact lens wearers.

l. There are well-documented advantages and disadvantages to all of the different lens materials. While the majority of the Working Group members prefer soft lens materials, the Working Group recommends that only polymethyl-methacrylate (PMMA) material not be approved for use.

m. The Working Group recommends that contact lens be approved for wear by individuals only when an operational requirement or advantage is clearly determined.

n. Because of the established markedly increased risk for corneal ulcer among contact lens wearers who smoke, the Working Group recommends that aviators fitted with contact lenses be strongly discouraged from smoking.

The results achieved in Working Group 16 "Operational Use of Contact Lenses: Benefits and Disadvantages" are intended to assist the individual flight surgeon, the aviators, and flight crewmembers in their decision for or against the use of contact lenses. The supreme principle behind a physician's decision must continue to be "Nihil nocere."

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% of pilots are spectacle wearers at intake, but 27% of pilots and 51% 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 in the form of 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. Poggio, et al.[86] have published data which indicate that extended wear contact lens users are 5 times to 6.8 times more likely to develop corneal ulcers than other contact lens users. Unfortunately, their statistics are based on cases admitted to hospitals for treatment. The figures do not analyze the details of individual ulcer cases with regard to compliance with the care regime or attendance at regular ophthalmic monitoring, both of which can significantly lower the incidence of corneal ulcers. For example, the elderly aphake using a constant wear soft contact lens, who is unable to keep their review appointments because of an age-related illness preventing them attending the hospital, is at greater risk for corneal ulcer development. Another patient who is at increased risk is the cosmetic extended wear soft contact lens wearer who does not comply with the cleaning and care regime and who is generally unhygienic and, again, does not attend for regular ophthalmologic monitoring. These examples would not pertain to the military contact lens wearer, and for such reasons, these civilian data cannot be extrapolated to the military aviator.

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 in the National Research Council (USA). The current Working Group, set up by AGARD AMP in 1990, has profited from this material, as well as from examining the recent US experiences in the use of CLs in selected flight personnel both in peace-time conditions and during the Persian Gulf conflict.

According to its mandate, this WG has evaluated the use of contact lenses by military aircrew in operational situations, and in the current report:

1) summarizes current scientific, clinical, and technological issues in the use of contact lenses;

2) reviews the operational requirements of military personnel relative to the use of contact lenses, with particular emphasis on the experiences of those NATO air forces that currently have aircrew flying with contact lenses;

3) seeks to identify the critical factors to be taken into account when the decision is made to permit the use of contact lenses by military aircrew.

MILITARY AVIATION EXPERIENCE WITH CONTACT LENSES

Since the beginning of military aviation, vision has been recognized as the critical sensory system 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 non-pilots 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 during 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[21,66] provided insight into some of the information relevant to contact lenses in aviation. The Committee on Vision, US National Research Council, published a report[21] 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[66] discussed the published information which served as basis for the decision by the US Army to pursue a large-scale study of contact lenses worn by rotary-wing aviators. Lattimore concluded that, although the presently available information indicates that contact lenses can be worn safely in aviation environments, they represent only a partial solution since they cannot provide satisfactory correction for all of the younger aviators and cannot satisfactorily correct the presbyopic, more experienced aviators.

Early Studies With PMMA Lenses

Military contact lens research has a history of almost 50 years. In 1944, Jaeckle[58] 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, DeVries and Hoogerheide[27] 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[117] and Turnour and McCulloch[118] 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%) 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% 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[76] 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 had increased conjunctival injection because of overwear of the PMMA lenses, one of whom had corneal stippling near the lower limbus. 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 et al.[80] 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 reduction in size and number with decreasing altitudes. Two of their subjects having large central bubbles 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.[114] Morris,[79] in 1964, provided early information concerning the issue of long-term wear of PMMA corneal contact lenses by aviation personnel. He obtained followup 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% reported that they were either full or occasional wearers of the lenses, but only 20% were full-time wearers (defined as 10 or more hours per day, 7 days per week). He could not determine 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[32] 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[123] 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% of the pilot population, and they accounted for 0.43% of the accidents. Wick also thought that the risk of lens decentering or loss was quite minimal in commercial aviation.

These early reports of investigations using 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[79] 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 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 fighter/attack profile of high performance aircraft, the tanker/transport/patrol (maritime) mission, 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 low humidity, usually between 10% and 15%. For these conditions, experiences in civilian commercial aviation are directly applicable. Boissin[7,8] 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 less than 3 or 4 hours. However, for longer flights, they were uncomfortable. Similarly, Eng[39] collected questionnaire data from 744 commercial flight attendants. Almost all reported some eye discomfort which, as reported by almost 50%, started less than 2 hours into the flight. Most attributed the discomfort to smoke. There were no reported differences between attendants wearing contact lenses and those not wearing lenses. Runge and Friedrich,[101] 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 greater than 2 hours. They also recommended that passengers should be warned to remove their lenses.

In a study directed specifically toward military aviation, Draeger, Schroder, and Vogt[35] exposed subjects wearing both soft lenses and rigid lenses to simulated altitudes of slightly greater than 8000 feet with a humidity between 12% to 15%. No findings were made that indicated any deterioration in the fit of the lenses, acuity, or compatibility. In comparison, Punt and coworkers[90,91] 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% 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 milder degree and 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[50] fitted soft lenses to his subjects who were then exposed to simulated altitudes of 9000 feet for 6 hours. After 6 hours, his two control subjects not wearing lenses complained of dry eyes along with one of eight soft lens wearing subjects. He observed minimal corneal staining and no changes in visual function. Flynn et al.[42,43,48] 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%) 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.[112] 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.[29] 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 contents 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 correlate 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[107] 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 et al.[40] 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[54] 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 was noted along with lacrimal debris and ciliary injection. Among 6 subjects wearing both rigid and soft lenses, Draeger et al.[35] found only one rigid lens wearer who had a small gas bubble with a simulated altitude of over 16,000 feet. Forgie[49] reported that two of ten soft lens subjects had small gas bubbles trapped at the limbal sulcus at a simulated altitude of 25,000 feet. These disappeared after ten 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[15]. Among seven subjects who wore soft lenses at a simulated altitude of 12,000 feet for three hours, he reported that all had some objective findings. The most serious observations were corneal erosions in four eyes and opacities of the corneal stroma in ten eyes. Brennan and Girvin[10,11] 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 showed changes in measured contrast sensitivity. Similarly, using low- and medium-water content soft lenses, Flynn et al.[42,43,48] did not report 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.[45,47] 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% of the eyes wearing rigid lenses. With soft lenses, bubble formation only at the limbus was detected in 24% of the eyes tested, sometimes occurring at altitudes as low as 6000 feet. Acuity was not affected.

Punt and Heldens[90] 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 et al.[35] 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 response at a number of +Gz levels in centrifuges. Forgie[49] and Forgie and Meek[50] 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[10,11] 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.[44] 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 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.[89] 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[90] 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.[28,29] 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 is provided by reports about contact lens use among ground soldiers. Rouwen[97] 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% of the 53 contact lens wearers receiving followup exams had switched back to combat spectacles. The remaining 79% 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[119] 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% did not use their contact lenses from the start of field maneuvers. An additional 28% of rigid lens wearers and 17% of the soft lens wearers discontinued their contact lenses during the field exercise. Approximately 62% of the original contact lens wearers continued to use their lenses during the exercise.

Marquardt[75] 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 et al.[24,25] 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[9] and Burden[13]. These data are interesting for the lack of major problems among the aviators despite wearing histories of more than 10 years.

Bachman[3,4] 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 they reported a large preference for contact lenses over spectacles for all aviation-related duties. He reported an 86% wearing success rate and no flight days lost due to the contact lenses during the 6-month trial period. Lattimore[65] 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[10,11] 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[117] and Turnour and McCulloch[118] exposed PMMA lens wearing aviators to temperatures of -50° F. and +130° F. without demonstrating any functional loss. Brennan and Girvin[10,11] 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, another potential challenge to contact lens wear by rotary-wing and fighter/attack aviators is 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.[64] 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.,[30] 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 et al.[103] 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[11,69] 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[5] reported results after fitting 11 keratoconic patients with rigid lenses. Nine of the 11 personnel were returned to flying duties. Tredici and Flynn[113,114] 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[98] 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% 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 followup care.

Summary

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[87] 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[81] 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,[23] 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 1982, Perdriel[85] discussed the different materials used in fabricating contact lenses and reviewed the advantages and disadvantages 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[115] 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,[89,90,96,98] the Dutch military medical authorities principally recommend the use of rigid gas permeable lenses with aspheric designs. In 1989, the US 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[72]) 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[17] 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 six months. His

report is the longest continued observation of the same individuals by the same person to date. The US Army currently is conducting large scale contact lens trials in helicopter environments[65]. 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[104] from US 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 reported that no adverse medical or operational events have occurred and acceptance of the lenses by the aviators has been quite positive.

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.

CONTACT LENS MATERIALS

RIGID CONTACT LENSES

Research on the use of rigid contact lenses in military aviation started in the 1940s. Fogging of glasses caused by temperature changes and air turbulence in the cockpit were the most important reasons for considering the use of these early glass scleral lenses. However, the wearing time of such lenses was very limited (1 - 2 hours).

In the 1950s, the development of smaller corneal rigid lenses made of polymethylmethacrylate (PMMA) material was an important evolution in efforts to provide an option to spectacles for correcting refractive errors. However, limited wearing time, unstable centration, possible loss of the lenses, and formation of gas bubbles trapped underneath the lenses were generally considered containdications for using them in military aviation. Although innovations in lens design, improved lens materials, and greater fitting skills have expanded the use of rigid contact lenses in the civilian community, a similar growth in rigid lens use in the military community has not occurred. This probably is attributable to an existing conviction among some medical professionals that all rigid lenses have the same disadvantages found with the original PMMA lenses. Some of the more common difficulties with this lens material include the following:

- flare and glare (related to small lens diameter)
- spectacle blur (inability to correct refractive errors with spectacles following PMMA lens removal; caused by corneal molding or edema of the corneal stroma due to the lack of O_2 transmission)
- foreign body entrapment, lens decentration, and lens loss (caused by small lens diameter, poor fitting, absence of parallel tear lens, especially accompanying astigmatism)
- discomfort and long adaptation time (related to lens mechanics and low O_2 permeability)

While many of these disadvantages with PMMA lenses have been overcome with newer lens materials, some aviation-unique environmental conditions still present significant challenges for wearing rigid lenses in military aviation. Some of the principal conditions which should be considered are the following:

- low atmospheric pressure (bubble formation behind the lens during decompression)
- low relative humidity (diminished thickness of the tear film)
- low O_2 saturation (negative influence on corneal metabolism)
- cockpit air flow (diminished thickness of the tear film)
- high G-forces (dislocation or loss of lens)

Advances in lens materials to provide improved oxygen permeability and innovations in fabrication technology that yield lenses which have a better fitting relationship with the corneal surface warrant reconsideration of the utilization of rigid gas permeable lenses in the aviation environment. Also, increasing knowledge of tear film chemistry and the physiological response to contact lenses have made it possible to advise more rationally in choosing the most appropriate type of rigid contact lens.

