CHAPTER 1

THE HISTORY OF OPTICS, VISION SCIENCE, OPTICIANS, AND EVENTS THAT LED TO THE ESTABLISHMENT OF THE PROFESSION OF OPTOMETRY

INTRODUCTION

The unique history that eventually led to the legal establishment of the profession of optometry in the United States spans more than 600 years before the first state passed an optometry practice act. It seems safe to assume that most optometrists are not familiar with the early time period in the evolution of what would lead to the profession of optometry. Much of optometry's development takes place over the time course of decades, in some centuries many decades, so it is not surprising this early history of the evolution of the antecedents of the profession remains largely unknown and underappreciated. However, contained within this time period are some of the most fascinating aspects of the scientific and clinical development of what would eventually, give rise to the profession of optometry.

The foundation for optometry was not established through the efforts or discoveries of clinicians (opticians) just as the founding of scientific medicine was not through the efforts of practicing physicians of the day. Both professions were advanced by a wide array of learned men with frequently long time periods between discoveries.

It was during the 19th century that the evolution of health care professions came about. Optometry owes its legal beginnings to the efforts of the physicist Charles F. Prentice in the last decade of the 19th century. Optometry as a legal profession was established almost exclusively during the first quarter of the 20th century. It was a uniquely American form of eye care that evolved as the country grew in size and population. From 1901 until 1924 all of the states, the District of Columbia, and territories of Hawaii and Alaska had passed optometry practice acts (1). It was the rationale provided by Prentice that formed the basis for the establishment of a separate profession.

The history of the Alabama Optometric Association (ALOA) is more clearly understood when explained against the background of an international, national, and finally a state perspective.

A description of many of the optical instruments, charts and procedures used, some perhaps more in the past than present, is provided in **Appendix I** at the end of this chapter,

THE EARLY HISTORY OF GLASS, OPTICS, SPECTACLES, AND VISION SCIENCE

The earliest expression of appreciation for the human eye was found in the code of Hamurabi who reigned in Babylon, in the period from 2067 BC to 2025 BC. The code was formulated for the benefit of judges in order that judgments and punishments might be standardized, and to encourage skillful treatment of the eye. It included three precepts related to the destruction of the eye (2). The best known of these precepts is "an eye for an eye', that is, if a man destroys the eye of another man, they shall destroy his eye.

Chronological Periods

Hirsch and Wick (3) divided the evolution of optometry into three chronological periods which may be characterized briefly as the following:

1. Pre-optometry (before 1300 AD). This period covered tens of thousands of years. During this time some eye diseases were recognized and treated by physicians of the time. However, spectacles had not been invented and vision defects were neither understood nor ameliorated. The major historical event that ended the first period was the invention of spectacles.
2. Early "Optometry" (about 1300-1900). During this 600-year period the contributors to this science were not optometrists as we know them today but were astronomers, physicists, mathematicians, and other scientists or learned men.
3. Contemporary or Modern Optometry (about 1890 – to the present). This encompasses the decade leading to the passage of the original optometry practice acts, the years following the original practice acts and all those acts that followed to more clearly define the profession, and those acts that expanded its scope of practice.

In general terms this broad categorization still serves as a reasonably accurate contemporary guideline for understanding the evolution of eye care.

It is a well-known principle in the history of science that the time between succeeding discoveries/contributions decreases geometrically and this has been the case with optometry. The opticians of 1700 and 1900 have more in common than do the optometrists of 1901 and 1950, and the optometrists from between 1975 and 2000 more in common with those of 2001 and 2017 than the groups before. Eye care is a very technologically driven industry and it changes with ever increasing rapidity.

THE EARLY HISTORY OF GLASS

Glass was most likely discovered by accident but its exact history is unknown. Regardless of the precise time of the invention of glass, there is little doubt the manufacturing of glass has occurred for many centuries. There is some evidence that transparent glass was being manufactured perhaps as early as the 14th century BC. It is known that the manufacture of colored and transparent glass flourished in Egypt and at another independently established center in the Aegean at this time (4). Though there is no evidence to support when man first realized that hard transparent substances could be made from certain kinds of earth, several sources believe this time to be dated to 3000 BC in ancient Syria (2, 4-6). It has been reported that a group of Phoenicians cooking food on the sandy shores of the Eastern Mediterranean were surprised to find a glass-like material under the ashes of the wood fire (5). Certainly the necessary elements were there to have made it possible, since the carbonates of soda and sand, which when melded together, form an impure glass.

Major Advance in Glass-Making

The major advance in the quest to produce greater transparency of glass came in the blowing of glass in 50 BC. Gaius Plinius Secundus, better known as Pliny the Elder (23-79 AD), wrote in his history of glass that nearly colorless or transparent glass was the most highly valued form of glass. It would appear that the expansion of the ancient art of glass manufacture was rapidly brought about by the invention of glass blowing and the commercial stability afforded by the Roman Empire. In fact, by AD 220 a tax had been imposed on the glass manufacturers of Rome who were so numerous that a section of the city was assigned to them (7).

Examples of Glass Discoveries

Sir Henry Layard (1817-1894), in 1848, discovered among the ruins of old Ninevah, specifically while exploring Nimrud Palace, a plano-convex lens of rock crystal (2, 5, 8-9). This lens, or perhaps more appropriately "lentoid", dates from the seventh century BC. Nimrud was an ancient Assyrian city located south of Ninevah on the Tigris River. This site was the original capital of Assyria in the 13th century BC but gained fame in 880 BC when it was again made the capital. Whether this lens was used as an aid for vision is impossible to know. One of the earliest known pieces of clear glass is in the Berlin Museum. This piece of glass is in the form of a bead or pearl and is considered to have its origins sometime around 4000 BC. Another piece of glass in this same museum dates to around 3500 BC, while a small lion's head of blue glass is dated to the beginning of 2300 BC. Other lenses from Crete date to 1600 BC. In summary, glass manufacturing was known to the Phoenicians, Egyptians, Mohammedans, Hindus, Chinese and the Italians. However, glass existed well over 4500 years before spectacles were invented. Convex spheres were used as burning lenses at least since the time of Christ and probably long before (2, 8-9).

DOWNFALL OF WESTERN EUROPE AND ITS IMPACT ON GLASSMAKING

By 300 AD Cologne and Trier, now located in Germany, were founded as part of the Roman Empire. These cities were flourishing centers for glass manufacture. However, the manufacture and development of glass in Western Europe ostensibly ceased with the fall of Western Europe to the Germanic tribes. During this time period the manufacture of glass moved to Eastern Europe. In Europe, the Middle-Ages lasted from the fifth century until the 15th century. Over the centuries, especially during the late Middle-Ages in England, there was a gradual revival in glass craftsmanship as a result of need for stain glass windows in churches and monasteries. Venice had become an important glass center by the middle of the 11th century, especially on the nearby Island of Murano. Glass shops produced goblets and vases of clear glass.

Glass-making Survived Best in Italy

After the peak of its popularity it was in the northern provinces of Italy that glass making survived best. It seems likely that because of the existence of skilled craftsmen in the northern region that glass lenses were first made here for spectacles. It also seems logical that lenses were developed in Venice or Pisa and then moved later to the Island of Murano to obviate the risk of fires in the cities (5, 7). The Island of Murano remains a well-known glass manufacturing and fabrication center, especially for glass that is of the decorative arts motif.

EARLY DESCRIPTIONS OF REFRACTIVE ERROR

It is important to distinguish the description of refractive errors from the invention of spectacle frames or lenses used for optical correction. The first rudimentary description of refractive errors occurred some 1,500 years before the mention of spectacles.

Observations of Aristotle

The first purported description of refractive errors was offered by Aristotle (384-322 BC), the Greek teacher and philosopher, in his *Problemata*. However, an English translation *The Problems of Aristotle* was not published until 1597, and even this does not absolutely make this description attributable to Aristotle. Nevertheless, Aristotle was not a physician and did not discuss diseases of the eye. He did, however, discuss errors of refraction as deviations from normal.

Aristotle offered two theories for presbyopia or weak-sightedness of the elderly. One explanation was, that like the body as a whole, the ocular tissue, becomes dried out, no longer permitting light to pass through as readily as it formerly did. This is not too far afield from the contemporary explanation of age-related cataract. Aristotle's other explanation of presbyopia, was that rays from the eye come together at a greater distance from the eye than they do in youth. The part of this explanation that is correct is the rays of light coming together at an object like the modern concept of light coming to a focus (2, 10).

Aristotle also appreciated that presbyopia was different from myopia. He asked the question "why is it that though both a short-sighted and an old man are affected by weakness of the eyes, the former places an object he wishes to see clearly near the eye, while the latter holds it at a distance?" He reasoned it was because they were afflicted with different forms of weakness.

Furthermore, Aristotle also offered descriptions of nearsightedness and farsightedness. For nearsightedness he described the prominence of the eyeballs, the squinting of the lids together to obtain clear vision, and the tendency of persons with myopia to write smaller letters. His suggestion that the nearsighted person look through a narrow tube to see distance objects more clearly is a rudimentary form of a pinhole disk as a correction of weak sight. Thus, more than 1,500 years before the invention of spectacles one man had postulated theories of two of the various refractive conditions (2, 10).

THE EARLY HISTORY OF THE OPTICS OF LENSES

The earliest reference to lenses was the use of the burning glass as written by the Greek playwright Aristophanes (446-386 BC). This play, written in 423 BC, referred to using a burning lens to melt the writing off a wax tablet (2).

Early Descriptions of the Optics of Lenses

Euclid, who lived sometime between the 4th and 3rd centuries BC, has been called the 'Father of Optics", was best known as a mathematician. Although little is known about his life, it is known that he established such principles as the traveling of light in straight lines and equality of the angle of incidence and the angle of refraction. The understanding of plano-convex lenses was known as long ago as the first millennium. The Persian astronomer Alhazen (965-1038 AD) described the optical characteristics of such a lens around 1000 AD. He also taught that the visual rays pass from the object to the eyes, not the opposite direction, and that the angle of incidence was equal to the angle of reflection. This latter concept had first been put forth more than a thousand years earlier by Euclid, as early as 280 BC (2, 8).

The English scientist, philosopher, and Franciscan Friar, Roger Bacon (1220-1292 AD) described and made drawings of convex lenses in his *Major Opus* of 1266. In his advice he was essentially restating Alhazen's belief. Although not used as spectacles, it is clear Bacon understood the optics of convex lenses (11).

Concave lenses were first described in the book, "De Brillo" by Nicholas Causanus (1401-1464). Unfortunately, when concave lenses first appeared for nearsighted eyes, how they were discovered, and by whom, remains unknown. However, as eye care advanced the prevalence and incidence of myopia did as well.

THE HISTORY OF SPECTACLES

The inventor of spectacles will probably never be known for certain but there were many who contributed to their existence. Spectacles are unique in health care in that they are an important aspect of eye care but also possess an aesthetic quality that is more visible to the patient and public. The prescribing of lenses, lens design, and frame design are taken for granted today, but over the many years since their first use, they have had an enormous impact and influence on the development of humankind. Historically, among those who contributed to the invention or development of spectacles and the understanding of optics related to ophthalmic lenses, were philosophers, mathematicians, physicists, astronomers, chemists, and later glass makers, jewelers, and clockmakers.

Early References to Spectacles

Although the Chinese or the Hindus may have invented spectacles there is scant evidence to support either claim. Hofstetter described several sources that mentioned spectacles for aiding near vision but offered no conclusive evidence of their existence (12). For example, in Germany, Meissner stated that old people derived advantage from spectacles and that eyeglasses, or "Die Brillen", were well-known in 1260-1280 because of very explicit phrases in the songs of Minnesigners, that referred to the value of lenses to old people. Vitello, a Polish scientist and the first European man of science, wrote a book on optics in 1270, but did not mention spectacles in more than 400 pages describing optics and laws of perspective. During the Mongolian Dynasty (1260-1367) in China old people used spectacles to distinguish small print. In 1270 Marco Polo reported seeing spectacles in common use in China. Early Chinese spectacles were of a different design from early European glasses and suggested a separate origin. The old Chinese opticians attributed the invention of spectacles to Cho Tso. However, there is little documentation to clearly support these early claims (12). Perhaps the best documented description of spectacles originates in Italy.

Italian Claim to the Invention of Spectacles

There are three Italians who deserve mention in this discussion. Two monks from St. Catherine's Monastery, Giordino da Rivalto and Alessandro della Spina, provided the earliest documentation to support the time period of the discovery of spectacles. In a sermon dated February 23, 1305 Giordono da Rivalto stated "it is not yet 20 years since there was discovered the art of making eye-glasses which make for good vision, one of the best arts and most necessary that the world has". He coined the term "occhiale" (eyeglasses) and its use began to spread throughout Italy and Europe. This would place, perhaps, the first mention of spectacles in the last quarter of the 13th century at or around the year 1286 in Pisa, Italy (13-15).

Other sources have credited della Spina with the invention of Spectacles. Friar della Spina's 1313 obituary notice mentioned, "when somebody else was the first to invent eyeglasses but unwilling to communicate the invention to others, he (della Spina) made them and shared them with everybody".

Salvino D"Armato Degli Armati of Florence was at one time thought to be the inventor of eyeglasses based on an inscription on his tombstone but this has since been proven totally false.

Glasses may well have existed before this time but the exact history of their invention, inventor, or introduction is unknown. Certainly the existence of glass was known for more than 3,000 years before spectacles were invented. Clear glass existed for some 2,000 years before a lens was made, and convex lenses existed for 1,000 years, before they were used as an aid to vision.

Although no individual can, with certainty, be credited with the invention of spectacles, spectacle manufacturing became a minor industry in at least three cities of Europe. Nuremberg Germany; Haarlem, Netherlands; and Venice, Italy; were all engaged in the manufacture of spectacles. The subject of guilds related to spectacle manufacture will be discussed later in this chapter (12, 13).

