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The use of automated refractors in the military

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INTRODUCTION

The challenge facing military health care today is to provide high quality care to all eligible members at reasonable cost to the taxpayers. This is a difficult task as the resources available are limited compared to the size of the population to be served. Increased efficiency and attention to cost-effectiveness are the means by which the challenge will be met. Most of the effort necessary to achieve this goal must be directed toward serving the active duty person wherever he/she might be.

Optometry, as part of the military health care team, must do its share to meet this challenge. At present, most beneficiaries including active duty persons at isolated duty stations and on ships at sea, do not have access to high quality vision care on a routine basis. Like the other clinical specialities, optometry must seek ways to increase productivity and to extend quality health care to all eligible members.

Automated refractors are promoted as a means of significantly improving efficiency in an optometry clinic. They are also a means of extending a higher level of vision care into new areas inadequately served at present. For these reasons the Senior Navy Optometrist has suggested that this study of the potential uses of automated refractors to military optometry be undertaken.

PROBLEM

BACKGROUND

Persons eligible for health care within the military system include all active duty and retired personnel from the Department of Defense, the Coast Guard and the Commissioned Corps of the Public Health Service and National Oceanic and Atmospheric Administration, as well as their legal dependents and survivors. Several characteristics of this population directly affect the quality of health care, including vision care, that can be provided.

(1) The population is very large. The total number eligible for care is greater than 8 million.(148)

(2) The population is transient. For example, in 1982 338,200 men and women entered the armed services.(38) Each new inductee requires a thorough physical examination including a vision analysis.

(3) The population is mobile. The typical tour of duty in the continental United States is three years. Many military schools and overseas tours of duty are shorter. Approximately one third of the active duty members and their dependents will move to a new duty station each year. For the military optometrist this means an exceptionally large portion of patients will be new and thus require more extensive examinations.

(4) The population is geographically dispersed. Active duty members are spread throughout the world including isolated duty stations and ships at sea.

(5) The population is aging. At present approximately 30% of the people entitled to care at military facilities are retired perso@nel and/or their dependents.(147) As the percentage of older people rises in the general population the percentage of military retired personnel is expected to similarly increase in the future.(94, 158) This will result in an elevated demand for optometric services, as studies have shown that the elderly require more frequent eye care and longer examination times.(23, 131, 161)

Besides the population characteristics there are four other factors which directly affect the quality of health care that can be provided.

(1) Health care is provided at no charge to the member. This tends to make the system highly utilized compared to the civilian fee-for-service system. It has been conservatively estimated that demand for optometric services is 10% higher in non fee-for-service systems.(141)

(2) By law, staffing and facility planning are based on the number of active duty persons only.(64) This has contributed to a significant understaffing problem since active duty members represent only one third of the total eligible population.(147)

(3) In the military system of health care the optometrist

is the primary vision care practitioner. Unlike the civilian system, military ophthalmology tends to provide care on a secondary (referral) basis only.(100) Thus a higher percentage of patients initially see an optometrist for eye care than in the civilian system.(1)

(4) An alternative source of health care available to military dependents and retired personnel is CHAMPUS, the Civilian Health and Medical Program of the Uniformed Services. Users of this program are partially reimbursed by the federal government for medical services provided by a civilian practitioner. CHAMPUS, however, does not include routine optometric care.(114)

These characteristics of the military population and its health care system result in a higher demand for services than in a comparably sized civilian community. To meet the demand for vision care in this diverse population the military employs approximately 475 optometrists.(148) This is a practitioner/client ratio of 1:16,800. In the past this ratio has been as high as 1:39,000 in the Army.(6) This is in sharp contrast to the national civilian average of 1:11,000 and the 1:8,000 ratio recommended in a National Health Plan analysis conducted by Birchard and Elliott.(16, 124, 126) The American Optometric Association has long recommended an ideal ratio of 1:7,000.(101) The actual practitioner/client ratio is also much higher than the Department of Defense recommended ratio of 1:10,000.(27)

There are many similarities between optometry as practiced in the military and in a Health Maintenance Organization (HMO). An HMO is an organization which provides or arranges for complete health services for its subscribers and which is financed by a predetermined fee agreed to or paid in advance. (119) Both systems stress high volume/high efficiency care. (129) A significant difference between the two systems is the emphasis HMO's place on early disease detection and treatment as a means of controlling costs and increasing efficiency.(51) Two leading HMO's, Group Health of Puget Sound and Genesee Valley Group Health Association, use ratios of 1:13,000 and 1:12,000 to determine proper optometric staffing levels.(24, 75)

The high practitioner/client ratio results in great demand for available services and a large workload for the individual military optometrist.(41) In many clinics the demand for services cannot be met and backlogs of up to six months have developed.(155) In the past, the situation has reached a point in the Army that whole classes of eligible members (retired personnel and their dependents) have been denied care.(128) Richardson estimates that with present staffing levels quality eye care can be provided for only 18% of those entitled to care.(128)

In an attempt to meet the demand three steps have been taken:

(1) screening clinics have been developed.

(2) the number of patients seen daily has been increased.

(3) the quality of care provided has been lowered.

SCREENING CLINICS

A screening clinic is an effective means of prioritizing patient care on a most needed basis and the techniques are well established.(4) Johnson has described the screening system used at Fort Belvoir, Va.(74) As originally designed it is typical of other military screening clinics. A trained technician screens the patient and, based on predetermined criteria, assigns the patient a priority number. The lower the priority number the longer the wait for an appointment with the practitioner. With this system 8,000 patients at Fort Belvoir were screened in 14 months. Concerning the effectiveness of this program Johnson wrote, "While the program was accomplishing its initial goal of screening and sorting, there were certain aspects of it that caused nagging concern. For example:

a. Corpsmen who had obtained limited findings and had minimal training were forced to decide what constituted a significant complaint.

b. Upon subsequent examination, many of the findings of the screening were found to be grossly in error and, as a consequence, patients had been placed in an improper group.

c. Patients often related comments that the screener-corpsman had made to them at the time of their screening that were either incorrect or inappropriate.

d. Amblyopes were usually placed in Priority I or II when they could often equitably have been placed in a lower priority group.

e. Patients could return year after year and never be seen by an optometrist. Consequently the eye health status was never checked.

f. The question of under-referral was unanswered."

To solve these problems an optometrist was assigned to the screening clinic. His job was to supplement the corpsman's tests using more sophisticated screening techniques. This new system, while not typical, eliminated many of the problems encountered when an optometrist did not participate in the screening. A screening system is definitely a useful aid in very high demand situations. It is not without considerable problems of its own, however, and for the 45% of patients placed in priority III (no appointment needed at this time) the screening system provided less than optimum care.

WORKLOAD

The second step taken has been to increase the daily patient workload for each optometrist. Navy optometrists are expected to see thirteen patients daily for complete exams and sixteen patients daily if limited care is provided.(111) Similar minimum standards exist for optometrists in the other services. (52) Limited care, in this sense, is administered at any clinic which does not routinely use binocular indirect ophthalmoscopy.(123) Without allowing any time for management problems, prescription preparation, continuing education or ancillary duties this translates into a thirty minute examination time. In comparison the average civilian optometrist examines seven patients daily and the average time allocated to each patient is 39.6 minutes.(67, 125) Fourteen patients a day are scheduled for each optometrist at Group Health of Puget Sound, a leading HMO.(118) The daily workload of 13-16 patients is not excessive for military optometrists considering the quality of care provided, but it is demanding. This is, however, a minimum standard. Daily patient workloads are often much higher, especially at recruit processing centers.(41) In 1975, 12% of the military optometrists saw more than 18 patients per day.(52) There is probably little room for increasing the daily workload without adding significant new instrumentation and/or ancillary personnel.(129, 146)

QUALITY OF CARE

The third step taken has been to reduce the quality of care provided. Basing his work on an American Optometric Association sponsored seminar of federal service optometrists, Turner has described three levels of optometric care and applied them to the military system.(154) The three levels of care are:

A. Full Scope Care

(1) Detailed examinaton of eye and adnexa

including supplemental diagnostic procedures necessary for finalizing the disposition.

(2) Study medical records, take a complete systemic, familial, and ocular history, occupational and personal visual needs and analyze in relation to all complaints.

(3) Visual acuities, near and far in each eye; unaided and corrected.

(4) Baseline data on corneal curvatures, visual fields, and color vision.

(5) Objective and subjective determination of ametropia.

(6) Evaluation of binocular coordination and accommodation.

(7) Final diagnosis

(8) Disposition

a. Case presentation

b. Follow through with Visual Treatment Plan including specialty areas.

c. Direct referral when appropriate.

B. Basic Visual Care

(1) Detailed examination of the eye and adnexa (provisional diagnosis).

(2) Perusing medical records for significant history and reason for visit.

(3) Visual acuities, near and far in each eye, unaided and corrected.

(4) Objective and subjective determination of ametropia.

(5) Evaluation of binocularity and accommodation.

(6) Final diagnosis

(7) Disposition

a. reassurance

b. visual treatment plan

c. referral.

C. Minimal Visual Care

(1) Applicable to basic training centers and time of rapid mobilization.

(2) To include the detection of departure from the optimally healthy eye.

(3) History by checklist.

(4) Visual acuities; near and far in each eye, unaided and corrected.

(5) Evaluation of ametropia.

(6) Determination of binocularity.

Turner states that full scope care is necessary to provide optimum care of the visual needs of the beneficiary and to maintain the overall competency of the optometrist. In addition, he states that basic visual care should be provided only on a temporary basis to fulfill mission requirements. This would apply to active duty military personnel after other categories of patients have been restricted from the schedule and there is still a backlog of active duty.(154) However, high patient volume limits the amount of time that can be spent with each patient. Since basic care takes less time than full scope care it has become the standard in the military, and in many cases only minimal care can be provided. This is a significantly lower quality of care than can be routinely obtained in the civilian sector and not in agreement with the goals of military medicine.(6, 52)

The highest priority for military medicine is the full support of all active duty persons. However, many active duty members serving at isolated duty stations and on ships at sea do not have ready access to quality vision care. In 1981, the Navy had 270,000 men on ships at sea.(147) The largest ships, the aircraft carriers, have up to 6000 men aboard and can be deployed for periods of more than a year.(91) There is no optometrist nor ophthalmologist on board these aircraft carriers and other large ships. Vision care is administered by an aviation trained corpsman and/or a flight surgeon who is a physician specially trained in aviation medicine. Both are capable, qualifed people but their training in vision problems is often minimal; and the demands on their time and their own personal interests are often elsewhere.(140)

STATEMENT OF THE PROBLEM

This paper investigates the use of automated refractors to improve vision care in the military. It is postulated that use of automated systems may increase the efficiency of the eye care delivery system. The goal of military optometry is to provide high quality vision care to all eligible members. At present this goal is not being met. Chronic understaffing has led to an overall lowering of the quality of care provided. This problem has three components:

1. The overall demand for care must be satisfied. The population and system characteristics make this a difficult task.

2. The quality of care must be improved and made routinely available to all members. This is consistent with the overall goal of the Department of Defense and necessary for the well being of the members.

3. Both must be accomplished at reasonable cost to the taxpayers.(145)

To solve this problem with present staffing levels, each military eye care specialist must function at maximum efficiency and at the highest level of his or her training.(101) The time available for each patient must be utilized to provide high quality care.

IMPORTANCE OF THE STUDY

The imbalance between the need for vision care and the ability of military optometry to supply this care has led to an overall lowering of the quality of vision care provided. It is important that this problem be corrected because inadequate care has several adverse effects.

Patients are affected in two ways:

1. To properly diagnose visual and ocular problems a minimum number of tests must be conducted. When the time per patient is restricted the total number of procedures and the time taken for each procedure must be limited, including evaluation of the health of the eye through ophthalmoscopy, tonometry and visual fields. This increases the possibility that an abnormality will be missed with potentially serious consequences for the patient's vision. At clinics using a screening system there may be no direct contact between the practitioner and an individual patient for many years which also increases the possibility of a potentially serious problem escaping detection. A lengthy appointment backload can have a similiar effect.