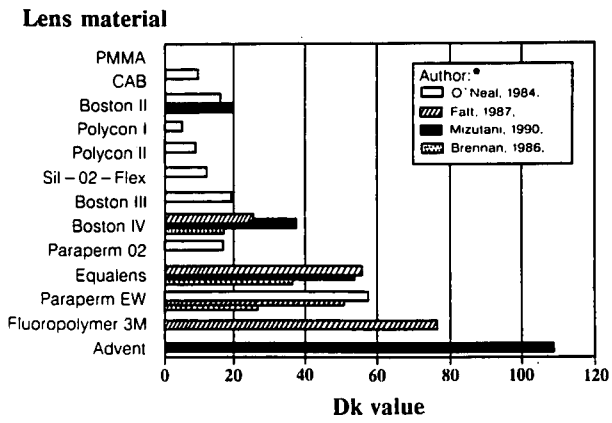
Materials

As discussed earlier, polymethylmethacrylate (PMMA) was the first contact lens material used in military aviation in other than limited research protocols. Because of the basic inability of this material to transmit oxygen, the corneal metabolic requirements must be supplied by a tear pumping mechanism when this lens is worn. Presumably,

oxygen is carried underneath the lens and to the cornea via the tears which are exchanged by a lens pumping action initiated by blinking. This action is usually inadequate as demonstrated by frequent corneal edema and complaints of spectacle blur caused by corneal hypoxia among PMMA wearers.

During the past 10 years, new materials have been developed which allow oxygen transport through the lens material itself. One of the first of these new generation materials was cellulose acetate butyrate (CAB) which was quickly followed by a second class of materials, the silico-acrylate copolymers. All of these materials increased O_2 transport sufficiently to allow rigid lenses to be worn without the discomfort and other complications that accompany corneal hypoxia. Recently, fluorinated polymers have also been used in contact lenses. The synergism of fluorine and silicone-acrylate chemistry has successfully increased the oxygen permeability to such a degree that extended rigid contact lens wear is possible. Today, the contact lens fitter has a variety of rigid gas permeable (RGP) lens materials from which to choose (Table 1). In Table 1, the oxygen transport capability is expressed in Dk values. Dk can be measured in 2 ways. In vivo, it is measured by measuring the speed of absorption of oxygen by a cornea from a lens. In vitro, it is determined by utilization of a polarographic probe measuring the exchange of oxygen between oxygenated and non-oxygenated environments, separated by the material to be tested.

Table 1. Dk values for rigid lens materials.



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Although Dk values are frequently used by materials developers in describing the advantages of the different lens materials, there are different ways of measuring Dk and these measurements are very dependent upon temperature and humidity measurement conditions. Also, while higher Dk values are associated with improved oxygen transport and generally are preferred, other material properties also related to the higher Dk values might be disadvantageous. Making a choice of one of the RGP lenses for military aviation may require that other materials properties, in addition to the Dk value, be included in the consideration.

The relationship between Dk value and the eye's physiological response has been the subject of extensive research. The oxygen transmissibility of a contact lens depends directly upon the oxygen permeability of the lens material and is inversely related to lens thickness (L). The partial pressure of oxygen is approximately 155 mm at sea level, and the requirement by the human cornea for normal function is considered to be approximately 75 mm Hg. Under open eye conditions a Dk/L of 44 will provide this partial pressure. However, even Dk values of 30 rarely cause hypoxic corneal changes during daily lens wear. In the closed eye situation (sleep), oxygen availability is reduced by 2/3 to approximately 55 mm Hg. Theoretically, an ideal extended wear contact lens would require a Dk between 130 - 140 which is 3 times the Dk requirement for daily wear. Current lens materials do not possess such high levels of oxygen permeability. However, prevailing extended wear fitting experiences indicate that Dk values of approximately 60 are practical for extended wear use. While this level of oxygen supply apparently does cause some corneal edema in the normal eye during periods of sleep, the cornea reportedly recovers to normal thickness within one hour after awakening.

Some Properties Of RGP Lenses

In addition to the much higher Dk values possessed by RGP lenses when compared to PMMA lenses, the mechanical and optical properties also are different. When selecting an RGP material, in addition to the Dk value, the following characteristics should be considered:

- hardness - Higher Dk values often are associated with increased fragility.
- stiffness - Higher Dk materials often are more flexible. The amount of flexibility depends upon lens diameter, thickness, and shape. This property provides an explanation for the failure of high Dk materials in fitting a cornea with astigmatism and the need for toric lenses in such cases.
- affinity for deposits - Some materials have greater tendency to accumulate deposits of proteins, lipids, and other organic compounds.
- wettability - Poor surface wettability is associated with higher Dk values. The wettability property of a material is provided as a wettability angle in arc degrees. This is the angle between a liquid surface resting upon the lens and the solid lens surface and provides some indication of the relative values of the forces of adhesion and cohesion. A large angle, indicating poor wettability, requires special wetting solutions to counteract the hydrophobic lens property.

In the most recent generation of RGP materials, a synergism has been developed by a chemical integration of silicon and fluorocarbon (high Dk value), methacrylic acid (improved wettability), and methylmethacrylate (high stability). This compound was formulated to overcome or reduce the impact of some of the deficiencies noted above which were present in earlier RGP materials.

Design Of Rigid Contact Lenses

The difficulties in designing a comfortable and physiologically acceptable RGP lens have always been challenging to the contact lens fitter. The principal difficulty with the mechanical design of an RGP lens is caused by the normal corneal toricity which is essentially

elliptical, but with a variety of peripheral curves (Figure 1). In the past, low Dk materials and limited manufacturing techniques dictated that only lenses having small diameters could be fitted. These early rigid lenses usually were approximately 8 mm in diameter and consisted of two curves on the inner or ocular lens surface, a flatter peripheral curve which provided a tear reservoir and a central curve which provided an optical zone. Only central corneal curvature readings were required to fit these lenses.

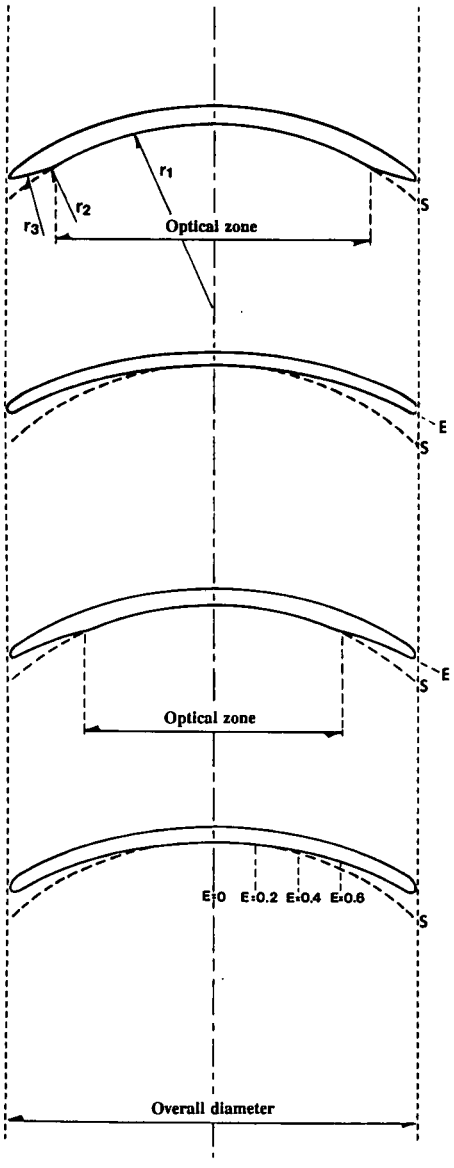

Fig. 1
Spherical lens

Fig. 2
Aspherical lens

Fig. 3
Margin aspherical lens

Fig. 4
Polycurve lens

The next attempt to develop a more acceptable RGP lens geometry was the tetracurve design. This lens consists of a central curve (approximating central corneal curvature), two peripheral curves, and one standard edge profile curve. The total diameter can be increased up to 9.50 mm. This design approaches the normal anatomical shape of the cornea, and, therefore, usually results in reduced eyelid irritation, better lens centration, and more satisfactory fitting for astigmatic corneas.

More recent developments have provided a variety of aspherical designs having different base curve radii (BCR) with variable peripheral flattening to approach the individual shape of the cornea. The first attempt at this design was a full elliptical ocular surface consisting of a BCR with a flattening component, or eccentricity (E), from lens center to peripheral edge (Figure 2).

The elliptical design improves the relationship between the lens ocular surface and the cornea. By measuring peripheral corneal curvatures, the lens fitter can tailor the lens E values to the individual corneal contour. However, the shape of the cornea is not truly elliptical. The visually critical central cornea is spherical. Unfortunately, the optical quality of aspherical lens designs degrades progressively from center to periphery. Therefore, two variations of the full elliptical lens design have been developed:

- a margin aspherical lens design consisting of a 4-6 mm central spherical area, with a gradual aspherical transition to the periphery (Figure 3).
- a polycurved lens with a progressively increasing E-value, e.g. a central E-value of 0, 0.2 at 10°, 0.4 at 20°, 0.6 at 30° (Figure 4).

The progressive flattening of the aspherical contact lens design allows one to stabilize the lens by enlarging the diameter and central optical zone. This reduces the problems of lens mobility and instability seen in the early spherical RGP designs.

Discussion

Optimally fitted, an aspherical lens design results in a nearly parallel tear lens without pressure points. The diameter can be enlarged up to about 10 mm to improve lens stability. Large lens diameters with parallel tear lenses also diminish the risk of foreign body entrapment and improve centration and retention during high G maneuvers. Visually degrading flare and glare, most especially present during periods of low light levels, also will be reduced or eliminated with larger optical zones.

Because of the environmental extremes in which aviators might wear contact lenses, the particular lens material from which the lenses are made is an important consideration. High material Dk values offering the possibility of extended wear may provide some resolution to the occupational demands of the military aviator, i.e. irregular, long hours in an ambient environment having reduced oxygen partial pressure. However, pilots likely to be subjected to high G forces should not be fitted with copolymers with extremely high percentages of fluorine, since this will increase the lens specific gravity and weight. Lenses having Dk values greater than 60 should not be chosen because of their increased fragility.