Spread of the Use of Spectacles

The use of spectacles is also documented over the next several centuries through the art work of notables wearing or holding glasses. The earliest mural depicting the use of spectacles was painted by Tomasso da Modena in 1352 of Cardinal Hugo of Provence. This mural is in the Sala del Capitolo at the Seminary of San Nichola in Treviso, Italy. Other early examples of art depicting the use of spectacles can be found in France; Germany; Prague, Czechoslovakia; and Spain (13). Actual specimens of spectacles were only found around the year 1500. There is sufficient mention of the use of spectacles to support the fact that lenses of early spectacles were in the form of simple convex spheres and purchased by the aged for reading. No doubt, age was utilized as a guide for selecting lens power, or by trial and error, until the best near vision was obtained.

Concave Lenses

The earliest mention of the use of concave lenses was in 1450 in the book "De Berillo" by Causanus. An oil painting of Pope Leo X done by Raphael in 1517, located in the Pitti Palace at Florence, provides further evidence of such lens use. This painting shows the subject holding a reading lens which, from the appearance of the reflection, is believed to be concave. Further evidence is provided in the written record of the Pope's nearsightedness by his claim that with his spectacles he could see better and farther than his companions. By 1535 eyeglasses were in vogue in England and were generally accepted on the decree of Henry VIII. The corrections worn were primarily for presbyopia and perhaps some for myopia (12, 13).

Movable-Type Printing Press & Spectacle Guilds

The 15th century brought forth two major developments of significance in the history of the progress of spectacle use. The first was the invention of the movable-type press with the consequent popularization of reading. The other was the formation of spectacle makers' guilds. The first guild was formed in 1465 in France under King Louis XI (1423-83) and the second in 1483 when the "Guild of Master Spectacle Makers" was formed in Nuremberg, Germany. The earliest known spectacle maker in England was Spyke Dowd who was making spectacles in 1485 (16).

Spectacle use increased rapidly as the need for required visual performance accompanied literacy. The confluence of the invention of spectacles, the manufacture and greater availability of paper, and the invention of the movable-type press all occurred within a 200-year time span in Western Europe (12). Although this may seem like a long time by contemporary standards it was relatively short considering what had occurred the previous 1,500 years.

EARLY LITERATURE RELATED TO OPTICS AND VISION SCIENCE

Theoretical Understanding of Optics

The work of the Persian astronomer Alhazen has been mentioned in the early history of optics. Clearly Alhazen understood the optics of the plano-convex lens having described them around 1,000 AD. His description of the concepts of optics and vision served as the effective beginning of the millennium leading to the eventual establishment of optometry.

In 1268, the English Oxford scholar, scientist, philosopher, and later Franciscan Friar, Roger Bacon (1220-1292), in his first book *Opus Major,* described the nature and optics of convex lenses. Many regard Bacon as the most important man of science in the Middle-Ages. Bacon also introduced concepts such as "scientific method", reasoning and deductive procedures, and methods of experimental study. He advised that when such lenses were placed on a page, they could assist old or nearsighted persons. In this advice he was essentially restating Alhazen's belief. Although not as spectacle use per se, it is clear Bacon understood the optics of the convex lens. It has even been suggested that Bacon may have been the inventor of spectacles although there is no evidence to support this supposition (11, 12).

Anatomy of the Eye and Visual System

Near the close of the 15th century the Italian artist and scientist Leonardo da Vince (1452-1519) was the first to identify the retina as the essential organ of vision and the crystalline lens as a refracting body rather than a receptor as believed by Alhazen (12).

Franciscus Maurolycus (1495-1575), an older contemporary of Kepler's, included in his writings the treatment of spectacles for correction of myopia and presbyopia. He also finished what da Vince had begun in dismissing the crystalline lens as the central organ of vision. Maurolycus's work was not published until after his death and after Kepler's work had been published (12). During this same time period G. Johannes Baptista della Porta (1538-1615) of Naples, in his book *Magna Naturalis*, published in 1589, contributed to the subject of optics by describing the treatment of spectacles for presbyopia and myopia as well as offering a considerable description of lens grinding as conducted at that time by opticians. This was nearly 300 years after the first reliable description of spectacles (12).

Felix Plater (1536-1614) was a physician and professor of anatomy at the University of Basil and the first, in 1583, to identify the retina as the receptive layer of the retina. Plater described the retina as containing photoreceptors responsible for capturing light (10).

Johannes Kepler published his treatise on optics entitled *Dioptrice* in 1611. This book described the mathematics of lenses, prisms and mirrors, as well as scientifically explaining the process by which the eye received light and formed an image. He believed light from an object, entered the eye, and was refracted by the cornea and lens. The eye formed an inverted image on the retina. He also differentiated the function of the central from peripheral retinal. In this manner Kepler solved the mystery of vision. Kepler also described the basis for the Galilean and Keplerian telescopes (12).

In 1619 Father Christoph Scheiner, a Jesuit priest, physicist, and astronomer measured the indices of refraction of the eye, performed the first measurement of the corneal curvature, described the location of the optic nerve, and observed that pupils constricted to light. He also demonstrated on animal eyes that the image formed on the retina was indeed inverted (12).

Understanding of Refractive Errors

Despite the work of Maurolycus, della Porta, Kepler, Scheiner, and others, the prevailing attitude was that people with refractive errors could be classified one of two ways; those who could not see clearly in the distance, in which case they were myopic, and their vision improved by concave lenses; or those who could see clearly at distance, but had difficulty seeing small print, in which case they were classified as having presbyopia and near vision could be improved with the use of convex lenses. In this sense they were incorrectly considered “opposite states”. This mistaken notion persisted for 200 years (10).

It would seem reasonable to assume at some point in time people unable to see clearly at distance, would on browsing through glasses in a general store or the spectacle peddler’s tray, notice they could see more clearly at distance when viewed through a reading lens (10). However, the history of hyperopia and its correction is less straightforward. As early as 1623 de Valdez mentioned when discussing presbyopia, that sometimes the sight of old people was so greatly weakened they were unable to see far away and many needed glasses to see at distance. While he did not describe the clinical entity of hyperopia the condition was at least implied (10).

The German mathematician George Hamberger in his book *Optica Ocularum*, published in 1696, explained the optics of hyperopia. The first adequate description of the condition in the English literature has been credited to the English physician William Charles Wells (1757-1817). Several years after Wells published his *An Essay Upon Single Vision, With Two Eyes*, in 1772, he described hyperopia in his own eyes (10). In 1813, the ophthalmic surgeon James Ware (1756-1815) described cases in which young person’s required convex lenses at distance to see clearly (10).

Confusion Between Hyperopia and Presbyopia

In spite of the adequate differentiation of hyperopia from presbyopia by Wells and Ware, the two conditions were persistently confused by writers for the next half a century. This is not surprising given that both conditions are optically corrected with the use of convex lenses. It was not until 1864, when Donders adequately described the condition of hyperopia on both a clinical and scientific basis. It was von Helmholtz who shortened the term hypermetropia to hyperopia (10).

Christian Huygens, a Dutch mathematician and astronomer, developed the wave theory of light and first presented it at the Paris Academie in 1678 but did not publish it until 1690 (12). Newton presented his theory of color vision in 1704 (12).

In 1757 the English optician John Dolland first succeeded in making an achromatic lens by a combination of glass and water as media, and later by combining different densities and qualities of glass (12).

THE FORMATION OF OPTICAL GUILDS

Guilds were part of the municipal government in Europe which served some of the functions of contemporary examining boards, professional associations, and trade unions. First and foremost, however, their purpose was the protection of local industry and the establishment of local standards. Optical guilds were not adopted in America, although some aspects of the system such as some type of informal or formal apprenticeship, were retained during the Colonial period.

Early Optical Guilds

As early as April 2, 1284 the Venetian guild of crystal workers warned members that no member shall dare to work colorless glass counterfeiting crystal. The first supplementary regulation stated no crystal worker shall dare buy, or sell, or caused to be sold, any work in colorless glass which counterfeits crystal. A second statement on June 15, 1284 authorized any person wishing to make glasses for the eyes for reading must come to the magistrate's office to swear he will sell the glass as glass (12, 13). Almost immediately (ca. 1300) spectacle manufacturing became a minor industry in at least the cities of Nuremberg, Germany; Haarlem, Netherlands; and Venice, Italy (12).

The earliest spectacle-makers' guild was formed in Antwerp, Belgium in the mid-fourteenth century. This area became the earliest spectacle-making center where spectacles were made and exported to nearby countries (14). Real progress in the development of spectacles may be said to date to about the mid-fifteenth century with the growth of the spectacle industry, and the rise of the guilds. The Gutenberg printing press was about a decade old and spectacles had become a necessity for many less affluent people.

The first spectacle-makers reported in Germany were from Frankfort, 1450; Strasburg, 1466; Nuremberg, 1478; and perhaps the most famous of all was the Opticians Guild of Regensburg, Bavaria in 1483 (15). The French spectacle-makers would appear to have also been among the earliest to become organized as a trade in 1465 under Louis XI (1423-1494). The spectacle-makers were grouped together with the haberdashers and upholsterers to form an amalgamated guild. In 1581, Henry III of France granted a combined Patent of Membership to the mirror makers, toy makers, and spectacle-makers, the former two trades having received their original statutes of incorporation in 1489. However, little more is mentioned about spectacles in the literature (16).

The Worshipful Company of Spectacle Makers

What was perhaps the most famous guild, patterned after those at Antwerp, Nuremberg, and Regensburg, was not founded until 130 years after the formation of these continental guilds. The Worshipful Company of Spectacle Makers was approved by King Charles I of England in 1628. This guild was chartered, signed, and sealed on May 18, 1629 by the King and countersigned by Cardinal Wolsey. Apprenticeships began at age 16 and continued for seven years until age 23. This was followed by a two-year period of journeyman and the presentation of the "masterpiece" to the Court of the Company. However, one was able to gain early freedom by patrimony or financial redemption. At its height, this guild had total control of the quality of optical goods sold in London, and later all of England. This guild had the power to levy fines and search the premises of the spectacle-maker for deceitful or counterfeit wares.

Unfortunately, these guilds often opposed technological advances much to their deleterious effects. While not initially of assistance to the customer or buyer, in making a selection of spectacles, these spectacle-makers gradually evolved into the forerunner of contemporary ophthalmic opticians as they were known in England for many years, and then later optometrists (14-16).

Decline of Optical Guilds

At one time the spectacle-maker was at the top of the social scale in terms of vision care. The peak of the guild system was in the 15th and 16th centuries and by the 18th century such guilds were in decline. Although the Worshipful Company of Spectacle Makers continues to this day as an organization in England, for the most part, European guilds died out long ago and this model was not closely adopted in America. What was similar was that while the fabrication or manufacturing of spectacles was regulated in England, the prescribing of spectacles was totally unregulated in both England and America (14). Many spectacles were sold in clothing stores or novelty shops, by itinerant peddlers in the countryside, or by the owner of an optical shop in the city. Any sight testing service would have been very rudimentary compared to contemporary techniques or procedures and, in many cases, consisted of trying on pre-fabricated spectacles to determine if the lenses improved vision. The development of sight testing began in the more populous areas of the country while itinerant "spec-peddlers" or other forms of sight testing and spectacle selection predominated in the rural areas (14).

THE DISCOVERY AND OPTICAL CORRECTION OF ASTIGMATISM

Until the discovery of astigmatism, the greatest emphasis had been on the need to supply pre-fabricated lenses for presbyopia. The discovery and optical correction of astigmatism has an interesting and somewhat complex history. Although astigmatism was described by others years earlier, it was noticed and experiments were conducted primarily by two individuals at approximately the same time, but on two different continents. However, astigmatism is an important aspect of any discussion on refractive errors since it is one of the most common, if not the most common, of all the refractive errors.

Discovery of Astigmatism in Germany

E. G. Fischer, (1754-1831) Professor of Mathematics at the University of Berlin, recognized the phenomenon of astigmatism perhaps as early as 1805 and perhaps even earlier. He was able to demonstrate the anomaly to his students using two series of parallel lines crossed at right angles to each other. A biographical sketch of Fischer stated that he discovered astigmatism in 1783. He also recognized the cornea as being the primary cause of astigmatism (17). Gerson was born in Hamburg, Germany in 1788. He received his early university education at Berlin and then proceeded to Gottingen in 1809 receiving his medical degree in 1810. After service in the German military and time in private practice he devoted time to the study of the shape of the cornea and the phenomenon of astigmatism (17).

Discovery of Astigmatism in England

Interestingly David Brewster (1781-1868), as early as 1789 at the age of eight, had noticed a difference in the clarity of a bent wire as he viewed it from the vertical position to the horizontal position. Brewster was sent to the University of Edinburgh at the age of 12 and graduated in 1800 with an MA degree. At the time of this observation Brewster was studying the effects of lacrimal fluid. Brewster correctly associated the production of astigmatism with the asymmetry of the cornea and crystalline lens. His observation was not published, however, until 1817, 16 years after Young's paper had been published. However, this was ten years in advance of when Airy's seminal paper was published (18).

As early as 1801, Thomas Young had mentioned his own astigmatic condition to William Cary (1759-1825) a scientific instrument maker. When Young mentioned this to Cary, the latter remarked that many people were obliged to hold concave glass obliquely in order to see with greater distinctness. In fact, Young had published a paper entitled "On the Mechanism of the Eye" in the Philosophical Transactions of the Royal Society this same year (1801). He brought this paper to Airy's attention some 27 years later in a letter dated May 7, 1828 (19).