2. Vision is our dominant sense, so adequate visual skills are essential to proper job performance.(62) The military recognizes the importance of adequate vision in the rigid standards established for various job categories. Strict distance visual acuity standards exist, for example, for flying and driving.(92) Adequate ability to accommodate and converge the eyes is necessary for skilled performance of near tasks. (162) Reduced ability may prevent adequate focusing on radar screens, control consoles, video display terminals, typewriters, instruction manuals, etc.(78) Inadequate vision care

can result in poor work performance and possibly time lost from the job due to missed detection and treatment of these conditions.(114, 163)

The lowered quality of care is not only a disservice to patients, it also affects the morale and job satisfaction of military optometrists.(73) Optometrists are trained to provide care in the areas of low vision, contact lenses, vision training, developmental vision and learning disabilities. Because of high patient volume, military optometrists are not able to provide these services on a routine basis.(6) As a result, maintaining a sufficient number of optometrists on active duty has frequently been a serious problem.(89) At a symposium of military optometrists in 1977 Ecklund reported that, within the Navy, optometry had the lowest retention rate of the Medical Service Corps (29%).(1) Most military optometrists are dissatisfied with the level of care they must provide, although recent developments in the economy and the Health Professions Scholarship Program have at least temporarily eased the problem of low retention.(26) In 1974 Greene and Fox, two military optometrists, wrote: "It is the opinion of a majority of military optometrists that they are rendering vision care which is significantly narrower in scope and lower in quality than that which they would be providing as civilians. In a recent survey conducted of all military optometrists, 84% of those responding felt they would be practicing a wider scope as civilians, and 51% felt the quality of their work would be higher."(61) Civilian optometrists and optometry students are also aware of military optometry's reputation for lowered quality care and limited scope of practice.(89) These factors will probably affect future recruitment and retention.

STATEMENT OF PURPOSE

Although instruments for the automatic measurement of the refractive error of the eye have existed for many years, recent advances in electronic microprocessors and optics have made them accurate and reliable enough to be clinically practical. During this period of rapid development much misinformation and exaggeration has been published about the purpose and capability of automated refractors. The many differences between objective and subjective refractors have often been overlooked or not fully explained. Some advertising brochures claim that automated refractors can significantly increase efficiency in a vision care clinic through increased speed of examination and task delegation. Manufacturers also claim that many of these instruments can be operated successfully by minimally trained technicians.(10, 13) If these claims are true then automated refractors are potentially a means of improving the quality of care provided to each patient and of extending care to military personnel on large ships and other locations lacking an eye care professional.

The purpose of this study is twofold.

(1) Distinguish between objective and subjective refractors through detailed explanation of the different purposes, values and capabilities of these instruments.

(2) Investigate the manufacturers' claims with respect to the potential value of automated refractors to the military. Prior to placing these instruments in clinics and on board ships an analysis of their accuracy, reliability and durability must be made.

The results of this study will be useful in developing an overall policy for the incorporation of these instruments into the military health care system. Special attention is given to cost-effectiveness, since their ability to increase efficiency must be balanced against their high cost. If it is determined that automated refractors can be effectively used in the military, specific recommendations as to type required in various settings will be made.

METHODOLOGY

A considerable amount of information has been written about automated refractors including discussions of their purpose, design, durability, operation and clinical validity and reliability. This study reviews the relevant literature, analyzes these factors and applies the data to the military situation.

The literature will be reviewed with particular attention to the impact of automated refractors on the following factors:

(1) screening clinics
(2) daily patient load
(3) quality of care.

REVIEW OF THE LITERATURE

BACKGROUND

Refraction is the process of measuring the refractive status of the eye.(37) It is a major component of a complete optometric examination (vision analysis). A refraction has two parts: a subjective and an objective measurement of the refractive status.(160) In the subjective portion the examiner, usually using a refractor, places various lens combinations before the patient's eyes. The patient is asked to choose between the lenses until the combination providing best visual acuity and binocular, comfortable vision is determined. This procedure is subjective because it is dependent upon reports made by the patient. The subjective refraction is considered the most accurate and reliable and, therefore, best measure of the refractive status. It is the standard against which other measurements of the refractive status are compared and the one most often prescribed.(127) Whether measured subjectively or objectively, the refractive status will vary slightly upon repeated testing by the same examiner or when measured by more than one examiner.(142)

The objective portion usually precedes the subjective testing and forms a basis for the subjective testing. In this procedure the examiner, usually using a retinoscope, observes light reflected from the patient's retina. By observing the relative motion of this reflex compared to the movement of the retinoscope and the adding of various lenses, the examiner determines an objective measurement of the refractive status. In many but not all cases this measurement is nearly the same as the subjective measurement.(18, 45, 133) Retinoscopy is patient objective because no reports are required on the part of the patient. It is, however, examiner subjective because he or she must judge the motion of the reflex.(81, 127) Retinoscopy also requires a great deal of skill on the part of the practitioner.(143)

A refractive measurement is only part of a complete optometric eye examination. A complete vision analysis also includes tests to evaluate the status of the subject's accommodation and convergence at both far and near distances.

There are two basic types of automated refracting instruments, objective and subjective refractors which parallel the traditional methods of refraction.(47, 105) Objective refractors rapidly produce a retinoscopy-like finding which can then be used as a basis for subjective refinement.(134) Many objective refractors are both patient and examiner objective, i.e. once the instruments are properly aligned and activated they do not require judgements on the part of either.(144) Most objective refractors can be operated by a trained technician thus saving time for the eye care professional.(47, 121)

Subjective refractors are designed to produce a final, wearable prescription similar to a traditional subjective refraction, i.e. they require patient responses as part of the measurement process. There is considerable variation among subjective refractors. Some may be used by a technician to measure the distance refractive status only while others can be used by the eye care professional to do a comprehensive eye examination. In general, subjective refractors feature increased speed of examination, reduced size and advanced technology.

The general term "autorefractor" is often used indiscriminately to refer to objective and subjective automated refractors. "Autorefractor" implies that the instrument can measure the refractive status accurately and give a final spectacle prescription automatically. However, no automated refractor, objective or subjective, can consistently produce a valid spectacle prescription at the touch of a button.(106)

HISTORY OF AUTOMATED REFRACTORS

A brief history will help explain the development of modern objective refractors.(12, 50) The first instruments used to measure the refractive status of the eye were called optometers, a word coined by William Porterfield (1696-1771). Optometers, the precursors of the modern automated refractors, can be traced back to 1619 when Christoph Scheiner discovered that a small light source viewed through a double pinhole was seen singly by an emmetropic subject and doubled by an ametropic observer, if the separation of the pinholes was less than the diameter of the pupil. When he combined a double pinhole disc with a moveable target on a sliding scale, Scheiner had made the first instrument for directly measuring the refractive status of the eye. This Scheiner disc principle is incorporated into some modern objective refractors.

William Porterfield developed an optometer based on the Scheiner disc principle but used slits instead of pinholes and a moveable vertical line for the target. The target was adjusted by the patient until he saw singly. A scale translated this point into a dioptric measurement of the refractive status. Porterfield's optometer could only be used on a myopic subject.

Thomas Young built the first clinically practical optometer in 1801. He added a convex lens to Porterfield's system making any subject an artificial myope and, therefore, measureable. Badal (1876) improved the optics in his design of an optometer so that changing the target distance did not affect image size and brightness. The optical principles of the Badal Optometer have been incorporated into some modern objective refractors.

The instruments previously described are subjective optometers. In the 1930's three objective optometers, the Rodenstock Eye-Refractometer, the Topcon Eye Refractometer and the Hartinger

Coincidence-Refractionometer were developed. These manual instruments work on the same principle as an ophthalmoscope. The Rodenstock Eye-Refractometer, for example, operates similarly to a direct ophthalmoscope. The instrument projects an illuminated pattern onto the retina of the patient. The examiner then adjusts the refractometer to focus this projected image with the amount of adjustment corresponding to the patient's refractive status.(156) The Hartinger Coincidence-Refractionometer operates similarly to an indirect ophthalmoscope. A condensing lens forms a real image of the retina in front of the eye. A telescopic system is then manually adjusted to focus this aerial image. The amount of telescope adjustment required correlates with the refractive status of the eye. The Hartinger instrument adds a split-beam imaging system. Focusing is by image alignment rather than image quality and is, therefore, more precise. Although all three are available in some form today, they do not have the speed nor accuracy of more modern instruments so are not realistic considerations for clinical practice.(157, 165)

These early objective optometers were plagued by two serious problems.(54) The first problem, "instrument myopia," is due to an awareness of the actual distance to the viewed target causing the refractive error to be overestimated in myopes and underestimated in hyperopes.(50, 54) Accommodation is the contraction of the ciliary muscle of the eye which allows the shape of the crystalline lens to change, leading to an increase in the dioptric power of the eye and a change in focus of the eye to a nearer position.(135) The ability to accommodate is essential for clear near vision, but to measure the distance refractive status accurately, accommodation must be relaxed (inactivated). Instrument myopia refers to the state of active accommodation that occurs for some subjects when they view a simulated distance target in a closed instrument. It leads to incorrect measurements of the refractive status. Instrument myopia is still a problem for many modern objective refractors. All of the modern objective refractors try to control instrument myopia in one or more of the following ways: using fogging lenses, blurring the target, and/or using an open view system.

The second problem in using early objective optometers was reliance on visible light which caused glare and discomfort for the patient and, most importantly, pupillary constriction. Under these conditions measurements were very difficult or impossible. These problems were solved by the use of infrared light. Since the human eye is insensitive to infrared light glare, discomfort and pupillary constriction were eliminated.

MODERN OBJECTIVE REFRACTORS

Collins (1937) developed the first "electronic refractionometer."(25, 28) He was also the first to use infrared light, combining it and Badal Optometer optics with an oscillating filament detection system to design the first automated refractor. He caused a lamp filament to oscillate rapidly and to be reflected off the retina and on to a grating located in front of the measured eye. The bars and spaces of the grating matched the oscillation width of the filament creating an area of maximum contrast just beyond the grating when the reflected light was at its best focus. A maximum alternating current was thus generated when the light on the grating was at best focus. Detection of this maximum current provided a measure of the refractive status. This Collins "electronic refractionometer" system is closely followed in the modern Dioptron.(50)

Modern objective refractometry became clinically feasible with the introduction in 1972 of the Ophthalmetron followed shortly by Acuity System's 6600 Autorefractor and the Dioptron. None of these instruments is manufactured today but all are important as a transition from the early non-automated objective optometers to the latest generation automated objective refractors.(63)

THE OPHTHALMETRON

At the time of its introduction in 1972 the Ophthalmetron represented a significant advance in objective refraction instruments. Conceived by Aron Safir and manufactured by Bausch and Lomb, it was a relatively simple means of measuring refractive status.(135) It was designed to be operated by a technician and to improve upon retinoscopy because it was both examiner and patient objective. According to Safir et al. its main purpose was "to enhance the ability of the practitioner to perform total refractions". They add, "We do not mean to imply that the objective phase of refraction is the whole of refraction or, indeed, the most important part. The practitioner's experience and judgment remain, as always, crucial factors in determining whether or not the patient is made visually functional, comfortable, and satisfied as a result of the refraction."(136)

The Ophthalmetron operated in a manner similiar to a retinoscope but used infrared light. A chopper drum (a hollow cylinder with slits) rotated around a light source causing parallel light to sweep across the eye at a rate of 720 times per second. As in retinoscopy, the reflected light showed no motion at the point of neutrality. The neutral point was measured in each meridian and recorded as a continuous graph which was then interpreted by the operator to determine the refractive status.(79, 88) The actual measurement time was three seconds per eye, but due to a need for careful alignment the total testing time varied from three to eight minutes. All measurements were taken monocularly. A three millimeter minimum pupil size was necessary and the normal range of measurement was from -18.00 to +17.00 diopters. To test calibration a standardized schematic eye was included with the instrument.(80, 109)

To prevent instrument myopia and to control accommodation the Ophthalmetron had a fixation target showing a rocket ship which was supposed to create the illusio. of great distance to the viewer, thus relaxing accommodation.(58) A low plus lens within the instrument also fogged the target slightly. Two studies involving the screening of approximately 500 school age children showed that accommodation was not well controlled with this instrument.(138, 139) The Ophthalmetron results shifted an average of +0.62 Diopters in those students given cycloplegic drops to immobilize their accommodation.(138) The shift indicated that excess accommodation was present prior to the use of the cycloplegic.