RGP lenses cannot be successfully fitted to or be worn by all aviators requiring refractive error correction. Ultimately, success will be determined by the motivation of the aviator, his ocular anatomy, and the skill of the fitter.

Recommendations For RGP Contact Lenses In Military Aviation

1. Large lens diameter
   Under the stress of high G maneuvers, the contact lenses must not move beyond the limbus. To prevent excessive movement, large lens diameters, approximately 80% - 85% of the visible iris diameter, are preferred.
2. Aspherical back surface geometry
   Advantages of the aspherical back surface design include

reduced thickness and weight, allowing larger diameter lenses with improved centration and stability.

3. Lenticular design lenses for high ametropia
For a given diameter, the center thickness and weight of a lens is determined principally by the power of the lens. Therefore, in case of high ametropic conditions, lenticular front curves are best. This will reduce the amount of material in the lens periphery. In the case of hypermetropia greater than +2.50 diopters, a minus carrier flange design should be used to enable the eyelids to hold the lens in place.
4. Specific gravity
Extremely high percentages of fluorine in the lens material increases the specific gravity to an undesireable level. This will affect weight, fit, and lens stability.
5. Toroidal lens for high astigmatism
A toroidal posterior lens geometry should be considered for cases of corneal astigmatism in excess of 2 diopters.
6. High Dk value
Lens materials having high oxygen transmissibility allow longer wearing times and require shorter adaptation times. Lens materials having Dk values between 50 - 60 are recommended.

SOFT CONTACT LENSES

Although rigid scleral or corneal lenses have been used since the beginning of this century, soft contact lenses appeared in significant numbers only in the late 1960's. Technical advances in material chemistry, variations in geometrical shapes, and increased clinical data from their use have made soft contact lenses the current material of choice by most CL fitters and patients because of the relative case of easier adaptation and increasing safety over PMMA lenses.

Soft lens materials are plastics from synthetic polymers which are created by either addition of monomers without component elimination (PMMA and Poly Hema), or by combination of monomers with the elimination of molecules (Silicone).

To fabricate lenses from these materials, one of the following three methods may be used:
(1) Spin casting - the polymerization occurs during centrifugation on a concave mold into which the monomer is injected.
(2) Casting - the monomer and initiator are put in a mold and the polymerization is accomplished by controlling the temperature cycle.
(3) Lathing or turning and polishing - a disc of the polymer is fixed on the axis of a rotating shaft and both anterior and posterior surfaces are shaped by a cutting diamond to the desired curvature and polished for the shortest possible time.

The physical requirements of the lenses produced include the following:
(1) Spectral transmittance - all lens materials must exceed 90 percent transmittance between 400 and 780 nanometers (the visible spectrum).
(2) Refractive index - between 1.35 to 1.49 (the corneal refractive index is 1.376).
(3) Resistance to external factors - The heat effect depends on the chemical composition. A linear molecular structure is thermoplastic and changes shape when subjected to heat. A reticulated molecular structure is thermostable.

The pH affects certain materials. For example, if the material contains methacrylic acid, it is subject to change of shape with pH variation. There is marked physiologic variations in tear pH, from 6.0 at night (with the lids closed), to a sudden temporary rise up to 9.3 one minute after the eyes open, and then settling around the normal average of 7.4.
(4) Hydrophilia (water content). Materials vary in this characteristic, from 30-80 percent. The oxygen transmissibility is positively related to the degree of hydrophilia.
(5) Oxygen transmissibility or Dk - Improvement of a soft lens' Dk may be accomplished by increasing its hydrophilia (water content) and/or by reducing it's thickness. The former decreases clarity and durability, and the latter increases fragility.
(6) Moisture capacity or "wettability." This characteristic affects the interaction of the lens and the tears and governs the relationship between the cohesive and adhesive forces which react on different types of molecules. This physical interaction is dependent upon three properties: the surface tension of the liquid, which must be low; the surface tension of the solid, which must be high; and the surface tension that binds the two, which must be low.

There are various ways to raise the surface tension of the solid, such as transplantation of hydroxyl radicals (OH) onto the material or making co-polymers with hydrophilic monomers. In clinical practice, anything that alters the surface of a soft lens, such as protein deposits, scratches, or aging of the material lowers its moisture capacity. The result is that the tear film will no longer smoothly cover the lens, resulting in possible adhesions with the corneal epithelium and/or reduced comfort.
(7) Material durability - dehydration of a soft lens affects its geometry (shape), index of refraction, and gas permeability. Generally, the higher the water content of a lens, the more rapid its dehydration. The tear film has a great effect on this process, not only in cases of decreased tear production, but also in its protein composition. Moreover, the so-called "ionic" materials, composed of methacrylic acid, deteriorate more rapidly.
(8) A soft contact lens has, of course, two surfaces. The posterior surface has an optical zone with a specific curvature. Peripherally, there may be other curves, called "clearing stripes." These curves may be spherical, aspherical, or toroidal. The anterior surface is the optical face which determines the lens power.
(9) Diameters vary from 13 to 14 mm, partially depending on the corneal diameter, since soft lenses are designed to extend beyond the limbus. This size can be compared with that of rigid lenses which do not cover the entire cornea. With rigid lenses the peripheral (uncovered) cornea's exposure to atmospheric oxygen maintains corneal metabolism, especially in cases of poor tear exchange beneath the lenses. Rigid gas permeable lenses, which have good Dk values, are of smaller diameters than soft lenses, and also move more on the cornea than soft lenses, although possibly less than PMMA lenses which are specifically fitted to encourage some movement.
(10) Lens thickness influences adaptation and comfort. Thinner lenses allow better tolerance but are more fragile and are harder to handle. The average lens center thickness is 0.10 to 0.20 mm.

Residual Astigmatism
Hard and rigid gas permeable contact lenses correct small to moderate amounts of corneal astigmatism, since tears will fill the gap between the steeper corneal meridian and

the posterior surface of the lens, creating a "tear lens." Soft contact lenses mold to the corneal contour and do not have this effect. However, small amounts (e.g., less than 0.75 diopter) of astigmatism are partially "masked" by and usually are not corrected for the soft lens wearer. Correction of more significant astigmatic errors requires special soft lenses which have toroidal surfaces.

Accommodation And Convergence
From clinical experiences, the accommodation-convergence synkinesis causes the myopic contact lens wearer to exert more accommodation than a myopic spectacle wearer; the opposite is true for the hyperope. On the other hand, the myope need not exert as much convergence with contacts as with glasses due to the absence of the base-in prism effect of spectacles for myopia.

ADVANTAGES AND DISADVANTAGES OF CONTACT LENSES

In the civilian community, patients must consider vision, comfort, convenience, costs, and safety when deciding whether to purchase and wear contact lenses (CLs). In the military aviation setting, these factors are of critical importance. The military aviation system works to put expensively-trained pilots and crew members over critical targets in expensive aircraft. Anything that interferes with or potentially could interfere with the successful completion of those missions or jeopardizes the safety of the aviators or the aircraft is unacceptable. Furthermore, public funds must be safeguarded in a responsible manner and used only for such visual appliances as are necessary to accomplish the military aviation mission. On the other hand, any visual device that can enhance a pilot's performance would be worthwhile.

With this in mind, this section will discuss the following topics regarding contact lenses: optical performance; medical complications and safety; sterilization; compliance; and supervision. Although polymethylmethacrylate (PMMA) contact lenses were the first type available and are still used in limited numbers, we shall largely confine our comments to the newer flexible gas-permeable (RGP) and soft hydrogel/silicone contact lenses (SCLs) which presently make up the lion's share of contact lenses sold. While most aviators are emmetropic or mildly hyperopic (and this is highly desirable for pilots), many require optical correction. Contact lenses must, then, be compared to spectacles as an alternate visual appliance.

Optical Performance
As Manfred Von Richthofen said, "Only a wonderfully trained, practical, and observant eye can see anything definite when one is traveling at a great height and at a terrific speed." Perhaps nothing worries a military pilot more than "losing" vision and not being able to see the enemy. Even in an age of radars, computers, and air-to-air missiles, pilots still operate in an intensely visual environment, both for distant visual targets and cockpit instruments. Colonel Robin Olds has written that excellent vision and fast reactions are the fighter pilot's greatest and most necessary assets. Anything that improves visual performance would be a decided advantage, and anything that degrades it would be cause for great concern.

Well-centered and well-fit spherical hard contact lenses (HCLs), i.e., PMMA and RGP lenses, provide a visual acuity approximately equal to spectacles. In one study, 92% of patients with RGP lenses achieved visual acuities equal to their best spectacle correction.[111] In the case of certain types of high refractive error and irregular and high regular astigmatism, these lenses may provide better acuity. When HCLs do not provide good acuity, the usual cause is imprecise optical correction, lens coating or warpage, or lens-induced corneal changes. HCLs can, however, increase the spherical aberration from the cornea and degrade acuity.[77] Toroidal HCLs can be used for high astigmats, but they introduce another complicated set of problems centering around the instability of the cylinder correction. Hopefully, no pilots and few aircrew members will require these, as they are very difficult to fit successfully.

Well-centered and well-fit spherical SCLs provide a visual acuity that is comparable to that of spectacles, although this can vary with the water content of the lens, high water content having a marginally negative effect. This is thought to be due to the water causing light diffusion.[59] Toroidal SCLs can provide an "acceptable" acuity, but stability of the axis of the correcting cylinder is difficult to achieve and residual errors are common. Contrast sensitivity testing with thin, low-water-content (38%) SCLs and spectacles demonstrated no difference.[82] However, one should bear in mind that not all SCLs give equal optical resolution.[88] There is significant variability in optical quality both among various types of lenses and within each type. The latter is due to manufacturing variations.

Some obvious advantages of contact lenses have been noted by the aviation community. They do not fog with weather changes, gather dust specks (as plastic spectacle lens do), or smear with sweat or salt spray. They provide a larger corrected visual field and an unobstructed visual field. Some eye professionals also feel that they eliminate the distortions in the periphery of spectacle lenses, although this is a debated issue. There are fewer reflections. SCLs dislodge only minimally with high +Gz and with no significant effect on visual acuity, due to the large diameters and optical zones.[42] Early data[31,90] suggest that RGPs with very large overall diameters may be stable under high +Gz. SCLs are reported to be more comfortable than spectacles, especially under +Gz. SCLs only marginally slow the effects of chemical agents on the eye, and only at the lowest concentrations.[28] Contact lenses allow for the combined use of many pieces of aviation equipment that must be fitted in front of the face, e.g., helmet display devices and chemical defense masks, although there are engineering design solutions to these types of problems. In Saudi Arabia, however, those Apache pilots unable to wear hard contact lenses and the M-43 chemical defense mask were either reassigned, flew without the M-43 mask, or wore the older M-24 masks that are not as compatible with night vision goggles and other sighting devices. Finally, moderate to high myopes obtain an increase in image size that may improve their best spectacle acuity by 1/2 to 1 Snellen line.