Airy's Research on Astigmatism

George Biddell Airy (1801-1892) first noticed, while a student at Trinity College, Cambridge, England, the visual problem in his left eye. It appears from his autobiography that this may have occurred as early as April 1822. He noticed that if he tilted his spectacle lens obliquely or fixated at a point near the edge of the lens, he could see the object more clearly. Airy described this condition in a paper read before the Cambridge Philosophical Society on February 21, 1825. He published a paper on the condition in the Transactions of the Cambridge Philosophical Society in 1827. However, he had conducted experiments on his left eye as early as August 25, 1824 (19).

After several failed attempts to have a cylindrical lens made to correct the condition, he located Fuller of Ipswich who completed the lens in November 1824. He also had William Cubitt secure two more pairs from Fuller in 1825. The term astigmatism was, at a later time, suggested to Airy to describe this visual anomaly by Dr. William Whetwell, Master of Trinity College at Cambridge (19).

Airy published progress reports of his astigmatism for almost the next 60 years, the last report being in 1884. In his subsequent correspondence he apparently was not aware of Donders' historical account of astigmatism. Donders credited Young with the discovery of physiological astigmatism and Airy with pathological astigmatism (20).

Discovery of Astigmatism in America

At about this same time in late 1825 or 1826, almost the same year that Airy's paper was published, the Reverend Chauncey Goodrich in the United States independently discovered and corrected this same condition in his own eye. It is remarkable these events took place at about the same time but an ocean apart. Goodrich had described his condition in an unpublished letter to Messrs. McAllister (21). This unpublished letter was mentioned by H. D. Noyes in a paper published in 1827 on the first recorded case of astigmatism in America for which cylindrical lenses were made (21).

Goodrich's Research on Astigmatism

Goodrich noted vertical lines appeared clearer with his naked eye but horizontal lines were clearer with the concave lens spectacle he had purchased for the experiments. Goodrich reasoned, that the lens of his eye was probably cylindrical and that if a lens were fabricated such that the greatest focal length was at right angles with the lens of the eye, it would produce a perfect image. In Goodrich's letter to McAllister, written some time in 1826, he stated the concave lenses obtained in New York did now clarify the horizontal positions of the ships rigging and the vertical positions were much less precise than when viewed with the naked eye. He experimented further by observing a pair of crossed horizontal and vertical lines. With the naked eye the vertical lines appeared clearer than the horizontal ones, and to see the horizontal ones with the same precision, it was necessary to turn his head 90 degrees in which case the vertical lines became indistinct. Equality of the clarity of the lines was achieved when he turned his head 45 degrees. Repeating the observations with the concave lenses he found the effects completely reversed. When he experimented further viewing squares and circles he noted their shapes were parallelograms and ellipses respectively (22).

It well may be that McAllister's test for astigmatism originated from an idea given him by the description of Goodrich's symptoms. Based on Goodrich's paper dated February 20, 1828 he procured from Philadelphia a plano-cylindrical concave lens in 1827, perhaps from the McAllister's. From this point forward there is considerable confusion as to who actually made the lenses for Goodrich. Since there was no consistent system for designating ophthalmic lens power, a lens of a specific number, may vary between the French, English, and American systems utilized at the time (21, 22).

First Cylindrical Lens in America

Goodrich's first cylindrical lenses were obtained in 1827 but in a paper dated February 1828 he references a second pair of glasses "got of McAllister" in May 1828. This May date either refers to a second pair of glasses or an error was made by Goodrich as to the date of the memorandum. Since it required several months to fabricate the lenses, the next part of his statement was in error, namely, "I wore 14 months", i.e. July 1829. Furthermore, the exact power of the cylinder is unknown for reasons mention regarding the lack of international consistency or standards (22).

Even so, Goodrich mentioned that a sphero-cylindrical lens should overcome the problem encountered by the plano-cylindrical lens. Unfortunately, it cannot be obtained with any degree of certainty if McAllister made any of the cylindrical lenses. It may be that McAllister ordered the lenses from Europe since lens grinding tools were not yet available in the United

States. It is known that until the 1830's almost all spectacles were imported from Europe. According to Frank W. McAllister, the grandson of John Jr., frames were made at McAllister's but lenses were imported from either Chance Brothers in England, or later on, from France and Germany. If indeed, McAllister did import the cylindrical lenses, they could have only come from Chamblant in Paris who had been constructing cylindrical lenses since before 1820 (23).

It seems most likely, that regardless of the attributions given to McAllister with regard to grinding a cylindrical lens, that he may have built up, over the years, a collection of stock imported lenses that he utilized to fill prescriptions. Frank McAllister commented that about the time of Donders book publication (1864), there were one or two oculists in Philadelphia who began examining eyes according to the system outlined by Donders. John McAllister, Jr. had the honor of furnishing the first pair of cylindrical lenses for use by a patient. The original letter ordering them was, according to Frank McAllister, in the possession of the McAllister family (24). It seems most likely that in the United States, Joseph Zentmayer was the first maker of sphero-cylindrical lenses in 1862. Zentmayer is said to have also made the first sphero-cylindrical lens for the James Queen Optical Company. Queen had started in the optical business in 1825 first as an employee of McAllister's and from 1836 to 1852 as a partner. In 1853 Queen began his own optical firm. The demand for cylindrical lenses was gradual and it was not until 1874 that Queen's firm began to supply its own cylindrical lenses (23).

Foundation for American Optometry

Nevertheless, the profession of optometry had its informal beginning at the optical business of John McAllister & Son. In many respects, the McAllister's may be regarded as the first family of opticianry and laying the foundations for the development of the profession of optometry. Not only were the McAllister's involved in these very early formative years, but later, so was the Queen Optical Company. Since there was no school of optics at this time in America, the only way to learn the trade was by performing an apprenticeship of some type. Most of the leaders in the optical business were interconnected having trained at either the McAllister or Queen firms. A few others learned at other firms, or they came to America with training received in England or on the Continent. Some optical businesses moved to the Midwest and, by the late 19th century, optical businesses had begun in the far west. These men formed the nucleus of what would eventually become the profession of optometry (24).

Among the more prominent early names were, in addition to John A. McAllister, Sr., Benjamin Pike, James Prentice, John McAllister, Jr., James W. Queen, Daniel Widdefield, Charles Lemke, Charles Prentice and Andrew Jay Cross. (25). Individuals trained by Queen who contributed to the development of the profession in America included Drs. John W. Jarvis, Harry Pine, Sr., William W. Russell, Henry Kaiser, and William G. Walton (26).

The contribution of the McAllister family will be discussed in greater detail later in this chapter. This remarkable family contributed to the evolution of vision and eye care for well over 150 years. An effort is currently underway to place an historical marker at or near the place of business of the McAllister's in Philadelphia. This plaque will, if approved, commemorate the important role this family played in opticiary/optometry over the many years it was in business. The Optometric Historical Society has joined with Dr. David Fleishman and others to make this historical recognition a reality.

Importance of Levene's Research

It is apparent that Dr. John Levene's research contributed much to clarifying our understanding of the discovery and correction of astigmatism in Germany, England, and America. Likewise, he contributed much to our understanding of early scientists whose interest was the eye or vision. Levene's book, *Clinical Refraction and Visual Science,* as much as the title might imply a clinical work, is in fact, a rich source of history as it pertains to individuals such as William Porterfield; the detection, recognition, and correction of refractive errors; ophthalmic instrumentation; the invention of bifocals; among many other ophthalmic topics of historical interest. His book is referenced as it specifically relates to the topic of discussion.

HISTORY OF THE PROFESSION'S PREDECESSORS

Early Books Related to Optics, Prescribing, and Instrumentation

The emphasis in this section is related to the idea of prescribing lenses for the correction of refractive error. Due to the overlapping nature of the topics some of these writer's and their books have been mentioned earlier in this chapter.

Benito Daca de Valdes

In 1623, Benito Daca de Valdes was a humble licentiate and notary in the Holy Office of the city of Seville, Spain. His essay, briefly entitled *The Use of Spectacles for Every Kind of Sight*, covered such topics as optics, ocular biology, and the first practical guide for prescribing spectacles. It also included a system for numbering lens power for presbyopia based on the age of the patient. Daca de Valdes lens powers were not in the same increments as those manufactured once standardization was achieved. In his book the table for prescribing began at +2.40 D. for ages to 30-40 years and progressed to +6.00 D. for those over age 80. Although the amount of power suggested for presbyopia correction was of much greater power than used today, the concept was much the same as the age-based concept used in contemporary clinical practice.

He also offered suggestions to prevent the prescribing of excessive lens power for myopia, discerned that weaker powered lenses should be in the form of plano-convex or concave lenses, and suggested that tinted lenses should be worn to protect the eyes from the wind and sun. Furthermore, he suggested that spectacles should be steadied by fastening to the ear or temple as well as over the nose (27). It is interesting to note that spectacles were in use for almost nearly 500 years before temples were added to frames.

Although the Spanish began fastening spectacles to the ears by thread loops at the end of the 16th century, it was not until 1728 that E. Scarlett, in England, published a description of his invention of spectacles with temples. However, attachments such as headbands, straps, or other forms of attachment may have been used during this time. (28).

William Molyneux

Over a half century later, in 1692, the Irish philosopher, astronomer, and mathematician, William Molyneux published a book in Dublin entitled *Dioptrica Nova.* In this book, he paid tribute to the invention of spectacles, and described fitting lenses for both presbyopia and myopia (29). Like Daca de Valdes he included a number of prescribing guidelines such as using the weakest power lens that solved the vison problem. He also recommended that those with myopia may require more than one pair of spectacles and that some eyes will not be helped with either concave or convex lenses.

Smith and Richardson

In England, patents had been granted to Addison Smith and J. R. Richardson as early as 1783 and 1797 respectively, for what had been called an alternative to bifocals. These consisted of an extra pair of rimmed lenses, which hinged to the main spectacles from above (30). In 1738, Robert Smith a professor of astronomy, at Cambridge University, used optical knowledge that had been applied to the eye by Kepler to publish a book entitled *A Compleat System of Optics* (30).

Ayscough, Browning, Sutcliffe, & Lawrence

In addition, James Ayscough published a third edition of *A Short Account of the Eye and the Nature of Vision* in 1754. This book described a "rule for choosing glasses proper for remedying all the different defects of sight". This book tended to provide evidence that spectacle fitting and lens selection was being conducted by the spectacle merchant of the day. The English optometrist John Browning wrote extensively on optics and authored a well-known book entitled *Our Eyes*. Robert Sutcliffe invented a refractometer and the English educator and author Lionel Laurence wrote *General and Practical Optics* and *Visual Optics and Sight Testing* both which became standard texts in applied optometry in England (31). Unfortunately, none of these books were known in America.

Nevertheless, it is remarkable that many of the concepts and prescribing guidelines mentioned by these men, albeit presented in a more simplified format, remain as valid in contemporary optometry as they were 300 years ago. These clinical insights were astounding considering the time period and level of knowledge about vision care when the books were written.

Importance of Donders Book

Franz Cornelius Donders was born in Tilborg, Holland in 1818. At age 17 he entered medical school at the University of Ultrecht, graduating at age 22. He served for two years as a military surgeon and then entered academia. The importance of refraction was firmly established with the publication of Donders book entitled *On the Anomalies of Accommodation and Refraction of the Eye, with a preliminary Essay on Physiological Optics*, this book was published in 1864 (32).

This book made a great contribution to the development of the understanding of refractive errors. Donders was a physician and professor of anatomy and physiology in Holland. Unlike many physicians of his time, however, Donders recognized the value of spectacles and contributed significantly towards the prescribing of them as a scientific procedure. Donders demonstrated the symptoms of uncorrected hyperopia were amenable to relief by the use of convex lenses (32). Donders was attempting to show that spectacles were the answer to refractive problems rather than lotions and eyewashes. This book explained the basis of hypermetropia, both clinically and from a scientific standpoint (33). It was Donders that named the condition hypermetropia and is in keeping with his other two terms, emmetropia and ametropia. It was von Helmholtz who used the synonymous term hyperopia (33). Thus, in a somewhat ironic turn of events, Donders' research and writing also laid the foundation for the development of clinical optometry. It may even be said that Donders played a critical role in helping the founding of contemporary clinical optometry.

Hermann von Helmholtz

Fortunately, von Helmholtz came to the field of physiological optics when he did. By the 1850's and 1860's, knowledge related to physiological optics had become a formidable body of information. However, what was needed was someone to bring together the known facts, organization of the subjects in the field, and further study and research in undeveloped areas. Physiological optics (now usually referred to as vision science) was for many years the most important body of knowledge in the optometric curriculum. It is the science of which, for many years, optometry was the applied branch. Von Helmholtz was, for most of his life, a physicist and physiologist (34).

Helmholtz had been born in 1821 at Potsdam near Berlin. He was a sickly child who had trouble in school with subjects requiring memory but he excelled in mathematics, physics, and later optics. He wanted to become a physicist, but his father prevailed on him to study medicine because of the family's need for money.

Career of von Helmholtz

After graduating from medicine, Helmholtz served in the military as a physician but never conducted a private practice. He became a professor of physiology at Konigsberg in 1849, professor of anatomy and physiology at Bonn in 1855, professor of physiology at Heidelberg in 1858, and finally a professor of physics and Director of the Physical institute at Berlin in 1871. He possessed knowledge in many domains of science. His greatest work was the three volume *Physiological Optics* published in Germany (33, 34). The first volume appeared in 1856 and the last in 1866. It was published in a second edition in 1885 and in a third edition after his death in

1909-1910. The third German edition had supplemental information provided by Gullstrand, von Knies, and Nagel. The third German edition was translated into English and published in 1924 by the Optical Society of America. This English edition contained significant new material prepared by C. Ladd-Franklin, Gullstrand, and von Knies with copious annotations by James P. C. Southall (34). It was re-published by Dover Publications in 1962 as a two volume set. However, von Helmholtz was to also influence eye care in several other ways. He influenced the introduction of the ophthalmoscope, introduced an improved version of the ophthalmometer, and contributed to the theory of accommodation and color vision (35).