Keech, on the other hand, in a study of ten students concluded that instrument myopia was well controlled with the Ophthalmetron.(76) Floyd and Garcia also concluded that instrument myopia was well controlled with the Ophthalmetron. However, the value of their conclusion is weakened by a criterion they used for including a subject in their study which was "one who could hold steady fixation and relax his power of accommodation." Floyd and Garcia also reported that the instrument broke down three times in the three month testing period and they found young children (under age 8), nervous people, and below average intellect people difficult to test.(44)

Two clinical studies involving 110 subjects showed Ophthalmetron results to be reliable and not significantly different from those of subjective refraction and retinoscopy.(81, 136) The data in these two studies was not analyzed statistically. Bizzell et al. studied 567 eyes and found a tendency for the Ophthalmetron to overcorrect astigmatism.(17) They concluded that the instrument was not as accurate as retinoscopy. They also had to reject 26% of the Ophthalmetron tracings as uninterpretable. A simliar rejection rate was found by Guillon in a study of aphakic eyes.(55)

The Ophthalmetron is no longer in production because it was hard to use, relatively slow, required interpretation of a graph rather than giving a direct readout, was very sensitive to eye movement and blinks, and did not adequately control accommodation.

6600 AUTOREFRACTOR

This instrument was developed and originally manufactured by Acuity Systems Inc. In 1980 Trilogic assumed control and continued production until 1983 when the 6600 model was replaced with a more advanced unit, the Rx6600 Autorefractor.(61) The 6600 Autorefractor was based on an earlier optometer developed in 1967 by Cornsweet and Crane.(32) It incorporated the principles of both the Scheiner disc and the Badal optometer.(12)

The original 6600 Autorefractor had several major innovations compared to the Ophthalmetron. First, it had an automatic fine alignment and eye tracking system for simplified operation. Second, 6600 Autorefractor results were not affected by eye movements or blinks. A sensing mechanism restarted the testing procedure automatically if a blink or eye movement occurred. Third, the actual recording time was reduced to approximately one and a half seconds per eye and the total examination time shortened to one and a half to five minutes. An additional feature was the "special patient" indicator light which warned the examiner of difficulties or possible erroneous results.

To control accommodation the 6600 Autorefractor had a monocular pulsating green light target which was supposed to have no cues to stimulate accommodation.(102) However, an environment lacking fixation cues can actually stimulate accommodation ("empty space myopia").(54) Studies of the effectiveness of this system yielded mixed results. Pappas, Anderson and Briese in a study of 200 subjects concluded that the 6600 Autorefractor tended to overestimate myopic status and to underestimate hyperopic errors, as well as tending to overestimate astigmatism corrections. They found that 49% of the 6600 Autorefractor's results were in error by more than 0.50 diopter with the average error equal to 0.60 diopters more myopic than the subjective refraction.(115)

Conversely, Hill found that for 100 randomly chosen eyes 81% of the 6600 Autorefractor results were within +/-0.50 diopters for the sphere, 92% within +/-0.50 for the astigmatism correction and 61% within +/-10 degrees for the axis correction compared to the subjective results.(68) Similar results were reported in three other studies.(40, 103-104)

Problems associated with this instrument were related to its high price (at one time close to $33,000) and its large size. It also had a limited range of powers, particularly for estimating myopic errors (-8.75 diopters maximum).

Cornsweet recommended that the 6600 Autorefractor be used as a starting point for a subjective refraction.(31) Pappas et al. reached a similiar conclusion, but reported that the "old glasses" provided an equally good starting point.(116)

THE DIOPTRON

The third automated objective refractor introduced during this period, the Dioptron, was designed by Munnerlyn and manufactured by Coherent Instruments.(110) It was based on Collins' refractionometer and differed from the other two objective refractors in its method of determining the refractive status and its system for controlling accommodation.

The refractive status of the eye can be computed from measurements taken in any three meridians.(20) Using this system, the

Dioptron made the minimum three measurements, but then measured an additional three meridians for increased accuracy and reliability. The second set of measurements was compared to the refractive status indicated by the first set. The result of this comparison was converted into a "confidence factor" which indicated the value of the test. In one clinical study of the Dioptron, the author concluded that rejection of the results based on a low confidence factor was "an almost sure prognostication that there is pathology present in the rejected eye." (90) However, another study indicated that the confidence factor was only a marginal indicator of accuracy.(122) In a third study 60% of the eyes were rejected; it was later determined that 88% of that group did have eye pathology.(77) Conditions which may be associated with both a low confidence factor and ocular pathology are: (1) small pupils, (2) lens opacities, and (3) irregularities of the cornea, retina and vitreous humor.(90)

To control accommodation the subject fixated the target binocularly, although measurements were taken monocularly.(34, 84) The eye being measured was automatically fogged (blurred) +1.50 diopters while the other eye viewed a photographically blurred starburst target. Alignment of the Dioptron was not as critical since the whole pupil was used for alignment and measurement. The Dioptron, also, required less skill to operate than the Ophthalmetron and 6600 Autorefractor. It, too, was programmed to automatically restart the measurement process if the subject blinked.(33, 85-86)

Four clinical evaluations of the Dioptron indicated that it had high reliability and validity without significant instrument accommodation.(39, 90, 122, 144) Only one study reported a high failure rate and unacceptable results.(77) The Dioptron has been used successfully in an orthokeratology practice, but it was reportedly difficult to use for refractions over contact lenses.(60, 87)

Following their evaluation Sloane and Polse suggested that the Dioptron would be useful in mass screening applications and as a substitute for retinoscopy.(144) Pose and Kerr reached a similar conclusion, but added that its use as a replacement for subjective refraction was not warranted because of the number of Dioptron results differing substantially from the subjective refraction. They also stated, "This trend toward sophisticated and efficient examination equipment will continue to reduce the role of the ophthalmic practitioner in the data-gathering process and thereby allow more time for diagnostic and treatment activities."(122) Following his evaluation of the Dioptron, Leigh concluded that the Dioptron was very accurate but did not replace the skill and judgement of the doctor in making the final diagnosis or writing the spectacle prescription.(88)

The major disadvantage of the Dioptron was its slow recording time of about 20 seconds per eye which made it difficult to use on the very young and the inattentive. There is also some evidence that the method used to control accommodation was ineffective. The Dioptron was discontinued in 1977 in favor of an improved model, the Dioptron II Ultima.

Although the Ophthalmetron, 6600 Autorefractor and Dioptron have all been discontinued or replaced by more modern instruments, they were important advances in the development of automated objective refractors. Many of the principles and features used in these instruments are incorporated into the objective refractors available today.

Described next are three other automated refractors which are no longer being manufactured. They were introduced after the Ophthalmetron, 6600 Autorefractor and Dioptron and represent an intermediate stage in the development of the modern automated refractor.

I. DIOPTRON II ULTIMA - In 1977 the Dioptron was replaced by the Dioptron II Ultima. The most notable improvement was the three indices of accuracy used to compute the confidence factor. French and Wood reported that this improved confidence factor was now "an important correlate of subjective validity." (49) The results of several studies attested to the Ultima's high correlation with retinoscopy and to its improved correlation with the subjective refractive status.(48, 93, 107, 153, 167). The Dioptron II Ultima was also more compact and had a more rapid recording time of 10 seconds per eye. Its 1983 list price was $18,500. Manufacture of this instrument was discontinued in 1983.(35, 108, 166)

II. DIOPTRON NOVA - The Nova was introduced in 1981 as a less expensive, portable (57 lbs.) alternative to the Ultima.(14, 36) It had fewer operating controls and was monocular.(59) The Nova had a "Path Alert" indicator that was based only on the level of light reflected from the eye.(165) There are no clinical studies available. Its 1983 list price was $12,800.

III. CAVITRON SUBJECTIVE AUTOREFRACTOR-7 - This subjective automated refractor monocularly "estimated" the distance refractive status using spherical lenses only.(60) It did not have any spherical or cylindrical refinement capability but did have some ability to measure the convergence and accommodation systems at far and near. It cost about $9,000.(14, 71, 82)

CURRENT OBJECTIVE REFRACTORS

I. RX6600 AUTOREFRACTOR - Introduced in 1983 by Trilogic Corp., the Rx6600 Autorefractor, like its predecessor the 6600 Autorefractor, provides rapid measurement and automatic tracking and alignment. Improvements are limited to changed location of operator controls and use of a better printer. The printout includes a confidence grade and the interpupillary distance. The test (vertex) distance is adjustable for measuring the refractive status for spectacles or contact lenses. The range of spherical lenses is -8.25 to +15.75 with up to 6.00 diopters of cylinder. The 1983 list price was $18,800.(61)

II. NIKON NR2000 - The Nikon NR2000 operates on the same principle as the retinoscope. This monocular instrument incorporates an interesting automatic fogging system for accommodation control. The target, a black star on a yellow background, appears blurred to the subject during alignment. When the testing begins the target clears momentarily then slowly fogs; at the point of maximum fogging the reading is made. The fogging process takes 0.5 to 1 second and the actual measurement takes 0.3 seconds. The NR2000 is programmed to ignore blinks and to alert the operator whenever a poor quality signal is obtained. The primary limitation of the Nikon NR2000 is its patient alignment system which is manual and critical. The range of spherical lenses is -15.00 to +15.00 with up to 6.00 diopters of cylinder. Evaluations of the effectiveness of this system have not been published. Its 1983 list price was $11,900.(14, 61, 113)

III. NIDEK AR3000 - Sold and serviced by Marco Equipment, the Nidek AR3000 features automatic fogging, rapid measurement (0.5 seconds) and a wide range of lenses. A video display makes alignment rapid and simple. Computer interface capability is included. The AR3000 is smaller and more compact than preceding models from this company. A planned future model, the

AR3300, will also have visual acuity measurement capability. The range of spherical lenses is -15.00 to +20.00 with up to 7.00 diopters of cylinder. The 1983 list price of the AR3000 was $13,995.(14, 61, 112, 150)

IV. HUMPHREY AUTOMATIC REFRACTOR - The Humphrey Automatic Refractor is an objective automated refractor with visual acuity and sphere refinement capability. It has automatic fine alignment and eye tracking. Fixation is binocular but it measures one eye at a time. It is programmed to ignore blinks and to print out a reflex number to indicate the reliability/validity of the recording. Accommodation is relaxed by a blurred colored light target followed by a fogged visual acuity test chart. Its unique features are (1) the objective finding can be verified subjectively through an internal visual acuity chart and (2) the objective sphere finding can be manually adjusted by the operator. No clinical studies have been published. The range of spherical lenses is -12.00 to +20.00 with up to 6.00 diopters of cylinder. The 1983 list price was $15,950.(14, 61, 149)

V. CANON AUTOREF R-1 - The unique feature of this instrument is the use of a non-simulated test distance in an open view system. It uses an external target which may be placed at any distance. This innovation reduces or eliminates instrument myopia, allows binocular fixation and permits limited testing of near vision.(14) It has the fastest measuring time (0.2

seconds) and a video display for easy alignment. Because it uses an external target, it needs more room and reduced room illumination. No clinical studies have been published. The range of spherical lenses is -15.00 to +15.00 with up to 7.00 diopters of cylinder. The 1983 list price was $11,800.(5, 59)

VI. DICON AR5000 - The Dicon AR5000 also uses an open view approach but without an external target. Rather, the binocular target, a fixation light, is imaged onto a glass plate in front of the subject's eyes. The AR5000 has a variable vertex distance and an error signal. It also has a standard computer interface and automatic fogging and eye tracking, plus visual acuity measurement capability based on a contrast sensitivity method. No clinical studies have been published. The range of spherical lenses is -15.00 to +20.00 with up to 6.00 diopters of cylinder. It lists at $7,995.(14, 30, 61)

Campbell, a scientist at Humphrey Instruments, claims that the Canon Autoref R-1 and the Dicon AR5000 will have difficulty determining the correct refractive error in hyperopes as a hyperopic subject tends to accommodate while looking at an object in open space.(22) However, Canon's specially designed target and Dicon's automatic fogging system are designed to overcome this problem. Another solution is to measure the refractive status while the patient wears temporary plus lens spectacles. A clinical evaluation of Campbell's claim needs to be undertaken.