The optical disadvantages of contact lenses are numerous. Precise fitting is required for HCLs, and especially for toroidal lenses, to obtain optimal acuity. SCL and, to a lesser degree, RGP lenses are flexible and have dimensional instability and flexure, especially on toroidal corneas.[52] Back toroidal lenses are preferred for corneas with astigmatism, to obtain the best correction and stability. The fitting of all HCL and RGP lenses is labor intensive. SCLs have limited selections of base curves, which may

lead to suboptimal fits and marginal acuity. Because CLs must move on the eye (HCL > SCL), acuity is less stable than with spectacles and fluctuates even with blinking (HCL > SCL). This is especially true in the extremes of gaze. The acuity with SCLs of high water content can be degraded by loss of hydration. This is especially a problem with lens water contents greater than 55%. The US Army has shown that SCLs of 58% water content decreased to 48% over 7 days of continuous wear.[67] HCLs can have associated edge glare and nighttime "ghosting" if pupil diameter and optical zone/lens diameters are not matched correctly. Contact lenses may bring on an early presbyopia in myopes, as greater accommodation is required with myopic contact lenses. The opposite is true for hyperopes.

Surface wettability and, therefore, vision and comfort can be a problem with RGP lenses. Lens deposits (organic and inorganic), as well as trapped mucus, can diminish visual acuity by interfering with light transmission. All forms of RGP lenses and SCLs are subject to deposit formation, which is typically preceded by symptoms of cloudy vision after several hours of CL wear, due to the development of a sheen on the lens. All types of CLs, especially RGP lenses, become scratched or marred over time. These create ocular irritation and promote deposit formation. Scratches are the most common reason for RGP lens replacement or alteration.[111] Certain RGP lenses have a tendency to develop fine cracks. This crazing imparts a spiderweb quality to one's vision, particularly at night or under reduced lumination.[59]

Dislodgement of a contact lens from the cornea or loss from the eye leads to an immediate and profound decrement in visual acuity that is intolerable during critical phases of flight, especially in combat. Dislodgement of a contact lens can be very irritating (HCL > SCL) and produce tearing in the opposite eye, which may interfere with vision in that eye due to the tears and/or the increased mobility of the CL in that eye. Both dislodgement and loss require stabilization of the aircraft, loss of operational effectiveness, and repositioning, retrieval and reinsertion, or removal of the contact lens. Dislodgement and loss, while thought to be primarily a problem with HCLs, also occur with SCLs.[121] In ejections, which fortunately occur infrequently, contact lenses appear to be adequately retained.[121] Displacements of HCLs into the inferior cul-de-sac can occur with high +Gz, and this can affect visual acuity, depending upon fit, lens type, lens parameters, and +Gz forces. The HCLs recenter with blinking, but drift rapidly down again.[31,90] However, using larger diameter lenses, such displacements do not uncover the pupillary area. Ocular irritation from any cause (e.g., dry SCL, trapped foreign body, minor abrasion) can lead to increased blinking, increased tearing, and decreased acuity. Many RGP wearers in the US Army were forced to discontinue wear in Saudi Arabia, due to the contact lenses trapping sand against the cornea. Corneal hypoxia from a poorly-fitted, warped, dehydrated, or overworn contact lens can lead to corneal edema (pooling of interfibrillar fluid in the stroma and epithelial changes) that causes glare sensitivity, diminished contrast sensitivity, and halos and rainbows around lights. These ocular problems resolve slowly over hours, once the contact lenses are removed; they continue as a visual problem during that time, even if the contact lenses are replaced by spectacles.

Over years, contact lens-induced hypoxia can lead to corneal distortion and thinning (molding or warpage) that reduces acuity, especially spectacle acuity. Diminished visual acuity, for whatever reason, is often the most common complaint of contact lens wearers.

Bifocal contact lenses of any type are extremely difficult to fit, often are a problem to keep centered, do not provide optimal distance and near vision, and reduce contrast sensitivity.[22] They and the technique of monovision (one CL fitted for distance vision and one for near) are unacceptable for military flying. The new "diffractive" lenses, which have several foci, are also unacceptable due to decreased acuity and contrast sensitivity. Orthokeratology, a procedure that involves fitting progressively flatter and flatter HCLs on the cornea to flatten the center of the cornea and alter its refractive status, is both potentially dangerous and a largely discredited procedure. It is used chiefly to pass eye tests temporarily. It is effective only for very mild refractive errors. The results are temporary and often unpredictable. Long-term damage to the cornea can result from such intentional misfitting of HCLs.

Compliance

While the potential for ocular complications from contact lenses cannot be eliminated, most ocular experts agree that this potential can be significantly reduced by strict adherence to well thought-out guidelines for lens care and sterilization. Ophthalmologists and optometrists have long recognized that lapses in lens care are responsible for 70 to 90% of the contact lens ocular complications.[38] Many examples have been documented in the ophthalmologic literature in case reports and studies. Studies have also shown that the majority of CL wearers (74-82%) are not performing correct lens care as they were taught.[95] This cuts across all levels of age, economic status, and education.[20] Non-compliance is likely to increase under military field conditions. It is, therefore, clear that mandatory CL education and re-education must be a major part of any military contact lens program, so that this important point is initially and continually emphasized and the flyers' lens care techniques are reappraised.

Initial and follow-up ocular education efforts should (as appropriate) emphasize the types of contact lenses, their adverse effects on corneal physiology, optical advantages/disadvantages, medical complications, need for follow-up examinations, in-flight CL problems, and solutions, lens care, and what to do when a problem arises with the eyes or contact lenses.

To ensure that the flyers take the care of their eyes (and the public's monies) seriously, removal from flying duties and contact lens wear rules should be clear, promulgated, and enforced at all levels. Noncompliance with follow-up examinations, wear instructions, and lens care should not be tolerated.

Initial data from the US Army indicate that 35% of their pilots with disposable contact lenses were wearing them continuously for longer than 10 days. Six days was the directed maximum wear period.[124] It appears that the military services will have the same severe problems with compliance that occur in the civilian world, except that the military services have the power to enforce compliance.

Supervision

In order for the military services to guarantee that their pilots and aircrew members receive the appropriate contact

lenses and care, they should develop an in-house program using only military health facilities. The program should be managed by the supporting flight surgeon who, of course, must be appropriately trained. Education of the flyer should be comprehensive and include a detailed request/counseling/acceptance form. Contact lens fittings should be done by military ophthalmologists and optometrists to ensure that aeromedical visual standards are met and that optimal fits are obtained. Another alternative might be strictly supervised civilian contract ophthalmologists and/or optometrists. The contact lenses and all supplies should be provided by the military, so that financial considerations do not cause a flyer to forego proper procedures for lens care. There should be specific fitting goals for each type of lens that carefully balance vision, ocular health, and stability. Certain contact lenses may not be appropriate for certain aircraft/aircrew positions. These can be avoided. One should bear in mind that the overall, long-term success rates for contact lens fitting in the civilian world, as well as the military world, seem to be about 60-75%, but can vary greatly depending upon selection criteria and the lenses used. Wearing failures will further reduce the initial success rates. The long-term failure rate in the USMC has been 22%,[74] and in the USAF TAC/TAWC study 11%.[67]

There should be regular, directed, required, and documented follow-up sessions with an ophthalmologist or optometrist. These will vary by type of lens issued. The "grounding" rules should be clear, absolute, enforced, and monitored. All complications, except fitting problems, noninfected abrasions, and mild allergic reactions, should be referred to an ophthalmologist.

Flight surgeons should monitor their programs and report regularly to their medical superiors, detailing the status and complications, so that intelligent and informed decisions can be made regarding military CL programs. Aircraft and life support designers and engineers should be told, immediately and irrevocably, that equipment not compatible with aircrew spectacles is unacceptable, as not every flyer can wear contact lenses.

Lens Care

Proper contact lens care is, along with proper selections of lens materials, patients and wear schedules, vitally important to prevent ocular complications that can temporarily or permanently ground a flyer. Detailed initial and recurrent education must be provided during fitting and follow-up ophthalmic examinations. It is essential that problems must be anticipated by the vision specialist and solved before they threaten the flyer's vision.

Because the materials available and the designs for contact lenses and lens care products are constantly changing, along with our expanding knowledge of their effects on the eye, it would be impossible to settle on one immutable system of rules for the care of contact lenses. However, some general comments can be made.

Because of our relatively young state of knowledge regarding the effects of various chemicals on the conjunctival and corneal tissues, there is some disagreement in data and in ophthalmologists'/ optometrists' minds regarding the safety and efficacy of various lens care products. There has not been uniformity in the types of organisms against which the products are often tested, nor has there been agreement on the degree to which pathogenic organisms should be inhibited or killed (D-value test). Thus, there are significant differences among the available lens care products that have been approved for use.

Some of the antimicrobial agents, e.g., hydrogen peroxide[116] and benzalkonium chloride,[16] are known to be toxic to the eye in certain concentrations. Others are thought to be neutral, that is, do not affect growth rate and morphology of endothelial cells, e.g., polyquarternium. Likewise, the preservatives that are used with the antimicrobial agents can cause adverse effects on ocular tissues (e.g., thimerosal and benzalkonium chloride).

Thus, a fine balance needs to be struck between the kill rates of effective agents against all bacteria, fungi, viruses, and acanthamoebae known to be a threat to the eye and these agents' toxicity to the eye. Many argue that this has not been done with current tests and products. Others offer reasons why the product testing or product deficiencies are not important. Clearly, however, the issue of cleaning and sterilization is not a closed topic. Much more needs to be understood about the effects of contact lenses on the eye, and the products suitable for cleaning and sterilizing contact lenses.

The old PMMA HCLs were relatively rugged lenses that required only surfactant cleaning to remove mild protein deposits. There were no "pores" in the material in which to secrete organisms or water where organisms could grow. Because they did not transmit 0_2 and CO_2(low Dk values), they were made in small diameters that permitted adequate tear flow for corneal metabolic needs. They exchange about 20% of the tear layer with each blink. When they caused hypoxic discomfort, they were removed, usually before anything serious happened to the eye. Ocular infections and blindness have been caused by hard contact lenses, however.