Early Books on Optics, Ocular Anatomy or Physiology

For the most part books on optics and ocular physiology, or other optical or optometric subject matter, were written by individuals with a science background/education, learned positions, or those trained in medicine. In general, our optometric forebears were not highly educated and or especially capable of writing textbooks needed by the profession. There had been a few significant books written by English and European opticians from as early as the early 19th century but nothing that appeared in America.

The French "optician-engineer" Gabriel Augustin Chevallier discussed the Franklin Bifocal in his Gazette De Sante in 1806. It was subsequently published in his *Conservateur De La Vue* as early as 1810 and later editions of this well-known book. In 1808 Biette of Lyon patented a bifocal type lens. John Hawkins, the inventor of the trifocal, realized that Chamblant lenses could be so constructed as to correct for astigmatism. He referred to Ree's Cyclopaedia for their method of construction in 1818 (36). There were, however, several American books on optometry that have recently been reported and shed some light on the level of knowledge that existed at the time they were written (37-40).

Optometric Books Written in America

Walter Alden

The first of these books was written by Walter Alden from Cincinnati, Ohio, in 1866 (37). This 150-page book was entitled *The Human Eye, Its Use and Abuse.* This book was self-published by the author who described himself as an optician. The book included chapters on the anatomy of the eye, accommodation, myopia, astigmatism, hyperopia, the relationship between hyperopia and convergent strabismus, presbyopia, cataract, and several chapters discussed various aspects of spectacles. Alden primarily addressed his book to the general public but it was also for use by his fellow opticians. It seems unlikely the general public of that time would have wanted or comprehended such detailed information. There was also an addendum of 12 unnumbered pages, mostly advertising other optical businesses. One of these advertisements indicated that Alden was in practice with the long-established Cincinnati optical firm of James Foster, Jr., & Co.

William Bohne

Before the discovery of Alden's book, the first book thought to have been written by an American optician (optometrist) was by William Bohne (1827-1906) in 1888 (38). Bohne had several years of college studies in Germany, during which time he studied languages, mathematics, physics, and other subjects. He was then a public school teacher for four years. When he developed lung problems it was recommended he move to a warmer climate.

In 1852, Bohne emigrated to New Orleans, Louisiana where he learned watchmaking. He opened a shop as "Watchmaker and Optician" in 1857 but devoted his efforts mostly to optical work after 1868. The 1870 and 1880 federal census for New Orleans listed his occupation as optician. In 1898 he was the first person to be elected to the office of second vice-president of the American Association of Opticians, later to become the American Optometric Association. The first edition of his book entitled *Hand-book for Young and Old Opticians: A Concise and Comprehensive Treatise on the Theory of the Optical Trade and of its Mechanical Manipulations,* was 108 pages in length, and published in New Orleans by Griswold in 1888 (36,37). The second and third editions had the same title except the words "Young" and "Old" were eliminated. The second edition was published in 1892 and consisted of 251 pages, and the third edition published in 1895 was 276 pages in length. The third edition included 29 chapters on various topics (38).

The first 14 chapters covered optics, characteristics of lens and spectacle frames, and related topics. Chapters 15 through 24 discussed the characteristics of the eye and methods of examination and treatment. Topics contained in these chapters were anatomy of the eye, refractive conditions, the ophthalmoscope, cataract and "second sight", emergency care for eye injuries, artificial eyes, different light sources and tears. The remainder of the book, chapters 25 through 29 consisted of a variety of topics. Chapter 26 presented a history of the invention of spectacles and the development of the optical trade. Chapter 27 was primarily historical in nature containing 114 biographies of prominent opticians, scientists, and inventors mostly from the 18^{th} and 19^{th} centuries. Chapter 28 contained miscellaneous notes on a variety of subjects including the relations of opticians and oculists, refractive errors, accommodation, neutralization of lenses, and the nature of light. Chapter 29 contained a glossary of terminology, and this last chapter was followed by end matter including a list of abbreviations and an index (38).

James Queen & Co.

The establishment of McAllister's firm served as a training ground for many men in the optical field and it is from them that the making of spectacles expanded. Perhaps one-half dozen or more spectacle makers were at one time or the other associated with the Philadelphia firm. James W. Queen (1811-1890) was listed as an optician in Philadelphia in 1839. Queen began working at McAllister's in 1825 and, following the death of John Sr., in 1830, he later became a partner in the firm John McAllister, Jr., & Co., serving in this capacity from 1836 to 1852. Queen along with John Jr., and Walter B. Dick worked in the firm, although John Jr., retired in 1835 (24).

In 1853, the firm of James W. Queen & Co., was established in Philadelphia. In time the company grew to become a very large importer, manufacturer, and supplier of all kinds of scientific goods, perhaps the largest in the United States. Joseph Zentmayer was said to have made the first sphero-cylindrical lens for James Queen Optical Co., and Queen's firm began to supply its own cylindrical lenses in 1874 (23).

By 1888 the firm had six departments: physical and chemical; engineering; ophthalmic; microscopical; magic lantern; and photographic. The ophthalmic department was known as Department No. 1 and was one of the largest branches of the business. In 1859 Queen joined with Mr. Samuel L. Fox and under their supervision and management the business steadily developed. Messrs. Samuel Fox and Edward B. Fox became owners of James W. Queen Optical Co., in 1870 and James Queen retired in 1885. The business continued under this name until 1893, when it was incorporated as Queen & Co. In 1912 the company was reorganized as the Queen-Gray Co. by John G. Gray and continued as such until Mr. Gray's death in 1925. After 1925 it became the Gray Instrument Company and continued in business until 1952 (39, 40). This company, or its successor companies, had been in business for 99 years by the time it ceased operation.

James W, Queen Co., Booklet

However, it was in 1888, three years after the retirement of James Queen, that the James W. Queen Co., published the booklet *How to Fit Glasses.* This booklet was subtitled *A Manual for the Use of Opticians, Jewelers, Druggists, (etc.)* (37). The early chapters 1 through 5, dealt with ophthalmic lenses and simple refractive errors by way of test-types and trial-sets. Chapter 6 dealt with cylindrical lenses and astigmatism, which many opticians still did not prescribe for, viewed as being too complex. Although Jackson's cross cylinder technique was being promoted at this time, evidently it was unknown to the author. Chapter 8 was titled "Frames and How to Fit Them". This chapter also included diagrams on differentiating spectacles and eyeglasses, and useful illustrations of the various components.

Pages 88 to 96 of Queen's booklet listed various standard outfits for different levels of ophthalmic practice. For example, druggists and jewelers in a small town may have needed only a modest range of ready-made spectacles; an optician in the city would be advised to have a trial-set, mirror retinoscope, test-types, astigmatic dial, and physician's textbooks on refraction as well as a large stock of spectacles and lenses; and an oculist an operating chair, surgical instruments, ophthalmometer, ophthalmoscope, perimeter, and a range of frames and lenses. Finally, there were two pages of distance and near test-types followed by 14 unnumbered pages of illustrated advertisements for optical and other products. It seems clear that Bohne did not know of the existence of Queen's booklet (37).

August Morck

Ironically in 1888, August Morck, Jr., published *Preservation and Care of the Human Eye* (37). Although both the Bohne and Morck books were published in the same year it is not known which book appeared first. It is known that by the time of Bohne's second edition was published, he was aware of Morck's book since he praised Morck's "Perfection Bifocals" but does not mention Morck's book (37). Morck was born in the small town of Warren, PA in 1855. His older brother Frederick was a jeweler in Warren. In 1882, at the age of 27, August joined the business as an optician.

Morck's book comprises some 70 pages and was addressed to opticians and the general public. It contained chapters on the anatomy of the eye, refractive errors, rules for fitting glasses, and the care of the eyes. It seems Morck had a limited education but was probably a good optician. His special achievement was the Morck's Patent Perfection in which cement of Canadian balsam was used in either one of two ways. A crescent-shaped stronger reading lens was cemented or fit into a slotted groove on the top part of the lens or a thin wafer of extra power was cemented on the front or back lower part of the distance lens. Even though the cemented lenses had the disadvantages of discoloration of the cement and chipping of the adjoining lens sections they survived into the 20th century. This was long after the introduction of the fused bifocal. Morck's small book seems largely a promotion for his business but it would have been useful to other opticians. In this sense it was almost like a textbook (37).

Queen & Company Book

After Queen's death in 1890, an updated version of his earlier book was published by his successor company. Entitled *The Human Eye – How to Correct its Defect by Properly Fitting Glasses*, this book was published in 1896 by Queen and Company (39). This was the company that had originally been begun by Queen in 1853. This book provided an understanding of refractive methods in the late 19th century. This book provided information relating to the correction of hyperopia, myopia, presbyopia, and astigmatism. For example, it was noted that the test for hyperopia was when the eye could see as distinctly, or more distinctly, through a convex lens. To determine the amount of hyperopia, it was recommended that one eye be covered and then placing in the trial frame before the other eye successively stronger convex lenses, until such time as the lens power was so strong distance vision was less distinct. The lens power was then reduced until the strongest lens that left vision clear was the correct lens correction.

This book also stated that if distance visual acuity was reduced and near visual acuity was better than distance visual acuity, it could be deduced that myopia was present. The book advised that the selection of minus lens power for eye each could be guided by the level of distance visual acuity in that eye, and the weakest concave lens power that resulted in the best distance visual acuity was the amount of the myopia.

To test for astigmatism, the book advised using a distance-astigmatic test card in which there were sets of parallel black and white lines of uniform size, running in different locations. These could be in the form of "astigmatic letters" in which the letters are made of parallel stripes with varying orientation from letter to letter or in the form of lines radiating from a common center, as in a clock dial.

For presbyopia, Queen and Co., recommended lens power based on the near point of accommodation and the habitual near point working distance. In a table of dioptric lens powers, were columns with working distances of 30, 20, 15, 12, 10, 9, and 8 inches and rows with near points of accommodation of 8, 9, 10, 12, 15, 20, 30, and more inches. For example, for a working distance of 15 inches and a near point of accommodation of 20 inches, the table would recommend +1.25 D. Based on the fact that the table was repeated with lens powers with focal lengths in inches illustrates that the diopter had not achieved universal acceptance (39).

These soft-covered booklets served as the very early literature of the profession and in this sense were the *Incunabula*, or books produced in the infancy of optometry book publishing (37-39).

It would be almost half-way into the 20th century before Borish completed the manuscript of his seminal book *Clinical Refraction*, which was first published in January 1949.

CLINICAL USE OF THE CROSS CYLINDER

Clock Dial Targets for Measuring Astigmatism

Prior to the description of the clock dial target by Green, in 1866, Goulier had presented his observations on astigmatism as early as 1852. Goulier'chart was comprised by a series of lines, some at right angles, grids, etc., for detecting astigmatism (40). By the early 20th century, the common tests for astigmatism were variants on the clock dial-like targets. Some optometrists mounted a pin in the center of the target so that finer gradations of axis could be determined other than by the separation of the printed lines. Use of this technique allowed for the determination of the axis by locating the darkest line on the clock dial. Then with the axis 90 degrees away the cylinder power was increased until the lines appeared equal in darkness thus determining the cylinder power. Many years later projected visual acuity charts would have a rotating clock dial indicator incorporated in the slide. This allowed the optometrist to refine the axis location in a more precise manner. Nevertheless, the clock dial chart and procedure are still utilized and best suited for patients who find the cross-cylinder procedure too complicated to comprehend.

The Cross Cylinder Technique for Measuring Astigmatism

The cross cylinder technique for measuring astigmatism was first described by George Gabriel Stokes (1819-1903). The Stokes lens was a variable cylinder, and consisted of two plano-cylindrical lenses, one convex, and the other concave, of the same power and arranged so they rotated in equal and opposites directions. These lenses were situated so they crossed at right angles. Stokes, an Irish mathematician and physicist, first described this lens in a short report to the British Society for the Advancement of Science in 1849 (41). This method was also referred to as the "Swinging Cylinder". This lens was evidently ahead of its time since it never became widely known or utilized. Evidently its use was restricted to the quantitative estimates of only relatively high degrees of astigmatism. This lens formed the basis of subsequent cylindrical lens designs for estimating astigmatism. This lens and was described by Dennett as "little better than an interesting toy". Javal and Dennett, as well as other investigators, eventually culminated in the elegantly simple refinements described by Jackson (42, 43).

Jackson Popularizes the Cross Cylinder Technique

It would take almost 50 years before the cross cylinder lens technique was popularized by Edward Jackson (1856-1942). Jackson was an American ophthalmologist, who published several seminal papers between 1897 and 1920, that advocated for and described testing procedures to determine the axis and power of the cylinder necessary for correcting astigmatism (44-48). Slowly over the course of the next three to four decades of the 20th century, the cross cylinder test became the preferred subjective method for the measurement of astigmatism (49, 50). The cross cylinder technique achieved wide acceptance once it was made an integral part of the modern phoroptor.

Introduction of the Modern Phoroptor

In 1917, Henry L. De Zeng published a 68-page manual entitled *The Modern Phorometer: including the Phorometer-Trial Frame, Phoro-Optometer, and the Rotary Cross Cylinder* (51). Five years later he published a 120-page book entitled *The Phoropter* (52). De Zeng introduced the first model of the modern phoropter in 1920. In 1923 Charles Sheard published a book entitled *A Third of a Century of De Zeng Instrumentation: An Account of the Scientific and Mechanical Contributions of Henry L. De Zeng to the Domain of the Eye, Ear, Nose and Throat Diagnostic Instruments* (53).