Four manual objective refractors are still available.(14, 60-61) Manual operation means that the operator must focus and align the test images to determine the refractive status; it is not done automatically. Three of the refractors are updated versions of the corresponding 1950's instruments. Two models, the Rodenstock Eye Refractometer PR-50 and the Hartinger Coincidence Refractionometer, are manual and use visible light.(19, 54) The Topcon Eye Refractometer RM-200B now uses infrared light for illumination and a television monitor to simplify patient alignment, but must be operated manually.(152) The fourth, the Hoya MRM, is very similiar to the Topcon.(60) Because none of the four have a system for relaxing accommodation, all are subject to variability due to instrument myopia.(56, 157) But accessories can sometimes be added to encourage accommodative relaxation.(132)

Objective automated refractors are changing very rapidly. Most of the models currently available were introduced or improved within the past two years; therefore, very little clinical data is available. Indications are, however, that they are becoming increasingly accurate, reliable and successful in controlling accommodation.(165)

CURRENT SUBJECTIVE REFRACTORS

To subjectively measure the refractive status using a refractor the patient is asked to respond to changes in lens power until maximum visual acuity with the most plus (least minus) power is achieved. Subjective automated refractors require patient response in the same way. The goal in both cases is a final, wearable prescription. Three instruments are included in this category: the American Optical SR-IV, the Bausch and Lomb IVEX and the Humphrey Vision Analyzer.

I. AMERICAN OPTICAL SR-IV - A brochure published by the manufacturer calls this instrument a Programmed Subjective Refractor.(3) The SR-IV is based on Guyton's Astigmatic Optometer (1972) and is a refinement of the SR-III introduced in 1977.(59) Beginning with any preliminary finding, such as retinoscopy, the AO SR-IV can be used by a trained assistant to determine the distance refractive status under monocular viewing conditions. The normal procedure is to have the patient refine the sphere by turning a control knob until the point of best acuity is reached. he astigmatic correction is then measured using a special target, and finally the sphere is refined using a bichrome (red/green) target. The evaluation procedure usually takes 2-4 minutes per eye. The results of the initial evaluation can be verified or modified while the patient views an internal visual acuity chart. The visual acuity chart can also be blurred as necessary to control accommodation. The range of spherical lenses is -20.00 to +20.00 with up to 8.00 diopters of cylinder.

The instrument has several advantages. First, its small size allows it to be used in a room as small as 5'X5'. It has single button automatic sequencing of the tests for very rapid examination of the routine patient. The Simulcross target, a specially designed Maltese Cross, used for measuring the cylinder power and axis, is a definite advantage. Patients are sensitive to small differences with this target. The two choices are presented simultaneously allowing the patient to make a direct comparison, as opposed to the sequential presentation technique used with the standard phoropter.(59)

The SR-IV has several limitations. It measures the refractive status under monocular viewing conditions and only measures it at distance. There is no way to balance the accommodative stimulus between the two eyes. An imbalance can affect visual efficiency, comfort and acuity. There are no tests of accommodation and convergence; these must be done separately using a refractor or other instrument. The largest letter on the acuity chart is 20/200 (87 mm. overall height) which is not large enough for patients with high refractive errors and/or low vision patients.

Several studies have examined the reliability and validity of the SR-IV and its predecessor, the SR-III.(7-8, 46, 120, 164)

Bannon and Waltuck compared the refractive error as measured with the SR-IV to that measured with the standard refractor on 682 patients.(9) The refractive error findings with the SR-IV were within:

Sphere:	+/-0.25 - 71%	Cylinder:	+/-0.25 - 80%
	+/-0.50 - 92%		+/-0.50 - 95%

of the standard refractor results.

Grosvenor et al. studied 131 myopes (ages 6-15) and found that the SR-IV tended to overestimate the myopia slightly (median: -0.75 diopters for the sphere) compared to a conventional refraction.(53) They attributed the difference to the lack of binocularity with the SR-IV; instrument myopia might also be a contributing factor. They found the repeatability of the SR-IV to be as good as that with the standard refractor. Its 1983 purchase price was $22,000 including a one year parts and labor warranty.

II. BAUSCH AND LOMB IVEX - IVEX is an acronym for Integrated Vision Examination System. Like the SR-IV, the IVEX has a compact optical system. However, unlike the SR-IV, the IVEX is designed to be operated by the professional and to replace the standard refractor, chair, stand and projector. It can be used for a complete visual analysis including retinoscopy, measurement of the subjective refractive status and measurement of convergence and accommodation at a far and a near test distance. The printout includes the retinoscopy and subjective findings plus the reading prescription.(60, 72)

The IVEX has two basic parts: the main instrument and the keyboard/display module. The keyboard has touch controls for the slides, lenses and prisms used in the instrument. Seventeen slides are available. The range of lenses is +19.75 to -28.00 sphere, up to 7.75 cylinder and 15.00 diopters of prism for each eye. Patient alignment is readily accomplished using electrically operated controls.(14)

The IVEX has several important features.

(1) It can be used to conduct a comprehensive examination including retinoscopy. The IVEX has a moveable back panel which opens when the retinoscopy function is activated.(130)

(2) The examiner has great flexibility in conducting the examination. Test sequence and conditions can easily be altered by the examiner.

(3) The principles of examination are familiar to a professional examiner. The techniques used with the IVEX, such as the Jackson Cross Cylinder and the Risley prisms, are similar to those of a standard refractor.

(4) The IVEX needs only a small space for operation; a room large enough for the examiner, the patient and the instrument itself, which will fit on a 2 ft. by 3 ft. table. This is much less space than the 20 ft. lane needed for the standard refractor.

(5) Binocular refractions are easy to do with the IVEX.

Two clinical studies comparing the IVEX System to the standard refractor have been completed. Roggenkamp et al. found that, "...the IVEX System can be used in place of a refractor for determining the distance refraction. The difference between methods is on the order of 0.25 to 0.37 diopters with the IVEX System yielding results with less plus or more minus sphere power than the conventional refractor."(13) Colson and Shute reached a similiar conclusion but found an adjustment for instrument myopia of -0.172 diopters. They also compared refraction with the IVEX System to a traditional monocular refraction for each of the 21 test procedures that comprise a complete vision analysis. They found small but statistically significant differences on the tests of vergence, amplitude of accommodation and positive relative accommodation.(29)

The IVEX has several drawbacks.

(1) Operation of the instrument is unfamiliar to most military optometrists. Although the principles of examination using the IVEX are similar to that of the standard refractor, the actual operation is not identical. For the typical examiner, touching buttons on a control panel to change lenses and test distances, and not being able to view what the patient views are significant differences.

(2) Some of the test results using the IVEX do not correspond precisely with a traditional refraction. Colson and Shute found statistically significant differences on the tests of

vergence, amplitude of accommodation, and positive relative accommodation. They also found that the standard IVEX targets for phoria testing and binocular refraction produced results which were statistically different from those of a standard refraction.(29)

(3) It is slow. From personal observation, The IVEX makes internal target and lens changes consecutively rather than simultaneously.

(4) Target contrast is very high, so best visual acuity may be overestimated.

(5) Instrument myopia is present and may be a significant factor in some patients. The 1983 price of the IVEX with accessories was $20,800.

III. HUMPHREY VISION ANALYZER - The Vision Analyzer, introduced in 1976, is a subjective binocular refracting instrument. It also is intended to replace the conventional chair, stand, refractor and projecter. The Vision Analyzer has a unique "remote refraction" system in which the lenses, actually located in the instrument console, are projected in front of the subject's eyes by a concave mirror.(14) Thus, there are no lenses in front of the subject's eyes. A dual channel system allows monocular or binocular testing without occlusion. Used by a professional, this instrument is capable of a complete vision examination, although the prism range is limited to 10 prism diopters. Through special clutch mechanisms the subject can adjust the lenses to the proper endpoint.(11, 65, 69)

The variable focus lenses ranging from -20.00 to +20.00 diopters of sphere and up to 8.00 diopters of cylinder represent a significant advance in optics.(2) It has excellent capability for refraction over spectacles or contact lenses.(70) Other features include its acceptance by patients and the special astigmatism testing targets.(21, 42, 66, 117, 168, 169) In addition, the test results are not affected by ambient illumination.(42, 70)

Problems associated with this instrument are the limited prism range and the critical patient alignment required. Other disadvantages are its large size, critical console to mirror distance, and unfamiliar refracting technique. The Vision Analyzer uses different targets for convergence and accommodation testing which yield results that do not correlate precisely with standardized refractor results.(159)

Kratz and Flom's (1977) study involving 21 patients determined that the Humphrey Vision Analyzer was as valid and reliable as a standard refractor in measuring the refractive status.(83) Another study concluded that this instrument can be used to accurately determine near vision prescriptions for presbyopic patients.(151) The 1983 price was $31,750.

FUTURE INSTRUMENTS

Two instruments presently under development give an indication of what will be available in the future.

The first is the Dioptron TRS (Total Refraction System) from Coherent Instruments. The TRS will provide both objective and subjective refractive findings using a monocular simulated distance target. Once the refractive status has been measured objectively, the lenses (sphere, cylinder and axis) can be manually adjusted by the operator. Although it is an improved system, cylinder adjustments must still be made on a trial and error basis rather than systematically as with the standard refractor.(61) The TRS will also have a five inch video display terminal to monitor eye alignment and display operating instructions; it will also have capability for visual acuity determination based on contrast sensitivity.(14)

The second refracting system has been under development by Marg and his co-workers since the early 1970's.(95-98) Their system couples a digital computer to an electrically actuated refractor to determine the refractive status without a clinician, although professional interpretation of the data is still required. The third model has been improved to the point where 95% agreement has been obtained compared to conventional refracting techniques.(99) Accommodation and convergence testing with this instrument is still under development.

Both objective and subjective instruments are becoming more accurate, more reliable, and less expensive. In the future, we are likely to see further development of combination instruments providing full subjective refinement of the objective results.(61) There will also be improved methods for controlling instrument accommodation and for evaluating accommodation and convergence. We may also see major changes in practice style as automated refracting instruments are incorporated into vision care clinics.(57)

ANALYSIS

A meaningful conclusion can be made about the value of a specific automated refractor only if a clear distinction is made between objective and subjective types. The two kinds are different in purpose so that direct comparison of both types is illogical. Comparison of individual models will be limited to a specific type, objective refractors and subjective refractors.

A complete vision examination (vision analysis) includes an evaluation of the health of the eye, an objective measurement of the refractive status, a subjective measurement of the refractive status, and measurements of accommodation and convergence. From this data, plus the case history, the examiner uses established guidelines and professional judgement to prescribe a course of treatment, e.g. a spectacle prescription. A satisfactory spectacle prescription can not consistently be determined from a single measurement. All of the data must be considered to formulate a correct spectacle prescription. The subjective refractive status measurement is the basis for the final lens prescription, but it is often modified depending upon the results of the other procedures.