RGP contact lenses are made of newer materials (fluoropolymers and silicones) that have very high Dk values (100 in some cases). While they are much friendlier to the eye in most respects and have largely replaced PMMA lenses, they also have different problems. These usually revolve around wettability and deposits, but ocular infections can develop because these lenses are larger and can mask early corneal problems. The major care that needs to be provided to RGP CLs is surfactant cleaning to remove deposits. RGPs also should be stored in the appropriate soaking solution to recondition the surfaces and to prevent warpage, because the materials are much more flexible and susceptible to distortion with drying. These soaking solutions have preservatives that prevent/retard the growth of pathogenic organisms, usually thimerosal and chlorhexidine. However, these preservatives can become concentrated in an RGP lens and adversely affect the eye (irritation, hyperemia, swelling of the cornea). Thus, it is important only to use those solutions specifically designed, tested, and recommended for the type of RGP material employed in the contact lenses one is wearing.

The cleaning and sterilization of SCLs is much more difficult, complicated, and important. This is largely due not only to the nature of the materials (hydrogels) which have large matrices that trap water, but also to the wearing schedules - extended versus daily-wear. With daily-wear,

the lens is cleaned and sterilized each day and is presumably exposed to more pathogenic organisms. With extended-wear, one is not able to keep the lens as clean, but there is less manual manipulation and, thus, probably less exposure to organisms. However, the cornea is more physiologically stressed with extended wear, and cleanliness and sterility are much more important. Only 1% of the tear pool is exchanged under a SCL with each blink. The importance of cleaning, sterilizing, and length of wear is made all the more clear by reflecting on contact lens history. There were a few corneal ulcers and blindness associated with PMMA lens wear. The reports of corneal ulcers began to increase with the arrival of daily-wear SCLs. Those reports reached alarming levels with the advent of extended-wear SCLs, despite early glowing reports.[62] Recent studies have confirmed the relative risks of infection with different CLs and methods of wear.[53,83,86,102] As a result, many ophthalmologists and optometrists will no longer recommend or fit extended-wear RGP or SCLs to be worn in an extended-wear regimen. Currently, SCLs account for 74% of all contact lens sales worldwide.[126]

SCLs tend to acquire a mucus/protein/lipid coat very rapidly (days) that can gradually build, act as a site for deposit formation, and serve as a site of attachment for pathogenic organisms. They must be cleaned meticulously each day according to recommended regimens. Even so, this will not remove all the deposited mucus/protein/lipid/pathogenic organisms. In addition, weekly proteolytic enzyme cleaning, after surfactant cleaning, will help to remove more muco-protein, as well as some pathogenic organisms. A sterile saline solution is also required to rinse the lenses.

After daily surfactant cleaning, SCLs must be sterilized with an antimicrobial agent and kept sterile with a preservative agent until they are worn again. The proper selection of these agents is an area that requires significant ophthalmic study and judgment, because of the inadequate and conflicting data on efficacy and safety that exist for the various lens care products. It is clear that all products are not equally effective.[94] It is also apparent that 52% to 100% of all contact lens care systems in use are probably contaminated to some degree.[34,125] CL wearers are simply not carefully compliant, but education can improve this percentage. In the military, one must also be concerned with systems that require electricity, great numbers of solutions, or are too complex. The systems should also provide long-term sterility after initial sterilization.

Some general comments can be made regarding efficacy. Heat sterilization appears to be the most effective, but it cannot be used with all types of SCLs, i.e., most medium or high-water- content lenses, due to induced lens distortion. Heating contact lenses for 10 minutes or more at 70-80°C has been shown to kill all pathogenic organisms, including both forms of acanthamoebae. These systems require electricity. As long as the case remains closed after heating, sterility is probably adequate for 1-3 days.

One-step chemical solutions can be effective as antimicrobial and preservative agents.[94,105] The preservatives, thimerosal 0.001% with edetate, benzalkonium chloride 0.01% with edetate and reagent, and chlorhexidine gluconate 0.001% for 4 hours, have been shown to kill both forms of acanthamoebae. However, thimerosal 0.001% without edetate, potassium sorbate 0.13% with edetate, sorbic acid 0.1% with edetate, polyquaternium-1 0.001% with edetate, and polyaminopropyl biguanide 0.00005% with edetate, each used for 4 hours, are not effective.[106] Often, the same types of variable effectiveness data can be shown with other organisms.

Chemical agents can have adverse effects on the eye. The only chemical solution shown not to have any negative direct effects on corneal endothelial cells and, in fact, to allow them to grow and function apparently normally is polyquaternium-1 0.001% with edetate (from company reports). Chemical solutions are reassuring in one respect, and that is that they provide "long-term" disinfection when the lenses are not worn. Those solutions which also allow for weekly enzymatic cleaning, while they are sterilizing, offer a one-step approach.

Hydrogen peroxide 3%, for 2-3 hours is effective at killing both forms of acanthamoebae.[105] Hydrogen peroxide is toxic and irritating to the eye, however, and must be neutralized with either another solution (2 step) or platinum disc (1 step). Following neutralization, the lenses are basically in unpreserved saline and vulnerable to pathogenic organisms. If the one-step system is used, it is much less effective as a sterilizer. Those systems that allow for simultaneous weekly enzymatic cleaning are more convenient.

The residual concentration of H_2O_2 that is safe is unknown. The systems are designed to have residual H_2O_2 concentration between 50-60 ppm after neutralization. The products' residuals actually vary from <1 to over 300 ppm. Some studies have suggested that perhaps a level of 10 to 17 ppm is the human cornea's toxic limit.[116,55] However, a residual concentration of <3 ppm caused significant changes in the intact rabbit cornea's metabolism and hydration, and <2 ppm caused significant changes in human endothelial cells.[55] These findings suggest that anything less than total neutralization of H_2O_2 may be unacceptable. No current system can consistently provide that.

Even the most successful program of lens care cannot function successfully without adequate replacement lenses and lens care supplies. Some of the US Armed Forces had great difficulty achieving adequate supplies of lenses and lens care products in Saudi Arabia. Other supplies (bullets and bombs) had higher priorities, and the logistics system made it impossible to find the supplies in-country. Complicating the supply/safety problem is the fact that preserved cleansing solution bottles can become contaminated with pathogenic organisms after opening.[34] Thus, long-term storage of unsealed/opened contact lens solutions is not advisable.

Soft Versus Rigid Gas Permeable Contact Lenses

Soft contact lenses have several aeromedical advantages over rigid lenses. They allow for easier adaptation and earlier and more complete comfort in the majority of people. Both have satisfactory optical qualities, offer dimensional stability for low spherical ametropia, and provide some "damping" (SCLs) or elimination (RGPs) of low degrees of corneal astigmatism. SCLs pose a smaller risk of dislodgement; both types cause minimal problems due to sweat or water vapor, and both generally are easily

manipulated. Initially, RGPs are easier to insert, and SCLs are easier to remove, although caution must be used to prevent damaging the fragile structure of SCLs. SCLs allow more flexible wearing schedules - intermittent, daily or extended wear capability - although nightly removal is strongly preferable. On the other hand, SCLs absolutely require more maintenance. Regular wearing of contact lenses represents a delicate balance between physiology and pathology. The higher water content soft lenses, while more comfortable and favorable to gas transfer, also absorb more metabolic waste and degrade more rapidly, resulting in an increased risk of infection. Increased blinking is required to assure hydration of both of the lens' surfaces. The tear exchange is only 5 percent in soft contact lenses, versus 20 percent with hard lenses, thereby increasing the risk of corneal hypoxia. In addition, waste products accumulate in this relatively stagnant space and further slow metabolic exchange. Soft contact lenses can reduce corneal sensitivity, and might decrease the early normally painful sensations, associated with corneal ulcerations. All disadvantages are markedly reduced simply by user compliance with the fairly strict manufacturers' wear and care recommendations. Finally, due to the large variety of excellent soft lenses being produced and regular arrivals of new types, no one specific make or type can be recommended. Certain specific criteria, however, should be met. These include a minimum of 1 mm overlap of the limbus, careful original fitting by a professional, meticulous follow-up by a professional at set intervals, and flight trial in a dual-piloted aircraft.

Medical Contraindications To Contact Lens Wear

There are few absolute medical contraindications to routine contact lens wear, but they are rather obvious - active ocular infections (especially corneal), certain corneal dystrophies/ degenerations, and the inability to understand or comply with correct lens wear and/or hygiene.

Relative medical contraindications to routine contact lens wear are more numerous. These include conditions such as chronic hyperemia, eyelid position abnormalities, pterygia, symblepharon, chronic conjunctivitis, hordeola, chalazia, corneal degenerations, corneal dystrophies, corneal vascularization, tear film abnormalities, and low-grade, chronic eyelid infections.

Medical Complications Of Contact Lens Wear

Contact lenses induce a wide spectrum of changes in the appearance and function of the cornea.[12] The factors causing contact lens medical complications can usually be grouped under one of the following categories: mechanical, physiological, immunological, tear film alterations. Hypoxia, low humidity, and lens wear time are of particular concern as etiologic factors for complications. However, not all the risk factors are necessarily known or defined. Complication rates have, also, not been clearly demonstrated. Reports of complications have increased dramatically since the introduction of soft contact lenses and, especially, extended-wear soft contact lenses. The type of complications and their severity vary somewhat by lens type. We clearly do not fully understand how to prevent complications, as some individuals get severe complications, even after careful selection, correct fitting, scrupulous follow-up, and standard lens care.[78] Sometimes these occur within days to weeks of obtaining the contact lenses. While only 28% of contact lens wearers in the United States are males, they are over-represented in terms of complications. This is a worrisome statistic, when one considers that most aircrew are males. All of the military services conducting contact lens studies have noted various medical complications. The numbers of subjects, however, are generally small, and the incidence rates appear unclear. These studies will be summarized at the end of this section.

Chemical hypersensitivity reactions have been very common in association with SCL use. These reactions are localized to the eye and are often secondary to thimerosal. The rate of occurrence in patients has been reported as anywhere from 2% to 40%, but most often in the 25% range.[1] Two immunologic mechanisms are thought to contribute - Type III Immune Complex Deposition and Type IV Cell Mediated. The treatment is to stop the use of contact lenses and solutions and await resolution of the signs and symptoms. This may take one or more weeks, depending upon the severity of the problem. Cautious restarting with different solutions and observation should allow the practitioner to isolate and eliminate the problem solution(s). If unrecognized, corneal neovascularization and permanent visual impairment can develop.

"Dry-eye" sensations are very common and can be difficult to treat in CL wearers - both RGP and SCL. The symptoms are caused by alterations in the normal tear film that are presumed to be caused by contact lens wear.[41] The dryness causes an uncomfortable, scratchy sensation. This can be brought on or be exacerbated by low humidity conditions, i.e. aircraft air-conditioners. More frequent blinking or artificial tears may help relieve the symptoms at least for a brief period of time. Also, adjustments to lens parameters (H_2O content or thickness) and fit may help. In the US Air Force and US Army studies, SCL wearers often did report the need to use artificial tears in flight (40% or more), although this has not been the experience in the RAF's use of high-water content SCLs or in the Dutch Air Force with RGPs.