THE EARLY FOUNDATION OF AMERICAN OPTOMETRY

The American Colonial Period to the Late 19th Century

Prior to 1783, there was no semblance of optics in the United States. All the spectacles used were prefabricated imports purchased at a general store and not at an optical shop. No glass was manufactured which was used for ophthalmic lenses and no lenses were made or ground prior to McAllister's optical establishment. McAllister's business was to have a significant influence on the future of optics, optical instruments, refraction, and the evolution of optometry in America. Since so much of the ophthalmic history from the 19th century, especially the latter half of the 19th century, originated in this shop it is important to discuss this family and the events that followed (54).

The Beginning of McAllister's

John A. McAllister, Sr.

John A. McAllister, Sr., (1753-1830) immigrated to America in April 1775 from Glasgow, Scotland. In Glasgow, he had served an apprenticeship part of the time with a turner and spinner wheel maker, and the rest of the time with a house carpenter and joiner. He arrived in New York City in July 1775 where he remained for five-years. He was employed as a journeyman with Ahasuerus Turk, a turner in wood and metals. During the first year after his arrival he formed a partnership with Andrew Wright, as a house carpenter. Interestingly, McAllister left New York for New Jersey when the British took possession of the city, but along with White was taken as a prisoner for a short period of time by the British in 1776. McAllister married Elizabeth Duncan in 1778 but she died in 1782, having given birth to two children who died in infancy (24).

On obtaining the requisite passport, he moved to Philadelphia in 1780. He was employed by a man named Kates, who was a turner and making cartridge boxes for the American army. With the end of the war, McAllister opened his own shop as a turner. His main occupation was making hickory walking sticks of all types. His first advertisement that appeared in the *Pennsylvania Packet*, was headed "Cane Shop" in Philadelphia in 1783. He also sold shoe buckles, knives, and other sundries. With no previous knowledge he turned his attention to making riding whips. It was not until 1796 or later that he was reported to have added spectacles to his inventory. Generally, it has been considered that McAllister, as early as 1783, the year he opened for business, included among his wares a "bushel basket" of prefabricated spectacles' purchased from a hardware merchant. However, a marginal note in a copy of *Optometry, the Profession* that was in the possession of the McAllister family, gave the date 1782, followed by the comment "box of spectacles was sent to McAllister in a shipment of whip material from London by mistake" (24).

Thus, it appears based on the McAllister family's note that John McAllister Sr., had received some spectacles by mistake, however, he did not enter the optical business until at least several years after opening his shop in 1783 (24). Based on the advertisement reported by Levene, it may have been as long as 13 years or more after opening his first shop (24). McAllister resided and conducted his business at 16 South Third Street from 1790 until 1796. In 1796, he established himself at 48 Chestnut Street in a house he had built two years earlier. Unquestionably, by 1799 or 1800, and perhaps even earlier, he was augmenting his business by the inclusion of spectacles. In 1798 he rented No. 50 Chestnut Street and two years later entered into partnership with James Matthews which lasted until 1803 (24). According to McAllister's obituary he had purchased 50 Chestnut Street in 1794 (24). McAllister clearly can be credited with being the first in America to have an optical shop. His influence would be felt for many years as refracting opticians slowly evolved into optometrists.

The Influence of McAllister's

Clearly by the late 1790's, whether in 1796, 1798, or 1800, McAllister had entered the optical business. He was to gradually eliminate the whips and canes and limit his business to the sale of spectacles and later other optical and scientific instruments. This is further proof of his success in the selling of optical goods. Although the partnership with Matthews did not last, significantly their advertisement stated they intended to keep a large assortment of spectacles, reading glasses, concave lenses, magnifiers, goggles, etc., and put new lenses into old spectacle frames. This signaled his serious entry into the field of optics. McAllister, Sr., was a perfectionist who, from the beginning, demanded high quality in the fabrication of lenses, spectacles, and optical instruments. This heritage of high quality optical work continued through the course of the business's existence. It had an impact on the men who trained there, and in this sense was the genesis of optometry in America, and influenced the emphasis on quality for many decades to come (24). John McAllister, Sr., may be considered the "Grandfather" of what would eventually become optometry in the United States.

Traditionally, it has been considered that McAllister supplied George Washington with glasses although there is no such proof. As Washington died in 1799 it would seem likely that he may have obtained spectacles from McAllister, Sr. According to Washington's Household Account it is known that Washington had ordered new glasses for himself and Mrs. Washington sometime between the years 1793-97. However, in this same account it is also mentioned that a William Richardson was paid for repairing glasses but there was no mention of McAllister. It is known that the famous instrument maker David Rittenhouse, who had made Washington a Surveyor's compass, also made him spectacles and a reading glass. (24). Benjamin Franklin was a friend and client of John McAllister, Sr., and is also credited with encouraging McAllister to begin his business (25). Although Franklin is usually given credit for inventing bifocal lenses he may have done more to promote their use than anyone else. As will be discussed later this family would continue to make many direct or indirect contributions to the establishment of the profession.

The Franklin Bifocal

Franklin had arrived in France in 1776 with a long established record as a diplomat and scientist. The first mention of bifocals by Franklin was during his residence near Paris in a letter describing "double spectacles" to George Whately on August 24, 1784 (54). Franklin did not actually claim to have invented bifocals but stated he was happy in their invention. In fact, he may have been wearing such spectacles since the late 1770's. When Franklin actually began to wear such lenses and who made them is not clear. It is known that H. Sykes, an English optician located in Paris, explained in a letter to Franklin dated April 24, 1779 that he had spoiled several lenses while cutting them. Thus, the reason for the delay in sending Franklin's order. Whately lost little time in drawing Franklin's invention to the attention of master optician Peter Dolland (54).

Levene devotes a significant part of a chapter to the discussion of evidence as to the inventor of bifocals. He discusses evidence, that besides Franklin, the first and second Presidents of the Royal Society, Sir Joshua Reynolds, and Benjamin West, among others, were involved in the early history of bifocals (54). There is some reference to Samuel Pierce as the man responsible for making Franklin's bifocals as early as 1760 when Franklin was 54 years old (54). However, there is no well-documented evidence establishing Pierce as the maker or inventor of bifocals.

Levene goes on the discuss Franklin as painted in portraits wearing glasses but none with a bifocal lens. He also describes the spread of the Franklin-type bifocal (55). Franklin's time in France was from 1776 to 1785.

It should be noted here that in England the first spectacle patents were awarded to Addison Smith and J. R. Richardson in 1783 and 1797 respectively. These patents were for an alternative to bifocals in which an extra pair of rimmed lenses were hinged to the spectacles from above or the side (55). (For readers interested in more detail on early lenses, frames, spectacles, spectacle collections, opticians or similar material consult the website www.antiquespectacles.com. (This comprehensive website is several hundred pages in length and is maintained by David Fleishman, M.D. Dr. Fleishman is a world authority on the history of spectacles and similar optical devices).

There certainly is evidence that Thomas Jefferson was a client of McAllister Sr. The earliest manuscript reference to the Franklin bifocal was contained in a communication from Jefferson to McAllister, Sr., dated November 12, 1806. In this letter Jefferson provides great detail regarding the fabrication and dispensing of the spectacles. It seems obvious that Jefferson had learned of the bifocal lens from Franklin since their time in France as United States ministers overlapped. Not only did Jefferson wear bifocals but such other friends and notable artists as Sir Joshua Reynolds, Benjamin West, Charles Willson Peale and his sons Rembrandt and Rubens, all wore bifocals (55). Perhaps as a result of being exposed to those worn by Franklin. President Andrew Jackson was also a customer of the McAllister's (56).

McAllister Family and Business

McAllister's business thrived as a family optical business in Philadelphia for more than 150 years. There is some confusion in the literature regarding the McAllister's. It is important to remember that John A. McAllister Sr., began the business which eventually became McAllister & Son. John McAllister, Jr., (1786-1877) was the second son of the second marriage of John Sr., to Frances Wardale Lieber, a cousin of Captain Cook. John Sr., married Mrs. Lieber in 1783 and they had three children. She died in 1814 at the age of 68. John Sr., did marry a third time in 1816 to Elizabeth Douglas but they did not have children (24).

John McAllister, Jr.

John McAllister, Jr., (1786-1877) entered the University of Pennsylvania in 1880 at age 14 and graduated in 1803 at 17 years of age. Such an early age of graduation was not unusual for this time period. He joined a counting firm in 1804 and stayed there for three years after which he joined his father's firm in 1807. In 1811 he became a partner in the firm John McAllister & Son. John McAllister Jr., married Eliza Melville Young in 1811 the daughter of William Young, a noted bookseller, printer and publisher. They had 10 children; of whom four sons and two daughters lived into adulthood. With the onset of the War of 1812, the importing of glass from England ceased. McAllister's began to make gold and silver spectacle frames using glass imported from Europe (24).

Following the death of John Sr., in 1830, the business was carried on by John Jr., Walter B. Dick and James W. Queen under the name of John McAllister, Jr., & Co. John Jr., was also a well-known local antiquary in Philadelphia and amassed an important library, including a valuable collection of ancient pamphlets, newspapers, maps, and manuscripts. Not surprisingly he was a member of the Library Committee of the Historical Society of Philadelphia.

McAllister's connections with the administration of Wills Eye Hospital were close. In view of the physician's dislike for refraction, considering the work somewhat below their dignity, or at the time not truly within their scope, it is not unreasonable to suppose that many cases were referred to McAllister for spectacles, by the eye physicians and ophthalmic surgeons. In fact, it is probable that in the early years of the life of the Hospital that all patients needing glasses were sent to McAllister for them, the surgeons relying on him to test the eyes of the patients as well as to grind the lenses (24). It is also known that Isaac Hays, the eminent physician on the surgical staff of the Wills Eye Hospital and recognized as the first ophthalmologist in the United States to correct for astigmatism, consulted with McAllister about the correction of his first case (24).

McAllister and the Legalization of Optometry in Pennsylvania

In total the McAllister family was in business, most of that time being in some manner related to spectacles or optical goods, for 173 years. Over one hundred and thirty years after the founding of the firm, the McAllister's were still influencing optometry in a profound manner. In an effort to subjugate the profession of optometry, the Medical Board of the State of Pennsylvania, had decided that optometry was a minor branch of medicine in accordance with the 1913 amendment to the Medical Act of 1911. It was John McAllister, Jr., who was credited in testimony, by his grandson, as being the first person in the State of Pennsylvania to measure the first pair of eyes for glasses and fit them. Among John Jr's., 10 children the oldest was William Young McAllister (1812-1896). He in turn had nine children and it was James Cook McAllister (1856-1928) who testified in this case in 1913.

The grandson, James Cook McAllister, remembered his grandfather, John McAllister, Jr., as being the first man in Pennsylvania to measure the first pair of eyes (perform a refraction) for glasses and fit them. The following testimony by John Cook McAllister proved to be critical in convincing the Court that the action taken by the Medical Board was unconstitutional insofar as it applied to optometry (57, 58). This case served as the legal basis for establishing optometry as a separate profession. In Prentice's opinion, the optometrist, or his predecessors, was the only eye refractionist known in the world and always had been since the invention of spectacles, a period of more than 500 hundred years (58). In the early days of optometry's becoming an independent profession, a great deal of emphasis was placed on precedence in the field about the group of "sight testing opticians".

Testimony of James Cook McAllister

James Cook McAllister provided the most famous defense of optometry's position on the basis of precedence in testimony before the Pennsylvania Court of Common Pleas. McAllister's testimony, presented in 1913, is as was reported by Albert Fitch (57). Fitch served as the first President of the Pennsylvania State College of Optometry. His tenure in this position was for 33 years (57). James Cook McAllister's testimony is as follows:

Question: What is your profession?

Answer: Optician

Q. How long have you been engaged in that profession?

A. Forty-three years.

Q. You are of the house of McAllister that has been an optician house since some time in 1700?

A. Yes.

Q. Do you happen to know who was the first man that measured the first pair of eyes in Pennsylvania for glasses and fitted them?

A. My grandfather, John McAllister, Jr.

Q. Do you happen to know the first man who taught the oculists in Philadelphia how to measure eyes?

A. My father, William Young McAllister, and James W. Queen.

Q. That is to your personal knowledge, you were in the store at that time?

A. Yes.

Q. Who were the first oculists to your knowledge in Philadelphia?

A. Peter Keyser, George Strawbridge, Richard Levis.

Q. After they had acquired their degree of Doctor of Medicine, to who did they go to learn refracting?

A. They got their knowledge of lenses and the use of the test case from my father principally, and other members went to James W, Queen. Those three men came to my father.

Q. Then the profession of oculist came in as a separate profession, or as a specialty in medical work, about when to your personal knowledge?

A. In the 70"s, early 80's.

Q. And the work of what is called the optometrists was done up to that time entirely by whom?

A. By the opticians.

On October 10, 1914, President Judge Robert N. Willson of the First Judicial District of Pennsylvania, in Common Pleas Court No. 4, of the County of Philadelphia, handed down a decision in favor of the optometrists opposing the Medical Board. The court's decision upheld the contention of the optometrists that they had historically performed "sight testing" and were entitled to continue to do so. The lower court issued a permanent injunction against the Medical Board declaring the Amendment to the Medical Act Unconstitutional insofar as it applied to optometry. Not surprisingly, the Medical Board and the Attorney General of Pennsylvania appealed the decision to the Supreme Court of Pennsylvania. The Supreme Court handed down a decision upholding the decision of the lower court in the early part of 1915 (57). This decision by the Pennsylvania Supreme Court was referred to as optometry's "Magna Carta". By 1913, 30 states had passed optometry practice acts, and by 1915, 35 had done so.

Sources Describing the Early History

Clinical Refraction and Visual Science

Somewhat surprisingly there are several sources that provide significant insight into the evolution of the profession, first in Europe, and later in the United States. The majority of this history is from the 18th through the 20th centuries, especially during the last half of the 19th century and first half of the 20th century. (59-64). Many of these sources are specifically referenced in this chapter. Each of these books brings a unique perspective to the history of the profession. Levene's book deserves a special mention because, in spite of its title, it is primarily a book describing the history of visual science, the early history of research related to refractive errors and ophthalmic instrumentation, and topics related to clinical optometry during the 17th, 18th and 19th centuries (64). Levene's primary interest was in the history of early ophthalmic discoveries and those responsible for such discoveries. In addition to his diploma in optometry he received a M.Sc. and Ph. D. degrees from Oxford University as a Medical Research Council Scholar.