OBJECTIVE REFRACTORS

The objective refractive status, whether measured with a retinoscope or an automated objective refractor, is not identical to the subjective refractive status. The objective status is measured over a larger and possibly different area of the retina and excludes psychological interpretation of detail.(14, 50) The objective measurement, while very useful, can only be considered preliminary information. The result of objective testing is not a spectacle prescription; it is always an approximation of the final prescription, and in many cases, it is the same. In special cases, e.g. a patient unable to communicate with the examiner, the spectacle prescription may have to be determined solely from the objective measurement.

As a measure of the objective refractive status, retinoscopy has two advantages: the instrumentation is inexpensive and the examiner gets an indication of the clarity of the media of the eye as when a cataract is present. The disadvantages of retinoscopy are: (1) it is examiner-subjective and thus variable depending upon his or her skill and (2) it consumes professional time because of the level of skill required. This is an important factor only if time is limited and could be spent on other procedures.(50)

The two advantages of an objective automated refractor are: (1) it can be operated by a technician, saving time for the eye care professional and (2) it is examiner-objective, the results are independent of operator skill or bias. Objective automated refractors do not work well on patients with pupils smaller than 3 mm., on some patients examined while wearing spectacle lenses, and on patients with media opacities such as cataracts.(14, 56)

There are currently six models available. In choosing among them several factors must be considered.

(1) Validity - This term poses the question, "Does this automated refractor truly measure refractive status?" Several factors affect the answer.(60, 139) Firstly, comparisons are very difficult as there are three independent components of the refractive status: the sphere, the cylinder and the axis. A particular model might measure one component more accurately than another or might determine a value for a component (eg. the axis) when no astigmatism exists. Secondly, these instruments are so new that little evaluative data is available. There are many clinical studies of the Ophthalmetron, 6600 Autorefractor and Dioptron which give an indication of the validity of objective automated refractors as a class, but there are very few studies of the current models. There are especially few studies comparing one model to another. Thirdly, there is no single standard of comparison. Both the subjective status measured with a refractor and the objective status measured with a retinoscope have been used as the basis for comparison. Fourthly, the standard of comparison

may vary upon repeated measurement or when measured by different examiners.(7)

To produce valid measurements, the objective refractor must have an effective system to control accommodation. All of the objective automated refractors have some method, but the open view design of the Dicon AR5000 and the Canon Autoref R-1, and the binocular fogging system of the Humphrey Autorefractor seem to be superior to the others.

In 1982, Wood compared the Humphrey Autorefractor, the Canon Autoref R-1, the Dioptron II, the Nidek AR2000, the Nikon NR1000, the Ophthalmetron and the Topcon RM-200 for validity and reliability by analyzing the results of studies involving these instruments.(165) He found on average that 50% of the spherical components and 75% of the cylinder power results of the infrared (objective) refractors were within +/-0.25 diopters of the subjective results. He found that the newer instruments were much more accurate than the older models. The correlation was better than that of retinoscopy to the subjective refractive status. It must be pointed out that some of the studies cited had very small samples and/or were conducted by the manufacturers themselves. Also, some models have since been changed.

Wood concluded from his review that "those instruments based on retinoscopy or the Scheiner disc do not appear to perform as well as those instruments based on quality image method of measurement."(165) This conclusion favors the Canon Autoref R-1 and the Humphrey Autorefractor. Kleinstein feels that validity should be the primary factor in choosing one instrument over another.(78) However, Polse and Kerr point out that, if used as a replacement for retinoscopy or as a screening instrument, validity need not be as high.(122)

(2) Reliability - This refers to the repeatability of the finding. The results of several studies indicate very high reliability for virtually all of the current automated objective refractors; higher reliabililty than a human examiner using traditional retinoscopy. Wood's limited comparison indicated highest reliability for the Humphrey Autorefractor and lowest for the Nidek AR2000.(165) The Humphrey Autorefractor and the Nikon NR-2000 have reliability indicators to help identify erroneous results.

(3) Ease of operation - For better patient co-operation speed of measurement is important. The Canon Autoref R-1 has the fastest measurement time of 0.2 seconds, but when patient adjustment time is included, the Humphrey Autorefractor has the shortest estimated total time needed (2-5 minutes). To make operation easier the Humphrey Autorefractor and the Rx6600 Autorefractor have automatic fine alignment and eye tracking systems. The Canon Autoref R-1 and the Nidek AR-3000 have a video display to simplify patient alignment, and the Canon

Autoref R-1 has the fewest operating controls.(60) Concerning ease of operation, Guyton wrote in 1983, "All of the instruments are easy to operate. The Nidek AR-3000 appears to be the easiest to operate."(61)

(4) Durability - Studies of this factor are very limited. Breakdowns of the early instruments were a serious problem, but the latest generation seems to be more durable as there are fewer reports of breakdowns in the literature.(33, 44) The Nikon NR2000 has a two year warranty while the others have a one year warranty; this may be an indicator of durability. Wood points out that reputation for service should be an important consideration when choosing one of these instruments.(165) Because the Rx6600 Autorefractor has been manufactured for a much longer time than the other instruments currently available, it may be more trouble free. Based on physical appearance, the Rx6600 Autorefractor and the Humphrey Autorefractor appear to be the most solidly built. None of the instruments have a specific way for the user to check or adjust calibration.

(5) Cost - The Dicon AR5000 ($8,000) has the lowest and the Rx6600 Autorefractor ($18,800) has the highest initial purchase price of the currently available objective automated refractors. The list price of several models has dropped significantly in the last few years. Because competition is increasing, this trend may continue.

The initial purchase price must be compared to the effective cost to determine the true value of an instrument. There are approximately 250 different military medical facilities where eye care is routinely provided. There are also twelve aircraft carriers and a large number of isolated duty stations with limited eye care. It is possible that 300 different sites could be identified as benefiting from the use of an automated refractor. This does not include the likelihood that large facilities with mobile eye units or separate screening clinics could use more than one instrument. The price range of current objective and subjective automated refractors is from $8,000 to $32,000. Based on 300 sites, the total cost of automated refractors to the military would range from $2.4 to $9.5 million. Using an eight year instrument life span, the annual cost would range from $0.3 to $1.2 million. Subsequent discussion will show that, in military eye clincs using an objective automated refractor, an optometrist with an average patient load will be able to increase his daily volume by 1.5 patients. This is a 10% patient volume increase. To get the same effective increase in patient volume through increased staffing would require adding approximately 47 optometrists (plus appropriate support personnel and facilities). Using $40,000 as an average salary, the cost of the additional staff would be $1.88 million in yearly salaries alone. On this basis, using automated refractors instead of increased staffing to increase patient volume would result in an annual savings of

$0.7 to $1.6 million.

Considering the high initial purchase price and the very high possible total cost, can automated refractors be truly cost-effective? In 1980, Felliti addressed this issue with regard to the use of automated equipment within the Kaiser Permanente HMO.(43) He stated, "Our experience indicates that costly automated equipment turns out to be the least expensive in the long run...In a high volume operation, labor costs predominate over equipment costs." He feels that because they save time and labor, automated instruments are cost-effective. Another study concluded that when manpower resources are limited, it is "economically unfeasible for a health practitioner to perform those routine duties which can easily be performed by someone with much less technical training and knowledge."(62) One way to achieve high quality/low cost care is by allowing each person to function at the highest level of his or her training. An objective automated refractor allows performance of an additional duty by a lesser trained (and, therefore, lesser paid individual). Whether used to increase the number of patients seen or to provide a better quality of care, automated refractors can be cost effective.

(6) Special Features - With the Humphrey Autorefractor the objective finding can be subjectively verified and modified through an internal visual acuity chart. The Canon Autoref R-1 can be used to measure the amplitude of accommodation by

setting the external target at different distances.

Following his study, Wood did not recommend a single, best automated objective refractor.(165) He did suggest that the Humphrey Autorefractor and the Canon Autoref R-1 have outstanding features which make them a likely "best buy." My own analysis confirms this conclusion, but the best instrument for any particular setting must be determined on an individual basis. The Canon Autoref R-1, for example, while an outstanding instrument, works best with a minimum viewing distance of five meters, a requirement that is not always easily met. When the Dioptron TRS is introduced it may prove superior to all of the presently available models. At the present time clinical data is too limited to make a more specific statement.

Recommendations which have been made about the best use of objective automated refractors include the follow-up care of contact lens patients, the refraction of aphakic patients (who have no ability to accommodate and on whom conventional refractions can be difficult), the examination of very young children, and in any high volume practice.(10, 33, 68, 115) One of the most frequently made recommendations is as a screening device.(17, 122, 144) The problem with screening clinics is twofold: (1) getting enough information in a short time to make an appropriate decision and (2) evaluating the ocular health of those patients who do not need furthur referral. An objective automated refractor increases the information available without using professional time. A participating eye care specialist can limit himself/herself to ocular health evaluations, patient interviews, and data analysis. This will lead to more appropriate referrals and a more efficient screening clinic.

There are five settings within the military system where an objective automated refractor can make a significant contribution; the screening clinic, the full-service eye clinic, the recruit processing center, ships, and isolated duty stations. Its value in a screening clinic has been described previously. Many of the patients seen in an optometric clinic do not need a complete vision analysis. Some, for example, only need a form completed (eg. driver's license renewal or school physical) while others want a regular check-up but do not have a specific complaint. Morris estimated that 20-30% of patients visiting military optometric clinics do not need vision care.(15) From ten years experience as a Navy optometrist, I have learned that about 25% of the prospective patients can be handled satisfactorily at the screening clinic level. Explaining the value of screening clinics to the military, Vasa wrote, "....numerous individuals eligible for vision care at military facilities seek this care, (and) request examination even though there are no manifest visual problems or complaints. This emphasizes the need for adequate, careful screening techniques which readily determine those individuals who require vision care. Good screening procedures help the military optometrist use his time more effectively and are essential to the proper operation of any busy clinic".(15) A screening clinic can be an effective means of sorting out those who do not need professional care and in the process improve overall efficiency by 20-30%. An objective automated refractor can help ensure that the appropriate decision is made about the proper care of each patient.

An objective automated refractor may also be useful in the full-service eye clinic. Many Navy optometrists schedule sixteen patients daily or one patient every thirty minutes for a vision analysis. Several studies estimate that retinoscopy takes about three minutes per patient.(62, 135) This times sixteen patients equals 48 minutes saved daily, the equivalent of an additional 1-1/2 patients a day. In one user survey the estimated amount of time saved varied from 2-15 minutes per patient.(33) In the same survey 41% of the responders felt that they could increase the size of their patient load as a result of using an objective automated refractor.

Many authors feel that the best use of an objective automated refractor is not to increase patient volume but to increase the quality of care provided.(10, 47, 50, 84) When an objective refractor is used by a technician in place of retinoscopy, the time usually spent on ophthalmoscopy or visual field screening or patient consultation can be almost doubled according to Haffner's time analysis.(62) In addition, studies have shown that efficiency is much higher in eye clinics using trained ancillary personnel.(125) Many tasks can be delegated without adverse effects on the quality of care. When this is done the specialist can concentrate on those tasks utilizing his skills.(86, 146) Trained technicians are available in virtually all military eye clinics and an objective automated refractor would increase their productivity and contribution to overall clinic effectiveness.

The quality and efficiency of vision care provided at a recruit processing center can also be improved through the use of an objective automated refractor. At recruit processing centers an optometrist may be required to evaluate the visual status of thirty or more individuals in less than three hours. Because of the limited time, a complete vision evaluation is impractical. Spectacle prescriptions must often be based on the retinoscopy (objective) measurement only. An objective automated refractor may be useful in two ways: (1) it provides more accurate screening to determine which patients do not need professional evaluation and (2) it replaces retinoscopy as a measurement of the refractive status. This may reduce the total number of patients needing professional evaluation. In addition, with retinoscopy unnecessary, the optometrist can devote more time to evaluation of ocular health or refractive status. The result would be better care, more accurate prescriptions and possibly faster recruit processing.