Lens intolerance may occur because of chronic irritation caused by the presence of a foreign body (the contact lens) in the eye. This presents itself as an inability to tolerate the contact lens due to pain or other inflammatory symptoms, such as hyperemia, irritation, or mucus production. The etiology of this intolerance may be any or all of the following: the lens material; the fit of the lens; alteration of the lens with time (scratches, deposits, protein build-up, etc.); preservatives. Treatment consists of discontinuing lens wear until the symptoms resolve. Refitting with a new and/or different lens and/or solutions may solve the problem.

Meibomitis is an inflammation of the eyelid meibomian glands which may be quite difficult to treat. These glands produce the oil that covers the watery tears on the surface of the cornea. This oil layer retards evaporation of the water layer, drying of the cornea, and consequent alterations in acuity. Sufficient oil-containing tears are important to lubricate the eye and allow it to tolerate a contact lens. The "dry-eye" symptoms of meibomitis can occur when keratinized oil plugs the ducts of the glands. Some individuals are more susceptible to this condition. Meibomian gland dysfunction, thought to be secondary to preservatives, can occur from lens care solutions. It produces the same symptoms. Treatment, for other than mild conditions, often calls for discontinuance of lens wear and therapy for the underlying condition or switching to other solutions.

Giant Papillary Conjunctivitis (GPC) is a common conjunctival complication that occurs chiefly in SCL wearers, but it can occur in RGP and PMMA wearers also.[2] Estimates are that 1-5% of SCL and 1% of RGP wearers are affected by this condition. It may take only months for a SCL wearer to develop GPC, whereas it usually takes years for a HCL wearer. It is characterized by elevated, large (>1.0 mm diameter) papillae located in the superior palpebral conjunctiva overlying the tarsal plate. It appears to be a hypersensitivity reaction of the Types I and IV. The specific antigen(s) prompting the reaction has not been identified. Speculation has centered on lens type, lens scratches, deposits, protein build-up, and excess wear. The CL wearer complains of blurred vision, redness, excess mucus, excess movement of the lens with blinking, and discomfort. Symptoms are minimal early on but increase with continued wearing. Removing the lens greatly reduces the symptoms. Long-term treatment, after resolution of the symptoms and reduction in the papillae, focuses on finding the best tolerated lens material, ensuring scrupulous cleaning, and reducing wearing time. This may take months and be both tedious and expensive. Cromolyn sodium eye drops may be helpful in management. This drug is presently off the market in the US.

Epithelial microcysts are small cyst-like areas in the epithelium of the cornea. They appear as translucent, irregular dots scattered across the cornea and are thought to represent an effect of chronic metabolic stress, probably hypoxia.[55] They appear with greater frequency among extended-wear SCL wearers. If present in appreciable numbers (>50), contact lens use should be discontinued and the corneas followed carefully. Contact lens wear may be restarted upon resolution of the microcysts, but only with some modification in the program (newly fitted lenses, reduced wearing time, etc.).

Subepithelial corneal infiltrates are not well understood. It is not clear whether the mechanism is toxic, infectious, or mechanical. They can become infected and may be precursors of ulceration. They can reduce vision, if they are in the center of the cornea, and can be physically uncomfortable. Treatment involves stopping the wear of contact lenses. Topical antibiotic drops should be considered, along with careful follow-up. Refitting of CLs should be accomplished only after resolution.

Corneal abrasions can occur with any type of CL and can be related to corneal hypoxia. It is known that corneal hypoxia causes changes in the epithelium and, thereby, creates fragility.[34,40] In one large study[26] abrasions were the most common clinical complication. They tend to occur in the central cornea, on the visual axis, and farthest from the edge of the contact lens. They can be caused by the "tight lens" syndrome, overwear, or both. Severity is variable, from punctate stains to large epithelial defects that take several days to fully heal. Patients complain of hyperemia, pain, blurred vision, and photophobia. Treatment is controversial, due to the infectious worries surrounding SCL. Generally, HCL and RGP abrasions can be treated with antibiotic ointment and patching each day, until the epithelium is healed. SCL abrasions should probably not be patched. They should also be followed daily and should receive topical antibiotic drops. This may retard the speed of healing, but, hopefully, it will prevent progression of any infection present. After a corneal abrasion has healed, recurrent erosions of the epithelium are possible. Several military studies of SCLs have documented punctate staining inferiorly on the cornea in a large percentage of aircrew members.[29,121]

Corneal molding, an induced change in the normal shape of the cornea, can be caused by contact lenses. It may represent an hypoxic effect in normal corneas, and corneas with astigmatism seem to be more susceptible. It is more common with HCLs (PMMA and RGP lenses) than SCLs, but can occur with the latter also if the lenses are not properly fitted. Thus, lens rigidity seems to be a factor. Sub-contact lens bubbles can also produce localized changes in corneal curvature. The induced change of curvature from molding is often irregular and not correctable with spectacles ("corneal warpage"). As a result, when one removes his contact lenses, his vision with spectacles is blurry. The alteration in the cornea can be mild to severe, with increasing effects on vision. It may take days to weeks to months for this to resolve.

If the corneal stress is prolonged, dangerous corneal thinning can also occur.[12] It may be difficult to tell how much thinning is present, until co-existent corneal edema resolves. Although debatable, it has been reported that perhaps 25% of keratoconus cases might have been caused by contact lenses.[71] Treatment for both conditions involves discontinuing contact lens wear, until the cornea returns to its normal shape or stabilizes. A reevaluation should then be done to determine whether any and, if so, which contact lens should be used. The cornea may never return to its precontact lens shape. Thus, contact lenses may be required to obtain clear(er) vision.

Corneal edema consists of swelling of the epithelium or stroma of the cornea, when it is stressed by hypoxia or other causes and is a common clinical problem associated with contact lenses.[53] Even in emmetropes and spectacle wearers, the cornea normally swells about 4% overnight when the eyelids are closed. This does not appear to affect visual acuity. If contact lenses are worn overnight the overnight swelling can be considerably worse (6-13%, or more).[6] Even with daily-wear contact lenses worn only during the day, corneal edema can also occur (5% or more). Corneal edema can cause a mild to significant reduction in vision (either with CL or spectacles) that may take hours or days to resolve once the contact lenses are removed. Whether corneal edema develops depends on several factors - lens polymer, lens design, lens fit, duration of wear, quality and condition of the lens, tear film, and wettability. Usually the first two are factored together into measurable values that reflect the ability of a lens to pass 0_2 and CO_2. These values are determined by dividing the diffusion coefficient by the lens thickness (Dk/L) which yields the equivalent oxygen percentage (EOP) values. To restrict overnight corneal swelling to 4%, which is the level experienced by non-lens wearers, extended-wear lenses ideally need an EOP of 17.9% or a Dk/L of 87.0×10^{-9}. Most extended- wear lenses do not meet this standard. Most extended-wear lenses, however, do meet the ideal standard for use in daily-wear. Some practitioners argue that meeting the ideal standard may not be necessary. The treatment for corneal edema is to discontinue contact lens wear, modify wear (i.e. stop overnight wear or reduce wearing time), change to a contact lens with higher Dk/L values, or change the fitting parameters. The choice(s) will depend on the severity of the edema and other ocular problems. Increasing myopia in a contact lens wearer may

be a sign of corneal edema and corneal decompensation. As such, it should be viewed with great suspicion.

Corneal vascularization is a CL complication ranking second in Hammano's study[53]. When blood vessels invade more than 1 to 2 mm into the clear cornea, they are considered abnormal. This complication is most common in SCL wearers, especially when worn in an extended-wear regimen. There are two types of vascularization, superficial peripheral and deep stromal.[100] The former is most common. There are no direct symptoms, unless the visual axis is compromised, which happily, is quite rare in a properly supervised regimen. However, there can be signs and symptoms that attend the cause of the vascularization, corneal hypoxia. These include conjunctival hyperemia, irritation, corneal edema, lens intolerance, etc. The vision can be reduced directly by the blood vessels, by corneal scarring, or more likely by the lipid which leaks from the vessels. This lipid creates a permanent opacity that disrupts the passage of light. Minor degrees of superficial vascularization can be treated by switching to a CL with a higher DK/L value or altering the fit. With more severe superficial vascularization or stromal vascularization, CL use should be discontinued, perhaps even permanently, to allow for vessel regression. This may take months and leave "ghost" vessels.

The corneal endothelium is a single layer of cells on the innermost surface of the cornea. Once lost, these cells do not reproduce. Other endothelial cells must take up the load by sliding, expanding, and working harder. They are responsible for deturgescing, i.e., pumping water out of the cornea, to maintain corneal transparency. Endothelial polymegathism (abnormal variation in size) and pleomorphism (abnormal variation in shape) have both been demonstrated to occur in the corneal endothelial cells due to contact lens wear.[14,70] Presumably, these changes occur due to chronic hypoxia. While some of these endothelial changes occur normally with aging, they are more pronounced and occur earlier in life in CL wearers. They are much more of a problem in PMMA than SCL wearers. These changes do not appear to be completely reversible. The high Dk/L RGP lenses may cause the least change in this regard.[60] Damage to the endothelium can result in either temporary or permanent corneal edema, depending upon the extent of endothelial damage. CL wearing schedules that cause the least endothelial trauma should be used.

Corneal stromal infiltrates are thought to be aggregations of inflammatory cells in the stroma of the cornea that are caused by stress, such as that produced by chronic hypoxia and/or physical/toxic irritation. They usually occur in long time SCL wearers. Often the patient is without symptoms, but infiltrates can be accompanied by the other "red eye" complications - hyperemia, discomfort, tearing, and photophobia. Co-existent endothelial damage has been documented.[93] The presence of infiltrates is a sign that serious corneal problems are developing. Contact lens wear should be discontinued, until all of the infiltrates have resolved. This may take days to months. Sometimes the lesions do not resolve. Ultimately, wearing time, lens type, lens fit, or lens care procedures should be changed.