Autobiography of Charles F. Prentice

Of particular note, is the memoir and history written by Charles Prentice that provides an overview of the state of vision care in Colonial America, as well as care provided into the 19th century and early part of the 20th century (65, 66). A condensed version of Prentice's book is provided as an appendix in Chapter 2 of this book.

THE MEDICAL ATTITUDE TOWARDS PRESCRIBING FOR REFRACTICE ERRORS

Medical Attitude Regarding the Prescribing of Spectacles

As early as the 14th century physicians had discouraged the use of spectacles to address visual complaints. The traditional medical approach to eye care was to use eye lotions, eyewashes, or salves (medications) to treat ocular symptoms. It was obvious that progress during the first half of the 19th century placed more responsibility on dispensing opticians rather than the few refracting opticians extant. Physicians trained specifically in eye care were almost nonexistent in America during this time period. Of those physicians that did provide eye care most did not believe in prescribing glasses for relief of visual complaints.

Frederick Ritter von Arlt was born in 1812, the son of a Bohemian blacksmith. von Arlt (1812-1887) encouraged his physician colleagues to learn to fit spectacles. Von Arlt studied ophthalmology at the University of Praque, was a professor there for 10 years (1846-1856) then became a professor at the University of Vienna until his retirement in 1883. He encouraged his physician colleagues to learn to fit spectacles. His plea, however, was largely ignored over the course of the next 50 to 60 years. Von Arlt cautioned against leaving so important a matter in the hands of the optician (67). Von Arlt's pleas were taken up by Woods in 1918, some 72 years later (68). However, by and large this advice was ignored by the medical community. Woods warned that sooner or later the large number of the public seeking vision care from the refracting optician (optometrist) would result in optometry's legal recognition. The reasons for the resistance of physicians to refraction were several and included such reasons as: 1). the tradition of deprecating spectacles and their use was prevalent in medicine, 2). Some ophthalmologists, engrossed with new discoveries in the treatment of eye disease and surgery felt that vision work was not what they wished to do, and 3). The skills and attributes that led an individual to study medicine were not those related to clinical optics. This third reason may be the most important since it is clear there is now a difference in those wishing to diagnosis and treat eye and vision problems and those primarily interested in surgery (68).

Duke-Elder also noted that well into the 19th century oculists universally discouraged the use of spectacles. Even suggesting that patients visit an optician's shop to try a series of spectacles (69). Even as recently as 1932 Crisp doubted whether the cross-cylinder test was really familiar to more than five percent of ophthalmic surgeons in the United States, less than this percent in Great Britain, and negligible to ophthalmologists on the Continent (70). This attitude on the part of medicine over a 500 to 600-year span of time played a significant role in the development of the profession of optometry outside of the realm of the medical profession. Although some oculists did prescribe spectacles, many did not, and this vacuum in services in an expanding and increasingly literate United States population, gave rise to what would eventually become the profession of optometry. That optometry would come into existence is all the more remarkable considering the seminal work of Donders and others in contributing to the understanding of the nature of refractive errors and spectacle correction to relieve symptoms related to such conditions (69).

The Profession of Ophthalmology

Ophthalmology was among the earlier specialties in medicine to be established. It enjoys a long and rich history as regards the establishment of academic programs and eye hospitals. It is not the purpose of this chapter to explore this history but only mention some of its very early aspects. In 1773, Joseph Barth was appointed professor of anatomy and eye disease at the Vienna Medical School. One of his students was Georg Joseph Beer, who was employed by Barth, while still a medical student. In spite of Barth refusing to give Beer any surgical training, Beer taught himself how to perform cataract surgery and other surgical procedures. Appointed professor in 1786, Beer was the first to establish ophthalmology as an independent scientific specialty. In 1812, he founded the world's first university eye clinic at the Vienna General Hospital and chaired it until 1819. The Vienna Eye Clinic achieved a considerable international reputation for both scientific research and education. It was often referred to as the Vienna School of Ophthalmology (71).

Karl Himley was reputedly the first to teach ophthalmology as a separate discipline in 1803, at Gottingen University Medical Clinic in Germany (72). However, J. M. Langenbeck had studied ophthalmology under Joseph Beer in Vienna before moving to Gottingen in 1802. He was to become the first surgeon at the Academic Hospital. In 1807, Langenbeck founded the Clinical Institute for Surgery and Ophthalmology in Gottingen (72). This specialty would take several decades to fully develop as a specialty recognized by the field of medicine. Ophthalmology was not recognized as a specialty until approximately 50 years later. Over the next several decades a number of hospitals dedicated to the treatment of eye diseases would emerge in Great Britain and America. The existence of these institutions preceded the appearance of the practicing ophthalmologist (72). These hospitals provided centers where the care and teaching of the diagnosis and treatment of eye diseases could be cultivated, and the value of this special field of medical practice be demonstrated to the medical profession (72). It was to these early programs and institutions that other European and American's interested in this young specialty would come for further education and training.

The Establishment of Eye Hospitals

The first eye hospital in the world was founded by John Cunningham Saunders in London in October 1804. The original dispensary for Curing Diseases of the Eye and Ear opened on March 25, 1805. The hospital moved in 1822 to a purpose-built building in Lower Moorfields and was renamed the London Ophthalmic Infirmary. In 1816, army surgeon George James Guthrie founded the Royal Westminster Hospital in Mayfair and, in 1843, a third London eye hospital, the central London Ophthalmic Hospital was founded in Bloomsbury. In 1837 Queen Victoria gave the Lower Moorfields its Royal Charter and it was renamed the Royal London Ophthalmic Hospital, although everyone continued to call it Moorfields (73).

In the United States James Wills, Jr., was instrumental in the founding of Wills Eye through his bequest of $116,000 in 1832 to the City of Philadelphia. These funds were to be used specifically for the indigent, blind, and lame. Over the years it evolved into an eye hospital. The first Wills Eye Hospital open in 1837 near Logan Circle. Its faculty included several distinguished eye surgeons and in 1837 *A Manual of Diseases of the Eye* was published. It was written by Drs. Goerge Fox and Squire Littell. The Centennial Building of Wills Eye Hospital is six stories and was built in 1931-1932. Wills is managed by a tripartite organization consisting of the Board of Directors of City Trusts, the Wills Eye administration, and the medical staff. This hospital remains among the best eye hospitals in the world (74).

The Development of Organized Ophthalmology

While the factors and conditions that made possible the development of ophthalmology may be traced to the early decades of the 19th century, the fully developed specialty of ophthalmology did not make its appearance in America until after 1850. In June 1864 the American Ophthalmological Society was organized in New York. The organization of this society may be regarded as marking the appearance of ophthalmology as a formal specialty in America. During this time period, physicians interested in ophthalmology either trained at one of the eye hospitals in America or went abroad, usually to Europe, to study under one of the experts in ophthalmology (72). The American Academy of Ophthalmology and Otolaryngology was founded in 1896. In 1979 this organization split into separate academies for each specialty (75).

In 1914 certain committees from ophthalmology societies and academies recommended medical schools of the first class establish graduate courses in ophthalmology leading to an appropriate degree. Furthermore, these courses should not represent less than two years of systematic work subsequent to the taking of the medical degree (72). This recommendation failed to attract sufficient residents and also did not differentiate the competent from the incompetent in the practice of ophthalmology.

In 1916 the American Board of Ophthalmic Examiners was organized and it was incorporated on May 3, 1917. The name of this Board was later changed to the American Board of Ophthalmology. By June 1, 1939 nearly 1,600 ophthalmologists had received the certificate of the Board. In December 1941 there were only 180 residency positions available for those medical graduates wishing to enter the field. By 1945 the Council on Medical Education and Hospitals of the American Medical Association listed 56 ophthalmology residency programs and 43 ophthalmologic-otolaryngologic residency programs. It was not unusual, especially in the small to mid-size cities, during this time period (1920-1960) to encounter an EENT specialist, if there was a specialist at all (72).

Underlying the time period of the first two decades was the feeling by oculists and ophthalmologists that because the eye was part of the human body, the practice of ocular refraction fell within their area of expertise. Obviously the optometrists felt otherwise, but were much less educated or organized at this time. Despite the growing number of non-medical and medical "vision care" providers, many rural and urban Americans continued to test their own vision by ordering test kits, trying on spectacles selected from a general store or pharmacy display cases, or from the spectacle peddler's case, until they found the spectacles that gave them the best vision.

THE EMERGENCE OF THE PROFESSION OF OPTOMETRY

From the time period of the mid-1700's to the late 1900's vision care evolved slowly as did the system of delivery of eye care services. During the 18th century all spectacles were made in England and their manufacture and fabrication was strictly regulated by the Guild. The spectacles that were manufactured were either for presbyopia, or less frequently myopia, and the lens power was of equal amount. By the mid-19th century, especially in the latter part of the century, it was gradually becoming apparent that prefabricated lenses could not satisfy all visual complaints. Such conditions as astigmatism and its optical correction with cylindrical lenses, hyperopia, different amounts of ametropia in each eye (anisometropia), and bifocals had become more widely understood, appreciated, and encountered more frequently by those delivering sight or vision testing (76).

Nevertheless, the optical trade and later the profession of optometry, had its informal beginning with the establishment of the John McAllister & Son optical business. Not only were the McAllister's involved, but later on James McQueen established the Queen Optical Company. Since there was no school of optics at this time the only way to learn the trade was by performing an apprenticeship of some type. Most of the leaders in the optical business were interconnected having trained at either the McAllister or Queen firms. A few others learned at other firms, or they came to America with training obtained in England or on the Continent. Some optical businesses moved to the Midwest and by the late 1800's optical businesses had begun in the Far West. These men formed the early nucleus of what would eventually become the profession of optometry. Among the more prominent names of the very early leaders were Charles Spencer, Robert Tolles, Joseph Zentmayer, John and Peter Dollond, J. M. Johnson, John McAllister, Sr., & Jr., James Prentice, and James Queen (37, 67, 77).

The Formation of the Forerunners of Optometry

One of the early immigrants who came from England, where he had learned the optical trade, was Benjamin Pike. He opened a shop in New York around 1831, and trained his son Benjamin Jr., who also had a shop in New York, which opened in 1839. Clearly fitting of some sort was going on since his advertisement proclaimed "Spectacles, eye-glasses and lenses for optical purposes of every description". The Pike's furnished glasses or pebbles (lenses made from crystals) that were truly ground and fitted to the eye. They also trained other men who rose to prominence in the field (78).

James Prentice came to America from England in 1847. Having apprenticed in London, he opened an optical shop in New York as well as manufactured optical instruments. James gained wide fame for his work in manufacturing, but finally confined his activities to refracting, and inventing and patented the "anatomical eye glass", as well as improving frames and mountings (76). However, it was his son Charles who helped lead the fight for the legalization of the profession of optometry. It was in the 19th century that much of the history of refraction, and therefore optometry, was unfolding in America. In fact, although small in numbers, it was the refracting opticians who seemed better organized in America to protect themselves from what they considered to be an encroachment by the medical profession in taking over refraction (79).

It is a remarkable fact that man held glasses in such low regard since his very well-being, in many cases, depended on them. The nature of this attitude may lie in the fact there was not any system of well-developed eye care. Consider that refraction was rudimentary at best and almost all eye/vision care existed in the urban areas. Even if eye care had existed there was no place to order lenses except from Europe and then it would require several months to receive them. The first lenses to reach America were mostly prefabricated convex lenses and to a much lesser extent concave lenses. This explains why the first practicing refractionists were lens-makers. There were no prescription laboratories and when sight testing did begin the lenses were ordered or later fabricated by the person who did the testing (67, 76, 77).

The Development of Optical Laboratories

A critical aspect of the development of optometry was that in the beginning the sheer necessity of the marketplace demanded that spectacle merchants and lens-makers were the primary source of spectacles. It would have been unwise to open a prescription lens laboratory until there were individuals who possessed the knowledge to perform some form of examination or "testing" for vision and fill the lens prescriptions (77, 78).

The Forerunner of American Optical

Related to the development of optometry in America was the large scale production of frames and ophthalmic lenses by several wholesale optical firms. In about 1833 William Beecher started the manufacture of frames as a sideline to his jewelry business in Southbridge, Massachusetts. It seems likely Beecher placed lenses in the frames and sold them to the public or other optical outlets. He manufactured excellent frames, the first ones of silver and later of steel (1843) followed by gold (1848). Within six years he had to move to larger quarters and employ more people. By 1852 the factory was producing 15,000 frames per year. In 1862 William Beecher retired and Robert Cole became the president. The firm was reorganized in 1869 and became the American Optical Company (78, 80). The lens company continued in business until it was sold in 1965 and again in 1982 and moved its operation to Mexico. American Optical also purchased companies that manufactured microscopes and other instruments based on the work of Charles Spencer and later Robert Tolles. This became the AO Scientific Instrument Division.

Bausch & Lomb

Unable to find optical work in Buffalo, New York In 1850, John Jacob Bausch moved to Rochester, New York in 1853 and opened a retail optical shop. He was also an "optometrist" of his day, selling spectacles to the public. In addition to spectacles he also sold microscopes, telescopes, magnifiers, and other optical products manufactured in Germany. Bausch also conducted a workshop and laboratory and began manufacturing his own optical products. His partner in this business was Henry Lomb. Lomb had joined Bausch at some point in the early years of the business. Their business card stated "Glasses carefully adapted to the Eye". What the adaptation process consisted of is unknown but there was, at the least, some trial and error on the part of the seller. This card implied some testing and fitting was occurring. Bausch had learned to grind lenses and make horn spectacles from his brother in Germany. Lomb had originally loaned Bausch $60 after his first effort at owning an optical shop continued to struggle. Lomb entered the Union Army during the Civil War, and his pay was contributed to keeping the struggling business going. The Civil War had a fortunate effect in that it reduced the supply of European optical goods. By 1861, the partners had begun making sales to other optical outlets. In 1866 the partners rented a factory and were manufacturing optical goods to distribute to other opticians. At some point in time Lomb had learned edge grinding and fitting lenses in frames.