Another situation where an objective automated refractor may offer time or manpower savings is on large ships and at isolaed duty stations where professional vision care is not routinely available. Sagan, a Navy-Reserve optometrist, has written about his experience with an objective automated refractor on an aircraft carrier.(140) He feels that while the flight surgeon and aviation medicine technician have some background in eye examination, retinoscopy is often a limiting factor. He feels that for them "the availability of an autorefractor would greatly assist in providing the appropriate spectacle correction." An objective automated refractor could be used by trained personnel to help with refractions by eliminating the need for retinoscopy, or to screen patients so that when professional eye care is available; efficient, appropriate care is given. Because it yields only preliminary information, it must not, however, be used as the sole basis for prescribing lenses.

SUBJECTIVE REFRACTORS

While the objective automated refractors yield preliminary information, as a group the subjective automated refractors are designed to measure the refractive error as interpreted by the patient and produce a result comparable to that measured by conventional means. They are much more complicated to operate than the objective instruments and require a higher level of patient co-operation and participation. The three models currently available are so different that they are best examined individually.

The American Optical SR-IV is different from the other two models in this category in that it is not designed as a replacement for the conventional chair, stand, refractor, and projector (eye lane). It is designed for operation by an advanced technician as a supplement to conventional examination procedures. The result of testing with the SR-IV can only be considered preliminary subjective information, as it is done under monocular viewing conditions and only at a simulated far testing distance. Because there are no provisions for binocular balancing or tests of acccommodation and convergence, the result can not be considered a complete vision evaluation and is not a spectacle prescription. The correlation between the SR-IV and the monocular subjective refractive error measured with a conventional refractor is very high, but the data obtained is similiar in value to that obtained with an objective refractor. It is, however, slower, more complicated to operate, and more expensive than an objective automated refractor.

The Bausch and Lomb IVEX is essentially a refractor in a compact housing, so it can be used for a comprehensive vision examination including retinoscopy. It is intended for operation by an eye care professional and to replace the conventional examination lane. Two studies have shown that the IVEX System is a valid replacement for the conventional refractor in measuring the distance refractive error and in determining an appropriate spectacle prescription. The same studies show that test results may be biased by a small amount of instrument myopia.(29, 130)

Since only a small space is needed for operation, the IVEX may be useful on board ships and in mobile eye units when an eye care professional is available. It may also be a space saving alternative to the conventional examination lane when new clinics are being built. In the military, demand for medical care at any individual base can change rapidly as units are augmented or transferred. An IVEX may be useful in meeting a sudden increase in demand for vision care when extra professional staff is available, but space for expansion is not. A disadvantage of using the IVEX System as a replacement for the conventional refractor is its unfamiliar operation. This is a particularly important factor in the military where members are transferred regularly.

The Humphrey Vision Analyzer can also replace a conventional examination lane and is used for a comprehensive vision examination. Although results of testing accommodation and convergence do not correlate precisely with standardized refractor results, the Humphrey Vision Analyzer's validity and reliability as a measure of the subjective refractive error are well established. Careful alignment of the mirror by an installation specialist and maintenance of an exact 10 ft.

console to mirror distance are critical to successful operation of the Vision Analyzer. This makes it unsuitable for mobile units.

As with the IVEX, no real increase in the number of patients seen per doctor or the quality of care provided is likely to be achieved using the Vision Analyzer. Unlike the IVEX, the Vision Analyzer needs an 8X12 room, so it will not save space, and at $32,000 it is not a less costly alternative to a conventional set up. Its high price, sensitive lens system and unfamiliar refracting technique are other factors limiting its usefulness to the military.

SUMMARY AND CONCLUSION

The challenge for military optometry is to provide high quality vision care to all members including those on ships and at isolated duty stations. The diversity of the eligible population and an unfavorable practitioner/client ratio make this a difficult task. Three steps have been taken to meet this challenge. They are: (1) use of screening clinics, (2) increased patient volume and (3) decreased quality of care. This paper examines the use of automated refractors as a furthur aid in meeting this challenge. Based on a review and analysis of the literature, the following statements about the use of automated refractors in the military may be made.

I. No automated refractor can consistently produce a satisfactory spectacle prescription independent of professional judgement.

II. The substantial differences between objective and subjective refractors must be clearly understood in any discussion of the value of these instruments.

III. Objective automated refractors rapidly provide preliminary refractive data. Because of their ability to save professional time, objective automated refractors can be valuable to military eye care practitioners. Their widespread use in both vision screening clinics and full-service eye clinics will lead to increased efficiency, and from that increased patient volume and/or increased quality of care. The greater the demand for vision care, the greater will be the contribution of an automated objective refractor. Their simple operation also makes them a practical means of improving the quality of vision care on ships and at isolated duty stations.

Limited clinical data makes it impossible to identify a single, best model. Of the six objective automated refractors currently available, the Canon Autoref R-1 and Humphrey Autorefractor seem to be superior. The best instrument for a particular setting must, however, be determined on an individual basis. Local factors such as budget, ancillary personnel, and available space must be considered.

IV. Subjective Automated Refractors - Some of the subjective automated refractors are capable of a complete vision examination when used by an eye care professional. Two of them can replace the conventional examination lane. However, their operation is unfamiliar to the majority of military optomtrists who were trained on conventional refractors. There are three subjective automated refractors currently available.

(1) American Optical SR-IV: The result of using the SR-IV is similiar in value to that of an objective automated refractor, but the SR-IV's higher cost and more complicated operation make it a poor alternative.

(2) Bausch and Lomb IVEX: The IVEX can be used by a

professional for a complete eye examination. Its small size and moderate price make it practical for use where space is limited and an eye care professional is available. This may save expensive floor space in new clinics and in remodeling expansions as well as mobile and/or field units.

(3) Humphrey Vision Analyzer: This instrument can also be used by a professional for a complete subjective eye examination. Because of its large size, sensitive mirror system, unfamiliar refracting technique, and high cost, it is not a suitable replacement for the conventional examination lane and does not otherwise offer any significant advantages.

Some models of both objective and subjective automated refractors are compatible with automated data processing systems. This makes them well suited for use in facilities with computerized health records.

Except for the IVEX, subjective automated refractors do not at this time appear to be a practical alternative to the conventional eye lane or for general use within the military medical system. However, although objective automated refractors only provide preliminary information, they can be used to significantly increase efficiency in a vision care clinic. This in turn can be reflected in higher quality vision care and a broader range of services provided to patients. Analysis of the literature confirms the value of objective automated refractors as a cost-effective way to improve the overall quality of vision care available within the military medical system and of extending care into areas inadequately served at present.

This paper describes a need to provide better vision care to military health care clients, and shows that some types of automated refractors are an effective and cost saving alternative to increased staffing in meeting this need. It describes the currently available models and provides guidelines for determining the best automated refractor for any particular setting. The eight factors which must be considered when choosing an automated refractor are explained. They are (1) need, (2) type, (3) validity, (4) reliability, (5) ease of operation, (6) durability, (7) cost, and (8) special features. These are universal factors which may be used to evaluate the potential of an automated refractor to any organization.

In conclusion, both subjective and objective automated refractors can be very useful to the military. One subjective automated refractor, the IVEX, may be a space saving replacement for the conventional eye lane. Objective automated refractors can be used to improve screening clinics and increase patient volume in full service eye clinics. Both types can be used to improve the quality of vision care provided. A policy supporting the use of automated refractors in the military should be adopted.

DEFINITION OF TERMS

ACCOMMODATION - the ability to adjust the focus of the eye to objects at various distances by changing the shape of the crystalline lens

AMBLYOPIA - reduced visual acuity not correctable by refractive means and not due to any observable pathology

AMETROPIA - the refractive condition in which, with accommodation relaxed, the image of a distant object is not in focus on the retina - any deviation from emmetropia

APHAKIA - absence of the crystalline lens of the eye, due usually to surgical removal

ASTIGMATISM - the refractive condition of the eye in which light emanating from a single source comes to a focus in two different axial locations

AXIS - the meridian of least refractive power or of longest radius of curvature on the toric surface of an astigmatic lens

CONTRAST SENSITIVITY - ability of a subject to distinguish the light bars from the dark bars of a grating

CONVERGENCE - the ability to turn the eyes so that both point at the same object

CYCLOPLEGIA - paralysis of the eye muscles controlling accommodation, usually drug induced

DEVELOPMENTAL VISION - that aspect of vision training dealing with the natural growth processes of the visual-motor system

EMMETROPIA - the refractive condition in which, with accommodation relaxed, the image of a distant object is in focus on the retina

FUNDUS - the posterior, internal portion of the eye - the base of an organ

HYPEROPIA (farsightedness) - the refractive condition in which, with accommodation relaxed, light from a distant object comes to a focus behind the retina

LOW VISION THERAPY - treatment of patients with subnormal vision (e.g. reduced visual acuity or restricted visual fields) uncorrectable with conventional lenses

MYOPIA (nearsightededness) - the refractive condition in which, with accommodation relaxed, light from a distant object comes to a focus in front of the retina

OPHTHALMOSCOPY - examination of the ocular fundus with special instruments designed for that purpose (ophthalmoscopes)
Direct: ophthalmoscopic observation, at close range, of the virtual, upright, image of the fundus
Indirect: ophthalmoscopic observation, usually at approximately arm's length, of the real, inverted, anteriorly located aerial image of the fundus

PRESBYOPIA - blurring of near vision incident to advancing age, due to hardening of the crystalline lens and the resulting loss of accommodative ability

REFRACTIVE ERROR - the degree of variation of the eye from emmetropia

REFRACTOR - an instrument used to measure the refractive and muscular condition of the eyes; it consists of rotating lenses, filters, prisms and other accessories

RETINOSCOPY - objective measurement of the refractive error by directing light from a retinoscope into the eye and noting the movement of the light reflex in the subject's pupil in relation to that of the retinoscope

TONOMETRY - a clinical test to determine the fluid pressure within the eye

TORIC - pertaining to a lens which has one surface with meridians of least and greatest curvature located at right angles to each other

VISION TRAINING - the teaching and training process for the improvement of visual perception and/or co-ordination of the two eyes for efficient and comfortable binocular vision

VISUAL FIELDS - measuring the area or extent of physical space visible to an eye in a fixed position

BIBLIOGRAPHY

1. Alexander, A., Eklund, P., Gmelin, R., Herrera, M., Leddy, J., Poquis, R., Strickland, J., Walker, R. and Van Zetta, W., "Symposium: Is America Keeping its Promise to the Military OD?" Rev Optom pp. 40-47, May 1977.

2. Alvarez, L., "Development of Variable-Focus Lenses and a New Refractor," JAOA 49:24-29, 1978.

3. "AO SRIV," Monograph #4-0-0058 by American Optical, NY, 1983.

4. "AOA Guidelines on Vision Screening," JAOA 43(8):884-890, 1972.

5. "Autoref R-1" Monograph #B-CE-5007 by Canon Inc., Tokyo, 03/81.

6. Averill, R.W., "Military Optometry," JAOA 45:374-376, 1974.

7. Bannon, R.E., "A New Automated Subjective Optometer," Am J Optom 54(7):433-438, July 1977.

8. Bannon, R.E. and MacLeod, D., "A New Subjective Refractor," Rev Optom 116(8):63-66, 1979.

9. Bannon, R.E. and Waltuck, M., "Clinical Aspects of the SRIV," Am J Optom 59:815-820, 1982.

10. Barker, A., "Everything You Always Wanted to Know about Automatic Refractors," Optom Mgmt 17:37-45, 1981.

11. Bennett, A., "Some Novel Optical Features of the Humphrey Vision Analyzer," Optician 173:7-16, April 22, 1977.

12. Bennett, A., "Methods of Automated Objective Refraction," Ophthal Optic pp. 8-19, Jan. 7, 1978.

13. Bennett, I., "Automation: On the Way for Optometry?" Optom Mgmt 10:25-27, Jan. 1974.

14. Berman, M., "Recent Advances in Subjective and Objective Autorefractors," Optom Mthly pp. 309-322, June 1983.

15. Birchard, C.H. and Elliott, T.F., "Part II: A Re-evaluation of the Ratio of Optometrists to Population in the United States in the Light of Socio-Economic Trends in Health Care," Am J Optom 44:91-104, 1967.