Corneal infections (keratitis to ulcer) are the most serious ocular complications caused by contact lenses and are not rare. The incidence of infections is lowest in PMMA and RGP lens wearers and highest in SCL wearers. Extended-wear SCL users have 10-15 times the risk of daily-wear users.[102] From this same retrospective study, the incidence of infectious ulcerative keratitis was estimated at 2.0 (PMMA), 4.0 (RGP), 4.1 (daily-wear SCL), and 21 (extended-wear SCL) per 10,000 cosmetic lens wearers per year.[86]

There has been a dramatic increase in reported corneal infections due to contact lenses during the 198O's, as contact lenses have become a more popular and affordable optical device. This is evolving into a major health problem. Recently, the US Federal Drug Association decreased the recommended extended-wearing time to 7 days.[120]

The initial step in corneal infection is thought to be corneal epithelial changes caused by contact lens-induced hypoxia.[110] When this is coupled with contamination of the cornea by pathogenic organisms, the cornea is at high risk of serious infection. Some organisms can penetrate an intact cornea (Neisseria, Diptheroids, Acanthamoeba). Bacteria will adhere even to a new CL.[37] Over 52% of contact lens care systems are contaminated by pathogenic organisms.[34,125] Thus, bacterial contamination is almost inevitable before a lens encounters the eye. Even strict lens cleaning procedures cannot eliminate all infections. In one study, of patients using extended-wear SCLs and having corneal ulcers, 41% were strictly adhering to the proper lens care procedures.[78] Frequent lens replacements do not obviate the risk. Disposable contact lenses recently also have been shown to cause keratitis and ulcers.[36,61,92]

Somewhere between 17 and 70% of corneal infections occur in CL wearers.[33,51,63,84,122] They often occur at or near the visual axis. The severity of infection is variable, depending on several factors - pathogen, duration, treatment attempted, etc. Contact lens-induced corneal infections have worse bacteria (i.e. gram negative) as etiologic agents, and most of these organisms are Pseudomonas which reach the corneal stroma within 60 minutes after inoculation.[19,33,51,63,109,122] In one study, of those corneas infected with Acanthamoeba, an extremely difficult organism to kill, 83% wore contact lenses.[108]

Patients with corneal ulcers usually have pronounced symptoms of an ocular disorder. They have hyperemia, chemosis, photophobia, and pain. Treatment involves discontinuance of contact lens wear, scraping of the cornea for stains and cultures, antibiotics and/or antifungals every one to two hours, perhaps a corneal biopsy, and possibly a penetrating or lamellar keratoplasty.

While most infections can be halted, the visual outcomes may be poor. Between 25-40% will have a final best acuity worse than 20/30-40.[19,33,51,122] Those that do have reduced vision have central corneal scarring and irregular astigmatism from the destructive infection and may require full-thickness penetrating keratoplasties. Contact lenses have led to total blindness and enucleation.

In the short conflict in the Persian Gulf, only one known corneal ulcer developed in approximately 600 US Army aviators wearing soft contact lenses in the country.[26] There have been eight other corneal ulcers reported in US Army aviators not in the Persian Gulf. In another study, of 1,966 submariners, there were 48 ulcers, ten of which were

central.[104] This unpublished study also listed some rates for other medical complications. It is reasonable to assume that, with increasing use of contact lenses in the military, comparable percentages of aviators will suffer serious complications and reduced visual acuity caused by their contact lens wear. This percentage can be reduced by appropriate education, strict adherence to ocular and lens hygiene, and close medical surveillance.

Medical Complications In Military Studies Of Contact Lenses

All of the military services employing contact lenses in trials have noted some or all of the aforementioned complications. In many studies, the number of subjects was small. Often, the studies were of very short duration (months) or are still ongoing. Frequently, the data are reported in such a way that incidence rates per man-year cannot be calculated. Some of the studies have not been published. Nevertheless, the studies available are summarized in Tables 2 and 3.

Table 2.

Military contact lens studies

	1	2	3	4	5	6	7
Subjects	102	2235	82	50	223	90	1966
Duration	1 yr	2 yrs	12 yrs	6 mos	10 mos	?	years
Lenses	EWSCL	EWSCL	EWSCL	D&EWSCL & RGP	EWSCL &RGP	D&EWSCL RGP	EWSCL
Not Suitable	21		4		31	22	
Discontinued	9	205	27	12	19		
Eliminated	0	5	7	0		0	
DNIF Medical	4/18d	50/212d		6	3		
DNIF Admin		16/229d					

Study #1 = USAF TAC/TAWC Study in flyers (TAC Project #88G-005T)
#2 = USAF Operational Study in flyers (summary from quarterly HQ USAF/SGPA reports)
#3 = RAF Study in flyers[10]
#4 = USA Study in flyers[4]
#5 = USA Study in flyers[63]
#6 = USN Study in flyers[104]
#7 = USN Submariners[104]

Table 3.

Complications - military CL studies

	1	2	3	4	5	6	7
Hypersensitivity	1	7				0	16
Dry eye	23	3		60%			22
Occ. Discomfort	0	4		40%			
GPC	0	1	1			0	25
Microcysts	1	0					12
Infiltrates	0	0					18
Abrasions	1	14		4%	2		11
Deposits	0	2					
Edema	0	0		4%			38
Vascularization	0	2	2	35%			16
Infectious	0	11	1	1		0	48
Corneal Transplant	0	0	1				
A/C Mishaps	1	5					
CL Lost or De-centered in Flight	4	5				40*	
Torn Lenses	112	4				33	

Study #1 = USAF TAC/TAWC Study in flyers (TAC Project #88G-005T)
#2 = USAF Operational Study in flyers (summary from quarterly HQ USAF/SGPA reports)
#3 = RAF Study in flyers[10]
#4 = USA Study in flyers[4]
#5 = USA Study in flyers[63]
#6 = USN Study in flyers[104]
#7 = USN Submariners[104]

* These 40 incidents, one of which happened during flight, occurred with 11 first-time contact lens wearers. All incidents were recorded during the first 2 weeks of lens wear.

It is clear from these studies that the military aviation community can expect definite and predictable ocular complications of all types, some of them serious. Individuals will be "grounded" for variable periods of time to recover and may be permanently "grounded." These complications can be lessened by vigorous and effective education and reeducation programs, proper selection of candidates for contact lenses, proper selection of lens type/fit, meticulous cleaning and sterilization, and good judgment as to whether and when to wear contact lenses and seek medical help.

OPERATIONAL ISSUES

ENVIRONMENT

Flight in military aircraft can provide an inhospitable environment for contact lenses of all types. The advantages, however, of contact lenses in terms of wide field of view and their compatibility with the multitude of aircrew optical devices, especially those with limited eye relief, makes their use valuable.[17]

The aspects of military aviation of importance to contact lens (CL) wearers are as follows:

1. Reduced atmospheric pressure and hypoxia.
2. Sustained accelerations (G forces).
3. Temperature and humidity.
4. Vibration.
5. Irritant fumes and chemical agents.
6. Respirator usage.
7. Ejection and the miniature detonating cord.
8. Field problems.

The above topics will be discussed and the common extreme values of the environmental stresses will be given. In exceptional circumstances, these limits may be exceeded.

Reduced Atmospheric Pressure And Hypoxia

High performance military aircraft can fly at altitudes in excess of 50,000 feet, although 38,000 feet is a more common operational ceiling. The cabins of these aircraft are normally pressurised above 8,000 feet although some training aircraft fly with cabin altitudes above 10,000 feet, with the aircrew breathing oxygen. In the UK the following table gives typical pressurized cabin altitudes in feet for different aircraft heights. The approximate partial pressures of oxygen (pO_2) in millimetres of mercury in the cabin are given below. The dry pO_2 at sea level is 160mm Hg.

Aircraft Altitude	8,000	15,000	20,000	30,000	50,000
Cabin Altitude	8,000	10,000	12,000	15,000	21,000
Cabin Dry pO_2	118	110	101	90	70

In the USA, pressurization commences at 8,000 feet and is held isobaric until the differential pressure between cabin and ambient reaches 5 psi after which that differential is maintained with further increases in altitude. As the cornea is avascular its oxygen supply is primarily obtained from the ambient air; only small amounts are derived from the blood vessels at the limbus. The provision of oxygen to the respiratory tract necessary at altitudes greater than 10,000 feet, thus, has only minimal effects on the oxygenation of the cornea. With increasing cabin altitude and the consequent fall in the pO_2, the cornea becomes progressively more hypoxic, the pO_2 falling to under half its sea level value at 18,000 feet. However, when SCL-wearing

subjects were exposed for 2 hours to a simulated altitude of 27,000 feet in the hypobaric chamber, whilst breathing pure oxygen, there were no significant decrements to vision or changes visible on slit lamp biomicroscopy.[10] Rapid decompressions of subjects from 8,000 feet to 38,000 feet, in 3 to 5 seconds, as might occur when an aircraft is holed or loses a window, were also carried out. No significant decrements in vision or corneal changes detectable with a slit lamp biomicroscope were noted, nor was any bubble formation seen. The lenses used in the RAF Institute for Aviation Medicine trial were high water content SCLs, but bubbles under hard lenses have been seen after rapid decompressions.[44,46]

Sustained Accelerations

Various studies[10] have demonstrated that sustained accelerations of up to +8 Gz have only minimal effects on the centration of correctly fitted soft lenses. Any decrements in the vision were largely due to retinal ischemia. Depending on fitting parameters, similar results have been shown[30,31,90] with rigid lenses.

Temperature And Humidity

Extremes of temperature have been shown[10] to have little effect, either subjectively or objectively, on ocular comfort or visual performance. Ocular exposure for one hour to the zero humidity conditions existing at a temperature of -26°C, in still air, appeared to be without significance. Humidity is, however, an important factor to consider. Cabin conditioning systems and high rates of air flow both contribute to the dehydration of soft contact lenses which both impairs oxygen transfer and decreases visual performance and comfort.

Vibration

Aircrew, particularly in helicopters, may be exposed to sinusoidal vibration from 2-32 Hz at an average peak amplitude of 0.3 G, although this may rise, on occasion to over 0.5 G. Due to the blade pass frequency of rotors, typically 20 Hz, harmonics up to 60 Hz may be measured on the airframe, but these frequencies are normally largely attenuated by the aviator's body. In a study,[10] decrements in visual acuity were noted between 6-8 Hz for targets vibrating in phase with the aviator, but these decrements also occurred with spectacles and the naked eye. Impairments in the ability to see targets outside the aircraft also occurred between 6-8 Hz, but the reduction in visual acuity was much smaller.

Irritant Fumes And Chemical Agents

There is a host of water soluble chemical compounds, smokes, aerosols and products of combustion which could be absorbed by contact lenses and then slowly released. The theoretical possibility of persistent irritation or damage due to the variety of possible irritants has never been investigated. Anecdotal reports have confirmed the problems experienced by contact lens wearers working in high concentrations of tobacco smoke.

The problems of chemical warfare agents and contact lenses have been considered. Although few studies have been carried out, on theoretical grounds, it is probable that contact lenses would neither significantly delay absorption of agents at threat levels nor function as a significant reservoir permitting a slow release following exposure.