In 1866 a sales office was also opened in New York City. At about this same time, Bausch found that rubber made a good optical frame. By 1864 the rubber frames had done so well they sold the business to E. E. Bausch, John's brother, and Thomas Dransfield. This business moved to larger quarters and added more staff. They affiliated with a rubber company and for a short time became the Vulcanite Optical Instrument Company. Within a few years, the name was changed to the Bausch & Lomb Optical Company. In 1878 B & L entered the general ophthalmic lens market, in 1883 the photographic lens market, by 1896 meniscus lenses, and 1897 toric (cylindrical) lenses. Until 1890 lens and frames were not sold separately but as assembled units (78). Bausch & Lomb went on to produce a large variety of lenses for all types of optical and surgical instruments.

Shuron Optical Company

A third optical company was started in this same city in 1864. Edward Kirstein founded what eventually became known as the Shuron Optical Company later located at Geneva, New York. Kirstein was a typical "optometrist" of his day. He began selling spectacles of steel and silver rims with small elliptical lenses from his home. He later traveled the eastern part of the U. S. In 1962 this company merge with Continental Optical Company and continued business as Shuron Optical (78).

Manufacture of Bifocal Lenses

The Franklin type bifocal has been discussed earlier in this paper. Adjustable types of bifocals were available during the early 19th century in which a small lens with added power for near could be swung into position for reading. These lenses never gain much popularity. It was not until 1837 that Isaac Schnaitmann invented the solid upcurve bifocal in which a circular portion of the top part of the distance lens was ground down the appropriate amount. This one-piece lens design suffered from too small a distance field and bad prismatic effects. In 1866 Samuel Gregg originated the cemented bifocal in which a piece of convex lens was cemented to the bottom portion of the distance lens. Three men are known for this type of lens, besides Gregg; George W. Wells and August Morck all invented this style of lens. However, it was Morck who was granted the patent in 1888 (36, 81).

John L. Borsch began to make Kryptok lenses in Philadephia in 1870. In 1885, a series of toric lenses were produced by Borsch for display at the American Ophthalmological Society. Borsch invented the cemented bifocal in 1899. This was the first time that two different kinds of glass were used in the same lens (82). In this lens Borsch made a reading glass which had a higher index of refraction than the crown glass used for the distance lens. He ground out the countersink space in the lower portion of the distance lens in which the reading segment fitted. It was held in placed by a cover glass cemented over the entire lens. Although there were problems in grinding and polishing the surfaces, and with the cement, it led to the development of the fused bifocal. In 1908 Borsch invented the fused Kryptok bifocal which served as the forerunner for the many types of fused bifocal lenses used throughout the 20th century and into contemporary times (82).

Trifocal Lenses

In 1826, John Isaac Hawkins in England, invented trifocal spectacles. Hawkins was by inclination a civil engineer but his range of interests was broad to say the least. He left England at an early age for America to enter college at Jersey, Pennsylvania. His original interest was the field of medicine but he left school to pursue other interests. Among his inventions or other contributions were water purification, city planning, waterproofing clothes worn by firemen, distillation of liquors, manufacturing pianos, the polygraph, a machine for tracing silhouette outlines, the importance of interpupillary distance and the P. D. Gauge, and the trifocal lens. Hawkins and his wife moved to London in 1803 and lived there for some 45 years. Hawkins had presented Jefferson a portable polygraph in 1805. Furthermore, Hawkins befriended Raphaelle Peale by allowing him to use the silhouette machine without cost. Hawkins was also a friend of Charles Willson Peale and his sons Rubens and Rembrandt (84).

Progressive Addition Lenses

The progressive lens, has over the course of 60 years or more, come to dominate the optical market. In 1959, the optical engineer Bernard Maitenaz discussed the optical design characteristics of the progressive addition lens (PAL). This lens was given the name Varilux by its manufacturer Essilor. This lens was not reported on or introduced in the United States until 1965 at the American Academy of Optometry meeting. The Volk Omnifocal Lens was patented in the United States in the late 1950's. Subsequent improvements in the Varilux PAL continue to this day (85).

Aside from the national optical laboratories there emerged many local or regional optical laboratories that provided frames and lenses, primarily for opticians and optometrists, throughout much of the 20th century. The growth and skill of both the opticians/optometrists and the optical companies in America made possible the production of vision testing devices by the major optical firms. As early as the 1870's the refracting opticians had begun teaching medical practitioners refraction (57). Interest in refraction increased significantly in the period from 1890 to 1900. By this period many of the early manufacturers had set up training courses for refractionists, medical and non-medical, in the interest of their own sales (83).

The Emergence of the Refracting Optician

In the large cities there began to emerge a group of opticians who were performing sight testing or rudimentary refractions. As a matter of pure necessity this group of refracting opticians were lens-makers as well. This laid the foundation for optometry to provide complete vision care in one location. This relatively small group had evolved slowly over the prior two decades or so. Prior to this time all lenses were pre-fabricated, of the same power, and ordered from Europe (67).

In America, refraction and dispensing had been the exclusive domain of opticianry until approximately 1865. With the publication of Donders book in 1864 some physicians became increasingly interested in refraction and were taught the skill by American refracting opticians. At about this same time – the mid- and late-nineteenth century - medical practice acts began to be enacted by several states. These laws were written in such a way as to be all-inclusive, granting to physicians a monopoly over the entire field of health care. Despite the presence of these laws, by the end of the 1870's a tripartite eye care system had evolved: eye physicians (oculists or ophthalmologists), refracting opticians, and dispensing opticians.

As a point of clarification oculists were physicians who had been granted a license to practice medicine and thereafter limited, or primarily limited, their practice to the eye. They had received little, if any, formal training such as a residency in their area of specialty. They may, however, have studied under a more experienced practitioner or taken a short course in refraction. To further confuse matters there were a number of general practitioners who also performed refractions but did not term themselves oculists. Likewise, they usually had received no additional training.

In addition, many of the optical schools or colleges, of which most were proprietary, taught short two-week or four-week classroom or six-week correspondence courses and may have included students such as jewelers, watchmakers, or pharmacists. Before passage of optometry practice acts some programs would confer a "Doctor of Optics" degree on such students. All of this created an environment that complicated any understanding by the public but continued unabated as America grew in population and size, in terms of the number of small towns and communities. In the less populated towns and rural areas the demand for glasses outstripped the service in providing them. This gave rise to the spectacle peddler who flourished in America into the early 20th century (68, 77).

James Prentice came to America from England in 1847 and began an optical shop in New York where he manufactured optical instruments as well. In addition to John McAllister Jr., there were others such as Daniel Widdefield in Boston and Charles Lemke in New York who followed this same model. These men led the way in America in the adapting of cylindrical lenses for the correction of astigmatism. Charles Prentice, the son of James, stated that 1865 was the year that marked the beginning of a profession truly devoted to vision care (28). However, opticianry (optometry) was also practiced in better jewelry stores of the day where the watchmaker was also the spectacle maker. Instruction in these two trades was offered in the same school in the form of a short or restricted curriculum (76).

Some optical businesses moved to the Midwest and by the late 1800's optical businesses had begun in the far West. These men formed the nucleus of what would eventually become the profession of optometry. Among the more prominent names were the McAllister's, James W. Queen, Charles Lemke, and James Prentice. During the latter part of the 19th century and the first two decades of the 20th century many others would serve to move the refracting optician to that of a legalized profession. Central to this metamorphosis of moving from refracting optician to optometrist was Charles Prentice, son of James (56, 58, 65).

THE DEVELOPMENT OF OPTOMETRIC EDUCATION IN AMERICA

Although the McAllister family was the first family of the optical business in Colonial America, it is John McAllister, Jr., and James Queen, especially the latter, who gets the credit for training the first generation of several families that contributed greatly to the eventual development of the profession of optometry. Queen's influence on optometry continued into the 20th century. Among men trained by Queen were: Drs. John W. Jarvis, Harry Pine Sr., William W. Russell, Henry Kaiser, and William G. Walton. All of these families, even the second and third generations, made substantial contributions to organized optometry as well as private practice (75). It was during the period of the 1850's to the 1890's that much overlap in education existed. This era is unique in the sense that America never established a guild tradition like England and other countries of Europe. Education was on a private, individual basis and the free enterprise system prevalent in America. The open frontier made it possible for anyone to start their own business as soon as he felt he possessed sufficient training (77).

An important factor that also contributed to the demand for an increase in spectacles was the invention on October 21, 1879 of the incandescent light bulb by Edison. As with the invention of spectacles in the 13th century, the printing press in 1440, the invention of the light bulb increased the time available for reading. All of these technological inventions increased the need for the use of spectacles (86).

The Transformation of Medical Education in America

The same pattern had taken place in medicine regarding its education several decades before that of optometry. During much of the 19th century a number of proprietary medical programs had widely differing standards of admission and curriculum. In 1876, the Association of American Medical Colleges consisted of only 22 medical schools out of nearly 150 schools then in existence. Realizing it had problems, after a period of inactivity, the association was reorganized in 1891. It set minimum requirements for admission to membership and soon had 55 schools which qualified. Lacking organizational control of its members at this time, it became necessary to pass legislation controlling licensure requirements. By 1895, nearly every state had a state board of examiners in medicine. This was the same procedure optometry was to follow some 25 years later. In 1904, the American Medical Association established the

Council on Medical Education and Hospitals. By this time there some 160 medical schools of all kinds in existence. The problem of setting accreditation standards was a serious one.

To address this matter of bring organization to the medical curriculum, The Carnegie Foundation for the Advancement of Teaching surveyed the field of medical education in the United States and Canada. The Foundation's report was prepared by Abraham Flexner and published in 1910. Realizing its weakness in education, organized medicine adopted the Flexner Report. As a result of the recommendations contained in the Flexner Report many of the weaker schools were unable to continue. The Flexner Report helped change the face of health education in America (86). It is interesting to note that Fitch mentioned the *high school graduation requirement for entrance into medical school* was not made compulsory by law in Pennsylvania until 1906 (57).

It is important to note that enormous amounts of public resources from federal, state, and local entities have been utilized to fund all levels of medical education as well as medical clinics and hospitals. Much of optometry's funding, especially in its early years, was derived from private sources, usually the optometrists. It was not until the Health Professions Educational Assistance Act passed in the 1960's that optometry received any substantial federal funds.

The Beginning of Optometric Education

During the time period of the 19th century there were no legal restrictions or licensing requirements for a field such as opticianry. The first optometric "schools" were merely an extension of the individual instruction process. There were individual optometrists who developed a reputation for teaching optics and related topics. Some of these individuals began schools or colleges of optics. The schools or programs often took on the name of their founders who were in some situations also offered by companies manufacturing optical equipment. These courses were either one or two weeks to as long as six months in duration depending on the time period and nature of the program. The number of proprietary programs in "refracting" varied widely over this period of time and well into the 20th century (83).

Hofstetter provided a summary of data on the evolution of optometric education in the U. S from 1872 to 1946. From 1872 to 1901 there were 60 schools, none had any admission requirements, and were four to eight weeks in duration. By 1901 through 1914 the number of schools had decreased to 42, with no admission requirements, and were three to six months in length. In 1914 until 1922 the number was 36 schools, with admission requirements of an equivalent to admission to a high school education, and the length of the optometry program was one year. From 1922 to 1926 the number had fallen to 30 schools, with admission requirements of completion of two years of high school or the equivalent, and the length of the optometry curriculum was two years. By 1926 through 1936 there were only 10 schools, with a requirement of graduation from high school or the equivalent, and the optometry curriculum was three years in length. In 1936 to 1946 the number of schools was only 8, admissions requirements of graduation from an accredited four-year high school, and a program length of four years. By 1946 there were 10 schools with the same admission requirements but some pre-optometry/optometry curriculums were now five years in length (72).

A nice review of the early optometry programs or schools as well as those in existence through 2012 has been provided by Goss (88). Much of the early information has been taken from the *Blue Book of Optometry* for the years included in this survey. It also includes present day optometric institutions through 2012. Interestingly, Goss also has provided a list of reputable optical colleges taken from an 1899 issue of Optical Journal (89). The 1914 *Blue Book of Optometry* listed 27 schools or colleges of optometry in the United States (90).

The First College of Optometry

There was one interesting development in the 1870's in the training process for ocular refraction. At this time medicine was using approximately the same type of training in optics for its members as were the refracting opticians. It was only natural that at some point the two would merge. In 1872, Dr. Henry Olin established the Chicago College of Ophthalmology and Otology to tutor medical students and professionals in post-graduate eye and ear care as well as refraction. By 1878 Olin's college outgrew its Madison Street space and moved to more spacious classrooms on State Street (91).

In 1887, Dr. Olin invited Dr. J. B. McFatrich to become a partner in his enterprise. Dr. Olin, for reasons related to his health, retired in 1889 and Dr. McFatrich assumed control of both the practice and school's management. Following Dr. Olin's death in 1891, Dr. McFatrich assumed complete control and changed the name to the Northern Illinois College of Ophthalmology and Otology. It also relocated to the Masonic Temple Building at the corner of State and Randolph Streets. Dr. George W. McFatrich completed his medical studies in 1892 and 18 months later was appointed to be the Cook County Hospital's attending surgeon and oculist. In 1893 George joined the staff of the NICOO. In1896 George joined James and incorporated the school along with their sister Mary as its sole stockholders and corporate officers. The McFatrich brothers also established another enterprise in 1897; the Murine Eye Remedy Company. As a result of its success James, who had invented the remedy, spent most of his time with his medical practice and managing the Murine Eye Remedy Company (91).