16. Birchard, C.H. and Elliott, T.F., "Part III: A Re-evaluation of the Ratio of Optometrists to Population in the United States in the Light of Socio-Economic Trends in Health Care," Am J Optom 44:168, 1967.

17. Bizzell, J.W., Hendricks, J.C., Goldberg, M.F., Patel, M.K. and Robbins, G.F., "Clinical Evaluation of an Infrared Refracting Instrument," Arch Ophthal 92: 103-108, 1974.

18. Borish, I., Clinical Refraction 3rd Edition, Chicago, Professional Press Inc., 1970, pp. 692-694.

19. Bradford, R.T. and Lawson Jr., L.J., "Clinical Evaluation of the Rodenstock Refractometer," Arch Ophthal 51: 695-700, 1954.

20. Brubaker, R.F., Reinecke, R.D. and Copeland, J.C., "Meridional Refractometry: I. Derivation of Equations," Arch Ophthal 83:570-573, 1970.

21. Campbell, C.E., "A New Subjective Test for Astigmatic Error," Optom Mthly 69(9):153-158, 1978.

22. Campbell, C.E., "Hyperopia, Accommodation and Automatic Refractors," Ophthal Times, Nov. 15, 1982.

23. Carter, J.H., "Predictable Visual Responses to Increasing Age," JAOA 53:31-36, 1982.

24. Catania, L.J. and Roberts, J.S., "Eye Care Delivery in Prepaid Group Practice," JAOA 49:1383-1387, 1978.

25. Charman, W.N., "A Pioneering Instrument: The Collins Electronic Refractionometer," Ophthal Optic 16: 345-348, 1976.

26. Christensen, B., "Termination of the Health Professions Scholarship Program for Optometry in the Military: Alternate Sources for Future Manpower," Senior Thesis, Pacific University, Forest Grove, Or., Feb. 1981.

27. Clausen, L., Caplan, L., Johnson, D., Keller, J. and Myers, K., "The Federal Role," in R. Newcomb and J.L. Jolley (eds.). Public Health and Community Optometry, Springfield, Ill., Chas C. Thomas, 1980, pp. 281-314.

28. Collins, G., "The Electronic Refractionometer," Brit J Physio Opt 1:30-42, 1937.

29. Colson, D.L. and Shute, D.T., "Comparative Analysis of Bausch and Lomb's IVEX Refraction System and a Traditional Refraction, Senior Thesis, Pacific University, Forest Grove, Or., Feb. 1984.

30. "Considering an Auto Refractor or an Auto Perimeter?" Monograph by Dicon Equip., San Diego, Ca., 1982.

31. Cornsweet, T.N., "Computer-assisted Automated Refractions," Rev Optom 110(12):31-36, 1973.

32. Cornsweet, T.N. and Crane, H.D., "Servo-controlled Infrared Optometer," J Opt Soc Am 60(1):548-554, 1970.

33. Decker, T., "Commercially Available Automated Refractors and Their Use," Tr Am Acad Ophth & Otol 79:493-500, 1975.

34. "Dioptron Automated Objective Refractor," Monograph #1200B by Coherent Insts., Palo Alto, Ca., 9/77.

35. "Dioptron II Autorefractor - Description and Clinical Evaluation," Monograph #1230 by Coherent Insts., Palo Alto, Ca., 9/77.

36. "Dioptron Nova and Dioptron Ultima," Monograph #3002 by Coherent Insts., Palo Alto, Ca., 1981.

37. Dorland's Illustrated Medical Dictionary 26th Edition, Phila., W.B. Saunders Co., 1981, pp. 1138.

38. Dowd, M., "Answering Uncle Sam's Call," Time 121:18, May 23, 1983.

39. Drance, S.M., Mitchell, D.W. and Schulzer, M., "Studies of an Automatic Refraction Machine," Can J Ophthal 10:462-468, 1975.

40. Dyson, C., "A Clinical Study of the Autorefractor, An Automatic Refracting Device," Can J Ophthal 12:29-33, 1977.

41. Eger, M.J., "Why Would Anyone Want to be an Optometrist in the Army," JAOA 45(7):800-803, 1974.

42. Elmstrom, G., "Management Considerations of the Humphrey Vision Analyzer," JAOA 48:1293-1299, 1977.

43. Felliti, V.J., "High Volume Diagnosis," Group Practice J pp.5-7, May 1980.

44. Floyd, R.P. and Garcia, G., "The Ophthalmetron: A Clinical Trial of Accuracy," Arch Ophthal 92:10-14, 1974.

45. Freeman, H. and Hodd, F.A.B., "Comparative Analysis of Retinoscopic and Subjective Refraction," Br J Physio Optics 12:8-36, 1955.

46. Freeman, M.I., "Prescriptibility of the AO SR-IV Programmed Subjective Refractor," American Optical Corp., NY, Aug. 1980.

47. Freeman, M.I., "Automated Refraction," Contact Intraocul Lens Med J 7(3):252-257, 1981.

48. French, C.N., Nixon, J.A. and Wood, I.G.J., "Dioptron - and Retinoscopy - Subjective Discrepancies: Effect of Age," Ophth & Physio Optics 2(3):227-230, 1982.

49. French, C.N. and Wood, I., "The Dioptron II's Validity and Reliability as a Function of Its Three Accuracy Indices," Ophthal & Physio Opt 2(1):57-74, 1982.

50. Fuller, B., "Objective and Subjective Optometers - Their Operation and Likely Impact on Optometry," Aust J Optom 63:110-118, 1980.

51. Gensler, P., "An Impending Crisis - Optometric Participation in HMO's," JAOA 45:162-167, 1974.

52. Greene, B.C. and Fox, D.H., "Military HMO's," JAOA 45(7):806-808, 1974.

53. Grosvenor, T., Perrigin, D. and Perrigin, J., "Comparison of American Optical SR-IV Refractive Data on a Group of Myopic Children," Am J Optom 60(3):224-235, 1983.

54. Guillon, M., "Automatic Electronic Optometers," Optician pp. 12-16, May 12, 1978.

55. Guillon, M., "Automated Refraction in Aphakia: I. Its Accuracy and Repeatability Compared to a Single-Practitioner Conventional Technique," Ophthal Physio Opt 1(3):187-191, 1981.

56. Guyton, D.L., "Automated Refraction," Invest Ophthal 13:814-818, 1974.

57. Guyton, D.L., "Other Approaches to Automated Refraction," Tr Am Acad Ophth & Otol 79:501-507, 1975.

58. Guyton, D.L., "A Guide to Automated Refractors," Optician 173(4489):7,9,11, June 17, 1977.

59. Guyton, D.L., "The American Optical SR-IV Programmed Subjective Refractor: Principles of Design and Operation," Am J Optom 59:800-814, 1982.

60. Guyton, D.L., "Comparative Material on Automated Refractors-1982," Ophthal 89(8S):16-30, 1982.

61. Guyton, D.L., "Automated Refractors-1983," Ophthal 90(9S):36-44, 1983.

62. Haffner, A., Sherman, J., Herberger, M., Weber, R., Johnston, E., Philips, L. and Serfoss, R., "A National Study of Assisting Manpower in Optometry," Optometric Center of NY, NY, 1971, pp. 1,15,17.

63. Hardy, W.E., "Five New 'Automatic Refractors' under Test," Ophthal Optic 19(3):490, 1979.

64. Harris, G. "Capt. Harris Responds to Navy Times," US Navy Med 73(12):16-17, 1982.

65. Harwood, L., "The New Subjective Vision Examination System," Optom Wkly 67(2):800-802, July 15, 1976.

66. Harwood, L., "Patient Acceptance of the Humphrey Vision Analyzer," Rev Optom 114(8):49-50, 1977.

67. Hayes, G.S. and Randall II, H.G., "Geographical Distribution of the Ophthalmologists and Optometrists," Arch Ophthal 92:363-365, 1974.

68. Hill, F., "Comparison of Computerized Refraction with Standard Refractive Technique," Optom Wkly 64(52):1279-1282, 1973.

69. Humphrey, W., "A Remote Subjective Refractor Employing Continuously Variable Sphere-Cylinder Corrections," Optical Engring 15(4):286-291, 1976.

70. Humphrey, W., "Overrefraction and the Vision Analyzer," Optom Mthly 71(9):563-573, 1980.

71. "Introducing the Cavitron Subjective Autorefractor-7," Monograph #960-6565-001 by Biotronics, Irvine, Ca., April 1981.

72. "IVEX," Monograph #H-7102 by Bausch and Lomb, Rochester, NY, 2/82.

73. Johnson, A., "A Study of Optometric Practice in the U.S. Army: An Attempt to Identify the Barriers that Preclude Full Scope Optometric Services," Senior Thesis, Pacific University, Forest Grove, Or., 1981.

74. Johnson, D.E., "Optometric Triage in Military Screening," Optom Wkly pp. 32-35, Sept. 9, 1971.

75. Kaminski, A. and Pennington, J., "A Vision Care Module within a Prototype HMO," JAOA 46(9):875-880, 1975.

76. Keech, P.M., "The Effects of Cycloplegia on the Determination of Refractive Error by the Ophthalmetron," Am J Optom 56(4):228-230, 1979.

77. Kempster, J., "An Evaluation of the Dioptron in Hospital Practice," Optician pp.17-18, Aug. 29, 1975.

78. Kleinstein, R., "Epidemiology of Eye and Vision Disorders," in R. Newcomb and J.L. Jolley (eds.). Public Health and Community Optometry, Springfield, Ill., Chas. C. Thomas, 1980, pp. 65-84.

79. Knoll, H.A., "The Ophthalmetron," JAOA 43:73-77, 1972.

80. Knoll, H.A. and Mohrman, R., "The Ophthalmetron: Principles and Operation," Am J Optom 49:122-128, 1972.

81. Knoll, H.A., Mohrman, R. and Maier, W.L., "Automatic Objective Refraction in an Office Practice," Am J Optom 47:644-649, 1970.

82. Koetting, R.A., Akerman, D.H. and Koetting, R.R., "An Evaluation of the Cavitron Autorefractor-7 with Contact Lenses and Non-Contact Lens Wearing Patients," JAOA 54:115-118, 1983.

83. Kratz, L. and Flom, M., "The Humphrey Vision Analyzer: Reliability and Validity of Refractive-Error Measures," Am J Optom 54:653-659, 1977.

84. Krepick, W.A., "Clinical Comparisons of the Humphre Vision Analyzer and Dioptron Autorefractor," Coherent Inc., Palo Alto, Ca., June 1976.

85. Krepick, W.A., "A Second Generation Automatic Objective Refractor," Contacto 20(4):27-32, July 1976.

86. Krepick, W.A., "Automatic Retinoscopy: The Dioptron Today," Optician 1738(4477):8-9, 37, 1977.

87. Kroll, J.R., "Preliminary Report on Refractive Changes in Orthokeratology Patients Using Automated Refractors," Contacto 21:38-39, Sept 1977.

88. Lang, M.M., "Automated Instrumentation for the Examination of the Eye," Austr J Optom 57:335-345, 1974.

89. Legler, T.R., "Why the Career OD in the Army is Biting the Bullet Today," JAOA 47(8):1082-1084, 1976.

90. Leigh, R.E., "One Thousand Consecutive Cases Utilizing an Automatic Refractor," Presented March 1975 at Texas Medical Assn. annual meeting.

91. "Life on the 'Front Line' - Months of Tension at Sea," US News & World Report 92:32, Feb. 22, 1982.