Respirators

With most respirators, there is a significant problem integrating corrective flying spectacles. Contact lenses solve this problem. The UK "Aircrew Respirator NBC No 5" (AR5) permits the use of custom designed spectacles which are of a "wrap around" design incorporating a significant dihedral. Although these spectacles perform well, a study was done that included the respirator in an assessment of subjects wearing soft contact lenses. The AR5 requires a filtered air blower, the ventilating unit providing air flow across the eyes of approximately 50 litres/minute. No visual, corneal or comfort problems were encountered after two hours use in the laboratory. Similar testing was conducted by the US Army with similar results when their subjects wore SCLs under the M43 protective mask, a forced air system, for four hours. The USAF also has completed a test of its chemical protection masks and respirator with SCLs, RGPs, spectacles, and no optical devices. Only the RGP lenses appeared to cause significant punctate corneal staining, although no decrease in acuity accompanied the staining.

Ejection And The Miniature Detonating Cord

There is one known Royal Air Force ejection incident where a navigator, who was wearing soft contact lenses, ejected from a Tornado aircraft. No adverse effects were reported. In a review of 50 US Navy ejections, four incidents involved contact lens wearing aviators. Two of these aviators, one wearing RGPs and one wearing SCLs, lost their lenses during the ejection sequence. The remaining two aviators, both wearing SCLs, retained their lenses. (It is interesting to note that of the other 46 aviators who ejected, all of whom wore spectacles, 35 lost their spectacles during the ejection.)

The use of the miniature detonating cord may result in sterile foreign bodies (FBs) either becoming embedded within the cornea, or occasionally penetrating more deeply. If ametropic aircrew wore large diameter (>13.5 mm) soft lenses, it is likely that some FBs would be trapped within the lens polymer and would, therefore, not reach the cornea. Thus, wearing such lenses would give some measure of ocular protection.

FIELD PROBLEMS

Infection

Pathogen contamination can occur in soft contact lenses and in gas permeable hard lenses. It is less likely to occur in polymethylmethacrylate (PMMA) hard contact lenses, except on their surfaces.

When a contact lens becomes contaminated, the pathogens (bacterial, viral, or fungal) can transfer to the cornea and cause a keratitis. This is not always an emergency of rapid onset. It would occur gradually, and the subject would be aware of early symptoms (discomfort and slight redness) before the condition caused severe pain in the affected eye.

Note the advice to each aircrew member wearing contact lenses (Annex C).

Particulate Matter

The aircraft cockpit is a dirty place. Helicopter aircrew often are exposed to swirling particulate matter. Fine FBs may enter aircrew eyes and cause discomfort whether they wear combat flight spectacles, contact lenses, or have no optical aid.

In the case of the contact lens wearer there can be a significant difference, depending on the type of lens worn. With the PMMA and the RGP CLs, a fine FB lodging under such a lens can cause severe pain and watering, causing distraction from the individual's primary task. This is a mechanical problem; as the upper eyelid blinks it presses on the hard unyielding CL material which, in turn, forces the FB into the surface of the cornea - resulting in severe pain. Several such episodes requiring transfer of aircraft controls to the copilot have been documented in the US Army field study.

From the standpoint of foreign body involvement, large diameter soft contact lenses are safer for the following reasons. Firstly, the large diameter of the lens (> 13.5mm) and its "clinging" apposition to the cornea and limbus considerably reduce the likelihood of a sublenticular FB. Secondly, if the FB migrates beneath the lens, then blinking does not cause the same severe pain experienced with a hard CL. When the wearer blinks, the soft CL presses down on the FB, and thus onto the cornea. Because the CL polymer is soft, some of the downwards force (from the FB) is dissipated by indenting the inner surface of the soft polymer. Thus, although the subject may be aware of a FB beneath his soft CL, it will not give rise to the severe pain normally associated with a hard CL.

Contact Lens Hygiene In The Field

At peace, and more especially at war, aircrew may be dispersed from their base for many days. This is particularly relevant to Harrier and helicopter crews. It is impractical for aircrew to carry their CL cleaning equipment with them in most cockpits. Also, many field environments may make CL manipulation difficult due to such factors as temperature extremes, minor injuries, darkness, winds or improvised living quarters. Regardless of type, all daily wear CLs should be removed at the end of 16-24 hours to give the cornea time to acquire oxygen. If such lenses are not removed, the eyes become red and painful and vision is blurred. This is both a flight hazard and an ocular risk. If the subject is wearing extended wear CLs, he may continue to operate effectively. Aircrew wearing rigid or low Dk CLs can be subject to "spectacle blur" when they have to remove their CLs, for whatever reason, and revert to flight spectacles. Removing soft CLs, both medium and high water content, will rarely result in "spectacle blur" and, thus, obviates this visual flight hazard.

If aircrew forget to carry their combat flight spectacles in their flying coveralls and have to remove their CLs, for whatever reason, they could be visually handicapped. Note the advice (Annex C).

RESOURCE REQUIREMENTS (RAF Experience)

1. In addition to basic ophthalmic department equipment, a contact lens fitting and care service in the military context necessitates the following minimum requirements:[18]

a. A Consultant Ophthalmic Surgeon who has contact lens experience and who will be in overall charge of each aircrew member fitted with contact lenses.

b. A Senior Optometrist with contact lens experience, who is trained to fit and supervise the aircrew.

c. A qualified nurse or ophthalmic technician to assist in the CL clinic, whose special role will be to instruct subjects in the handling and care of their lenses. This assistant will also be responsible for ordering lenses, checking them on arrival, and cleaning and sterilizing the trial lenses.

d. Equipment to include:
(1) 1 Automated Pachymeter.
(2) 1 Keratometer.
(3) 1 Specular Microscope.
(4) CL Trial Sets.
(5) Lenses for first year.
(6) Solutions for first year.

e. CL-related training programmes for aviation medical support personnel.

2. An estimated example of the capital costs for the first year and the annual recurring costs for 200 subjects for the Royal Air Force in the UK is listed in Annexes A and B.

3. Annex C to this chapter is a "Form of Understanding" to be signed by each subject when he volunteers to wear optional contact lenses in place of his flight spectacles. Copies are to be held by the individual, within his Service medical records and in the Service Ophthalmic Department which supplied the first pair of contact lenses.

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ANNEX A

RAF SCL PROJECT 1991
CAPITAL COSTS - 200 SUBJECTS

Subjects to be fitted at 3 centres: CME, Halton, Wegberg.

Course for Doctors			POUNDS STERLING
Basic CL Course (5 days)	Inst of Ophth	£290.00	
Advanced CL Course (3 days)	Inst of Ophth	£190.00	
5 Doctors			2400.00
Ophthalmic Optician (Experienced CL Fitter)			
1 session £100.00 2 sessions per week at CME, Halton, Wegberg.			27000.00 pa
Ancillary Nurse			
2 sessions per week at CME, Halton, Wegberg.			6000.00 pa
Automated Pachymeters (3)			11211.00
Keratometers (3)			8208.00
Specular Microscope (Halton (1))			12500.00
Ciba Scanlens 75 Trial Set (at £2612.60)			
Halton, CME, Wegberg			7838.00
Lunelle Trial Set (at £2700.00)			
Halton, CME, Wegberg			8100.00
Scanlens 75 for 200 Subjects			
6 lenses each subject (3 pairs)			21216.00
10/10 Cleaning Solutions/Clerz Minims for 200 subjects/year			20600.00
FIRST YEAR CAPITAL COST			£125073.00

3 CENTRES
200 SUBJECTS

ANNEX B

RAF SCL PROJECT 1991
ANNUAL RECURRING COSTS - 200 SUBJECTS

3 CENTRES

Ophthalmic Opticians	POUNDS STERLING
2 sessions per week (Halton, CME, Wegberg)	27000.00
Ancillary Nurses	
2 sessions per week (Halton, CME, Wegberg)	6000.00
Lenses 200	21216.00
Solutions 200	20600.00
ANNUAL RECURRING COSTS FOR 200	£74816.00

ANNEX C

AIRCREW MEMBERS WEARING CONTACT LENSES

FORM OF UNDERSTANDING

NUMBER _____ RANK _____ NAME _____ DOB _____

1. I understand that I have volunteered to wear contact lenses in place of spectacles when flying.

2. I understand that complications can occur when using contact lenses, whether worn as daily or extended wear. Examples are blood vessels advancing into the cornea and corneal infections. For this reason I understand that I must attend my regular ophthalmic review appointments.

3. I understand that I must carry one pair of clear corrective flying spectacles with me when I am flying.

4. I understand that I may have to cease wearing my contact lenses if so advised by the Ophthalmologist.

5. I understand that I may have to stop wearing my contact lenses after many years wear, even though I am symptom free.

6. I understand that, if redness or discomfort occurs in either eye, I am to remove my contact lenses, revert to spectacle use, and report to my MO and if possible to my CL Practitioner within 24 hours.

Signed _____

Print name _____

Rank _____

Witness _____

Print name _____

Rank _____

Date _____

The witness is to be an Ophthalmologist

1 Copy to subject
1 Copy to Service Medical Records
1 Copy to Ophthalmic Department issuing the CLs

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14. Abstract

This AGARDograph summarizes current scientific, clinical and technological issues in the use and manufacture of contact lenses, and provides a 50 years' synopsis of the scientific experiments on CLs in the various military flight environments.

Rigid Gas Permeable CLs, and soft CLs are discussed separately, and their respective merits and disadvantages summarized.

The text discusses the operational requirements of military personnel relative to the use of contact lenses, and particular emphasis is given to the experience of those NATO air forces that currently have aircrew flying with contact lenses. Topics such as lens optical performance, user compliance, and a definition of adequate eye-care supervision, are highlighted. The text seeks to identify the critical factors to be taken into account when the decision is made to permit the use of contact lenses by military aircrew, and weighs medical considerations and military field conditions, in this regard. Finally, specific military aeromedical conditions in modern aircraft are discussed, with emphasis on the advantages and disadvantages of CL visual correction. Based on extensive deliberations in the group, WG 16 offers a detailed list of recommendations for the use of contact lenses by military aircrew. These recommendations will also be useful for military medical authorities supervising visual correction guidelines for non-flying personnel.

This AGARDograph has been sponsored by the AGARD Aerospace Medical Panel.

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Advisory Group for Aerospace Research and Development, NATO
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Edited by E. Alnaes
Published October 1992
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P.T.O.

AGARD-AG-334

Aviation medicine
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OPERATIONAL USE OF CONTACT LENSES BY MILITARY AIRCREW
Edited by E. Alnaes
Published October 1992
34 pages

This AGARDograph summarizes current scientific, clinical and technological issues in the use and manufacture of contact lenses, and provides a 50 years' synopsis of the scientific experiments on CLs in the various military flight environments.

Rigid Gas Permeable CLs, and soft CLs are discussed separately, and their respective merits and disadvantages summarized.

P.T.O.

AGARD-AG-334

Aviation medicine
Contact lenses
Military medicine
Military aviation
Ophthalmology
Visual correction
Contact lenses — medical considerations

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