92. Mahlman, H.E., Handbook of Federal Vision Requirements and Information, Chicago, Professional Press Inc., 1971.

93. Mailer, C.M., "Automatic Refraction and the Private Ophthalmologist: Dioptron II Compared with Subjective Refraction," Can J Ophthal 13:252-257, 1978.

94. Mangelsdorff, A.D., Hubbart, J.A. and Armstrong, T.S., "Prediction of Staffing in Selected Army Medical Treatment Facilities," Military Medicine 145(3):204-205, 1980.

95. Marg, E., "Computer-Assisted Eye Examinations. I. Computer-Actuated Eye Refractors," Am J Optom 50:601-615, 1973.

96. Marg, E., Computer-Assisted Eye Examinations, San Francisco Press Inc., San Francisco, Ca., 1980.

97. Marg, E., Johnson, D.E., Anderson, K.W., Baker, R.L. and Neroth, C.C., "Computer-Assisted Eye Examinations. V. Preliminary Evaluation of the Refractor III System for Subjective Examination," Am J Optom 54:2-8, 1977.

98. Marg, E., Anderson, K.W., Chung, K.O. and Neroth, C.C., "Computer-Assisted Eye Examinations. VI. Identification and Correction of Errors in the Refractor III System for Subjective Examination," Am J Optom 55:249-256, 1978.

99. Marg, E., Anderson, K.W., Chung, K.O. and Neroth, C.C., "Computer-Assisted Eye Examinations. VII. Final Evaluation of the Refractor III System for Subjective Examination after Reducing Software and Hardware Errors," Am J Optom 55:317-330, 1978.

100. Marshall, E.C., "Health Manpower," in R. Newcomb and J.L. Jolley (eds.). Public Health and Community Optometry, Springfield, Ill., Chas. C. Thomas, 1980, pp. 172-192.

101. Marshall, E.C., "The Optometrist's Role in Public Health," JAOA 53:371-378, 1982.

102. McDevitt, H.I., "Automatic Retinoscopy: The 6600 Autorefractor," Optician 173(4485):33, 37, 40, 42, 1977.

103. McTigue, J.W., "Automatic Refraction in Aphakia," Acuity Systems Inc., McLean, Va., 1973.

104. McTigue, J.W. and Cornsweet, T.N., "Clinical Test of the Acuity Systems Model 6600 Autorefractor," Acuity Systems Inc., McLean, Va., 1973.

105. Michaels, D.D., "Automated Refraction," West J Medic 130:545-546, 1979.

106. Michaels, D.D., Visual Optics and Refraction 2nd Edition. St. Louis, C.V. Mosby, 1980, pp. 347-356.

107. Michelis, M.K., "The Dioptron II Autorefractor in Clinical Ophthalmology: A Study of 27 Implant Pseudophakic and Aphakic Eyes," undated reprint from Coherent Insts., Palo Alto, Ca.

108. Milia, D., Educational Services Co-ordinater for Coherent Insts., Personal Correspondence, Oct. 1983.

109. Mohrman, R.C. and Hogan, J.G., "The Ophthalmetron," Optician 173(4475) pp. 20, 22, 27, 29, March 11, 1977.

110. Munnerlyn, C.R. and Clapham, T.N., "Automatic Instrument for Objectively Determining the Refractive State of the Eye," J Opt Soc Amer 64(10):1372, 1974.

111. "Navy Sets Patient Load Guidelines," Optom Mthly 72(11):4, 1981.

112. "Nidek AR2000 - Objective Automatic Refractor," Monograph by Marco Inc., Jacksonville, Fl.

113. "Nikon Autorefractometer NR-1000F," Monograph #9016 by Nikon Inc., Dec. 1981.

114. "Optometry in Third Party Programs: Prepaid Optometric Care," Third Party Care Committee of AOA, St. Louis, Sept. 1977.

115. Pappas, C.J., Anderson, D.R. and Briese, F.W., "Clinical Evaluation of the 6600 Autorefractor," Arch Ophthal 96:993-996, 1978.

116. Pappas, C.J., Anderson, D.R. and Briese, F.W., "Is the Autorefractor Closest to Manifest Refraction," Arch Ophthal 96:997-998, 1978.

117. Parrish, B., "What Automation has Meant to Me," Optom Mgmt 13(11):27-32, 1977.

118. Pennington, J., "Optometric Participation in the HMO," Am J Optom 49:765-768, 1972.

119. Pennington, J., "The Health Maintenance Organization - Is It for You?" JAOA 53(9):741-744, 1982.

120. Perrigin, D., Perrigin, J. and Grosvenor, T., "A Clinical Evaluation of the American Optical SRIII Subjective Refractor," Am J Optom 58(7):581-589, 1981.

121. Podell, S., "What You Should Know about Automated Refractors," Rev Optom 118(11):73-79, 1981.

122. Polse, K.A. and Kerr, K.E., "An Automated Objective Optometer: Description and Clinical Evaluation," Arch Ophthal 93:225-231, 1975.

123. Poquis, R., "Information Letter to Navy Optometrists," dated July 1982.

124. Redmond, D.W., Allen, J.R. and Bernstein, S., "Optometric Manpower Resources - 1973 Part I," JAOA 46:370-375, 1975.

125. Refowitz, R., "Effects of the Use of Ancillary Personnel on Professional Eye Care Services," Am J Optom 59(9):751-756, 1982.

126. "Review of Health Manpower Requirements Standards," US Dept HEW, Public Health Service, Health Resources Admin., Bureau of Health Manpower, DHEW Publication (HRA) 77-22, Oct 1976, pp A.3.

127. Richards, O.W., "A Literature Review of Retinoscopy," Rev Optom pp. 69-73, May 1977.

128. Richardson, W.O., "A Manpower Formula for U.S. Army Optometry Clinics," Masters Thesis, Pacific University, Forest Grove, Or., 1982.

129. Roberts, B.L. and Deiter, P.D., "Paraprofessionals, The Way to Go?" JAOA 46:399-405, 1975.

130. Roggenkamp, J.R., Krebsbach, J.B., Richardson, N.L. and Yolton, R.L., "The IVEX Refraction System: A Clinical Comparison," Clinical Report from Optometric Research Inst. Inc., Wash. D.C., Feb. 1984.

131. Rosenberg, R. and Skuza, B., "Geriatric and Rehabilitative Optometry," in R. Newcomb and J.L. Jolley (eds.). Public Health and Community Optometry, Springfield, Ill., Chas. C. Thomas, 1980, pp. 398-411.

132. Roth, N., "Glorified Ophthalmoscope," Survey Ophthal 17(4):265-270, 1973.

133. Rubin, M.L., "Symposium: Automatic Refractors I. Introduction," Tr Am Acad Ophth & Otol 79:481-482, 1975.

134. Rubin, M.L., "Symposium: Summary," Tr Am Acad Ophth & Otol 79:511-512, 1975.

135. Safir, A., "Automatic Measurement of the Refractive Properties of the Eye," Medical Research Engineering 11(2):12-20, 1972.

136. Safir, A., Knoll, H. and Mohrman, R., "Automatic Objective Refraction - Report of a Clinical Trial," Tr Am Acad Ophth & Otol 74:1266-1275, 1970.

137. Safir, A. and Kulikowski, C., "Problems in the Evaluation of Data," Tr Am Acad Ophth & Otol 79:488-492, 1975.

138. Safir, A., Kulikowski, C., Cracetti, A.F., Kuo, M.I. and Deuschle, K., "A New Method of Vision Care Delivery," Health Serv Rep 88:405-415, 1973.

139. Safir, A., Kulikowski, C. and Deuschle, K., "Automated Refraction: How it is Done: Some Clinical Results," Sight Sav Rev 43:137-148, 1973.

140. Sagan, W., "Computer-Assisted Refraction for the Fleet," U.S. Navy Medic 74(4):24-27, 1983.

141. Shulman, A.N., "Optometric Manpower Development and Utilization: A Look Toward the Future," JAOA 47(2):227-233, 1976.

142. Sloane, A.E., Dunphy, E.B., Emmons, W.V. and Gallagher, J.R., "A Comparison of Refraction Results on the Same Individual," Am J Opthal 37(5): 696-699, 1954.

143. Sloane, A.E. and Garcia, G.E. Manual of Refraction 3rd Edition, Boston, Little, Brown and Co., 1979, pp. 73-81.

144. Sloane, P.G. and Polse, K.A., "Preliminary Clinical Evaluation of the Dioptron," Am J Optom 51: 189-197, 1974.

145. Soroka, M., "Public Health Policy in Optometry," in R. Newcomb and J.L. Jolley (eds.). Public Health and Community Optometry, Springfield, Ill., Chas. C. Thomas, 1980, pp. 103-121.

146. Soroka, M., "Paraprofessional Utilization in Optometry," JAOA 46(9):885-892, 1975.

147. Statistical Abstract of the United States 1982-1983, US Bureau of the Census 103rd Edition, Wash. D.C., 1982, pp. 359-362.

148. The Blue Book of Optometrists-1982, Chicago, Professional Press Inc., pp. 540-542.

149. "The Humphrey Automatic Refractor," Monograph by Humphrey Insts., San Leandro, Ca.

150. The Marco AR-3000 Automatic Refractor by Nidek," Monograph by Marco Equip. Inc., Jacksonville, Fl.

151. Tlachac, C.A. and Patella, V.M., "A Comparison of Reading Add Values: Humphrey Vision Analyzer and Phoropter," Optom Mthly 70(8): 127-131, 1979.

152. "Topcon Eye-Refractometer RM-200B," Monograph #8306 by Topcon Insts, Paramus, NJ.

153. Turnbull, D.J., "The Dioptron II Automated Objective Refractor Versus Static Retinoscopy: A Clinical Comparison," Can J Optom 43:13-20, 1981.

154. Turner, H.C., "Optometry and the Military," JAOA 47(2):168-170, 1976.

155. Utech, M., "A Minimum Space Guideline for U.S. Air Force Optometry Services," Masters Thesis, Pacific University, Forest Grove, Or., 1983.

156. Volk, D., "Objective Methods of Refraction," Am J Ophthal 39:719-727, 1955.

157. Volk, D., "Objective Refraction Utilizing a Mechanical Optometer," Tr Am Acad Ophth & Otol 79:483-487, 1975.

158. Weg, R.B., "The Image and Reality of 'Old': Time for a Change," JAOA 53(1):21-29, 1982.

159. Werner, D.L. and Podell, S., "Interpretation of Heterophoria and Duction Findings when Using the Humphrey Vision Analyzer," Am J Optom 59(11):878-884, 1982.

160. Westheimer, G., "Refraction by Automation," <u>Am J Optom</u> 34:339-341, 1957.

161. Whitener, J.C., "Population Trends," in R. Newcomb and J.L. Jolley (eds.). <u>Public Health and Community Optometry</u>, Springfield, Ill., Chas. C. Thomas, 1980, pp. 52-64.

162. Wold, R., <u>Vision: Its Impact on Learning</u>, Seattle, Wash., Special Child Publications, 1978.

163. Wolfberg, M., "The Role of Vision Care in Society Today and in the Future," Office of the Assistant Secretary for Health & Scientific Affairs, Wash. D.C., July 1971.

164. Woo, G.C. and Woodruff, M.E., "The AO SRIII Subjective Refraction System: Comparison with Phoropter Measures," <u>Am J Optom</u> 55(8):591-596, 1978.

165. Wood, I., "A Comparative Study of Autorefractors," <u>Opthal Optic</u> 22:221-225, 1982.

166. Wood, I. and French, C., "The Dioptron II - In Theory," <u>Optician</u> 181:7-11, August 14, 1981.

167. Wood, I. and French, C., "The Dioptron II - In Practice," <u>Optician</u>:18-24, 30, Sept. 4, 1981.

168. Wood, W.H., "Revolutionary Subjective Examination," <u>South J Optom</u> 20(11):6-7, 1978.

169. Wood, W.H., "Rejuvenation of a Practice," <u>South J Optom</u> 21(10):19-21, 1979.