James McFatrich in particular had deplored the lack of optical education especially as related to the science of optics. He also realized that the opticians were as legally liable as the physician. At this same time the public was gradually beginning to demand better quality health care but still failed to realize the value of good eye care (91)

Until this time the school's enrollment was limited to physicians. In 1898 George McFatrich amended the school's charter to include the admission of non-medical candidates who possessed some practical experience and knowledge and discontinued the otology courses. The majority of the non-medical candidates were jewelers, refracting opticians, and dispensing opticians. Prior to this time there were not many institutions that accepted non-medical students. Among these were the Spencer Optical Institute in New York City and the King

Optical Company in Cleveland, Ohio. However, an 1899 issue of Optical Journal provided a "Directory of Reputable Optical Colleges". This directory provided a list of 17 colleges, institutes, or individuals who provided some form of education.

At the beginning of the 20th century the term optometry had not yet become common and its practice was referred to as "optics". Optometry schools had attendance or correspondence options and the requirements and length of study varied from school to school. There was one program listed in Toronto, Canada and undoubtedly the list provided in the directory was not complete. The background of these students varied and included physicians, jewelers, watchmakers, pharmacists, opticians and others. However, after opening enrollment to non-medical individuals most of the students were jewelers, dispensing opticians, and refracting opticians (89).

William Bray Needles, growing up in Sedalia, Missouri, worked in a small jewelry shop that sold spectacles. In 1899, he attended classes at Chicago's McCormick Optical College. After graduation he opened an optometric practice in Kansas City Missouri. Troubled by his colleagues' lack of professional knowledge Needles turned his attention toward optometric education. He began by conducting a series of evening classes and then accepted a position at the Kansas City School of Optometry. His classes were so successful, that in 1907, he founded his own school known as the Needles Institute of Optometry (92).

The Needles Institute of Optometry

In 1922 Dr. William B. Needles purchased NICOO's outstanding stock and assumed its presidency. In 1926, the two schools, Needles Institute of Optometry and NICOO officially merged and Needles changed the name to Northern Illinois college of Optometry (NICO). In 1936 Dr. Rueben Seid opened the Midwestern College of Optometry in Chicago and a year later renamed it the Monroe College of Optometry. As a result of difficulty in obtaining accreditation Monroe College of Optometry changed its name to the Chicago College of Optometry in 1949 with Dr. Hyman Wodis as its associate dean. Finally, low projected student enrollment in the early 1950's prompted a merger of the Northern Illinois College of Optometry and the Chicago College of Optometry. Both programs ceased operation on June 9, 1955 and opened their doors the next day as the Illinois College of Optometry with Dr. Eugene Strawn as its first President (92).

Thus, the Illinois College of Optometry has a history dating back to 1872, when its original predecessor opened as the Chicago College of Ophthalmology and Otology. In 1891 on McFatrich's assumption of control the institutions name was changed to the Northern Illinois College of Ophthalmology and Ototogy (NICOO). Admission to this program remained limited to physicians only although its primary mission was the teaching of refraction. In 1898 when non-medical candidates were admitted to the Northern Illinois College of Ophthalmology and Otology, the word Otology was retained in the title but the courses pertaining to otology were dropped from its curriculum. By 1908 NICOO was one of 42 independent optometry schools nation-wide offering students a six-month program guaranteed to prepare them to take state licensing examinations. Although the first year non-medical candidates were admitted to NICOO was 1898, the Illinois College of Optometry, by virtue of its predecessor institutions, is the oldest optometry institution in America. The first university affiliated optometry program was begun at Columbia University in 1910 (91, 92). It was decided to close the Columbia University program in 1950 and the last class graduated in 1954.

SUMMARY

This chapter serves as an introduction to the events that led to the discovery of glass, its centers of manufacture, defects of vision, or as they are properly referred to as refractive errors, the discovery of spectacles, types of vision/eye care, and education related to vision/eye care. This is followed by the efforts made to understand and correct refractive errors, literature related to these topics, and the evolution of some men in opticianry who wanted to assume greater responsibility regarding vision/eye care and began the journey towards the legalization of the profession of optometry. While the material in this chapter discusses events that occurred over a 900-year time period, the real journey began with the introduction of spectacles and the subsequent story of the correction of vision.

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August 1, 2015

September 11, 2017, reviewed and revised

June 9, 2018 reviewed and revised

August 28, 2018, reviewed and revised

APPENDIX I

A BRIEF HISTORY OF THE DEVELOPMENT OF OPHTHALMIC INSTRUMENTS, CHARTS, AND PROCEDURES

The evolution of contemporary vision/eye care would not be possible without the development of instrumentation that greatly facilitated eye examinations. Many of these instruments had their beginnings when the light source was the candle. With the introduction of electricity, it became possible to provide brighter light sources and more critical assessment of the eye. The battery helped free the instrument from a cord. The most recent advancement has been the evolution of digital instrumentation that supplement, or in some cases replace, manual instrumentation. In certain procedures such advanced instrumentation has allowed the delegation of procedures such as refraction, keratometry, lensometry, imaging, and visual fields to ancillary personnel. A brief history of some of these instruments, charts, or procedures is presented in this section.

Ophthalmoscope

Charles Babbage, (1792-1871) Lucasian Professor of Mathematics at Cambridge, constructed an ophthalmoscope as early as 1847 without perhaps understanding the true significance of his invention. Surely he understood it could be utilized to look in the eye or he would otherwise not have constructed the instrument. Unfortunately, Ferdinand Ritter von Arlt (1812-1887), who harangued his colleagues to take over the practice of refraction, made what was perhaps the most unforgivable faux pas in the history of ophthalmology when he turned down the invention of the ophthalmoscope as of no value (1).

W. Cummings, an Englishman and surgeon at the Royal London Ophthalmic Hospital, and independently, E. Brucke, in Germany, provided the theoretical explanation underlying the principles of the ophthalmoscope. That is, how the eye would appear illuminated to an observer, when the latter viewed in a parallel direction to that of the light rays entering the eye. Both men appreciated the significance of using high illumination, the use of concave lenses as illuminating mirrors being discovered to be a good expedient. Although there are differences in principle, the concept of the ophthalmoscope is the same regardless of whether one uses concave lenses, plates, or centrally fenestrated concave mirrors (1).

However, it was Hermann Ludwig von Helmholtz, a Prussian physicist and physiologist who, in 1851, invented an improved version of the ophthalmoscope and published his results (2). From this point forward it was recognized that this device would be a valuable diagnostic tool for viewing the interior of the eye. The use of the ophthalmoscope increased dramatically when Dennett invented and introduced the electric ophthalmoscope in 1885 (3). The indirect method of ophthalmoscopy was described the following year.

Ophthalmometer or Keratometer

As with so many inventions the original inventor does not always receive credit. Jesse Ramsden (1735-1800), was an English optician and instrument maker. Ramsden had apprenticed as a cloth worker, instrument maker, and then with several well-known English opticians, including Peter Dolland. He opened his own shop in 1762. He created a numbering system known to use sequential sets of lenses for vision testing. The 13 convex lenses were classified by focal length in English inches with power ranges from +1.00 to +6.70 D. His set of 22 concave lenses covered a much wider range of powers (4).

Ramsden invented the first ophthalmometer in 1796. He and Everard Home were attempting to determine if the cornea was the seat of accommodation. In 1865, von Helmholtz with the assistance of Kohlrausch, developed an instrument which precisely measured the cornea's refracting power. This ophthalmometer recorded the curvature of the central corneal area by determining the size of the doubling images reflected by the cornea itself. It was primarily a laboratory instrument. This is the same method employed by Scheiner in making crude estimates over 200 years before. However, it was Louis Emile Javal and Hjalmar August Schiotz who, in 1881, adapted Helmoltz's design into a clinically useful instrument. It could be rotated to measure separate meridians and had a doubling system in which the separation of the mires was adjustable. This instrument was manufactured by many companies but most notably by the Haag-Streit Company (4, 5).

In 1899, the Chambers-Inskeep Ophthalmometer was introduced. It was the first keratometer with self-Illuminated mires. The separation of the mires was constant and the position of the doubling prism was varied to make corneal measurements. It was manufactured by the Ottumwa Optical Company which was founded in 1887 in Ottumwa, Iowa. Two of the founding members were pharmacists who taught themselves optics and started selling glasses. The company moved to Chicago in 1888 and later sold a self-illuminated retinoscope, self-illuminated ophthalmoscope, and one of the first lensometers. After a change in ownership the company was taken over by American Optical Company. Both of these instruments were two-position keratometers (5).

John Hamer Sutliff was a British optometrist who invented a one-position keratometer. The Bausch & Lomb keratometer, which was introduced in 1932, was, like the Sutliff instrument, in that it was one-position in design. The B&L Keratometer remained popular until the advent of the automated instruments (5).

Retinoscope

The history of the retinoscope is not so clear. Donders gave his friend Bowman credit for making certain retinoscopic observations before 1864. Others credit the invention of retinoscopy to Cuignet of Lille, France. In 1875 Cuignet explained the use of the retinoscope not merely for detection of astigmatism but for the detection and even measurement of every form of ametropia. He called the procedure keratoscopy but the name "shadow test" shortly appeared and finally skiascopy. Popularization of retinoscopy in the late 19th century came through the efforts of ophthalmologists Mengin, Chibret, Parent, and Landolt. Near the turn of the 20th century Edward Jackson, in 1895, and James Thorington, in 1897, had both written books on retinoscopy and its usefulness in determining the refractive error. Some of the first books on retinoscopy by optometrists were by George Rogers, in 1899, William B. Needles, in 1900, and Andrew J. Cross, in 1903. The first retinoscopes were perforated mirrors on a handle, with illumination from a candle or from a lamp separate from the retinoscope mirror. The first retinoscope with an electric light source incorporated into the retinoscope was made in 1901 by Wolff. An early prominent electric self-luminous instruemnt was the De Zeng retinoscope (6).

The first electric retinoscopes projected a spot of light and the procedure was termed "spot retinoscopy". The streak retinoscope, which facilitated the observation of astigmatism, was patented by an optometrist, Dr. Jack C. Copeland (1900-1973) in 1927. Copeland worked at that time as a technical consultant to Bausch & Lomb. Retinoscopy became more popular with the invention of the streak retinoscope and Copeland did much to promote the instrument and the technique during the mid- 20th century. Copeland held more than 35 patents and did much to popularize streak retinoscopy through his publications, lectures, and demonstrations. He was well-known for his ability to walk down a line of individuals and call out their refraction as he performed retinoscopy (6).

Trial Case

The evolution of the subjective refraction technique has a less clear historical past. It is known that in 1843 the Bavarian physician Georg Fronmuller (1809-1889) of Germany invented the trial case. The use of the trial case took the matter of selection of a prescription almost entirely out of the hands of the buyer except insofar as they answered the question of the examiner when the trial lens was held before the eye. With technique began the process where there was a variation in style of frame, for now the glasses could be made to order. Instead of a frame made of steel or iron there subsequently appeared frames of shell, silver or gold. In 1840, there appeared in France the rimless frame. Obviously it took several decades before this was adopted in other countries (7).

Measurement of Visual Acuity

The most notable of the early research in the field of visual acuity was conducted by Tobias Mayer (1723-1762). His work involved gratings of two different patterns, grids of horizontal and vertical lines, and a checker board pattern. Mayer determined "minimum separable "for all four test-patterns (7). It was also in 1843 the test-type was invented by Heinrich Kuchler (1811-1873). A numbering system was employed to designate the visual acuity and a standard established for normal eyes. This test was used only for seeing at near. However, in 1854 Jaeger (1818-1884) published a complete collection of test types and invented the reading card that is identified by his name. More important was the invention, in 1862, of the squared test type by Hermann Snellen (1834-1908). Snellen visual acuity remains in common use in contemporary times (8). There are many methods used for estimating or measuring visual acuity depending on the age of the patient. For school-age children and adults many forms of visual acuity charts are available, although the Snellen chart remains the most popular. Most practices today utilize computer programs that project Snellen letters rather than using a separate projector stand. One chart used frequently in care of those patients in need of visual rehabilitation is the Bailey-Lovie Chart frequently used for the assessment of visual acuity. The latter is also known as the Early Treatment of Diabetic Retinopathy Study (EDTRS) since this was the chart utilized for this study to assess visual acuity.

Optometer

Another option for refraction has been the optometer. Christopher Scheiner, in 1619, described what was seen when an illuminated surface was viewed through two pinholes, whose distance apart was less than that of the diameter of the pupil. Scheiner's experiment illustrated a fundamental principle in vision science that formed the basis for many 18th and 19th century experiments. In fact, the principle of the optometer is based on Scheiner's experiment.

By 1696, De La Hire (1640-1718) had constructed what could be called a simple optometer. The first description of this instrument was given the name optometer by the Scottish physician William Porterfield in a paper published in 1737. Porterfield's simple apparatus consisted of a small plate of white iron with two parallel slits. Using this simple arrangement, he was able to estimate the amplitude of accommodation. Later, Thomas Young used an improved version of Porterfield's optometer to discover his own astigmatism. The late nineteenth century and early twentieth century saw the development of several optometers but all had problems with alignment and instrument accommodation that limited their usefulness (9).

During the latter half of the 19th century where there were no opticians or eye glass peddlers in many rural areas, people had to rely on mail order glasses. On request, opticians would send out catalogues and an eye testing apparatus that could be administered for a self-determined prescription. Optometers have, over time, ranged from the very simple to the elaborate. In 1854 Smee, a surgeon to the Bank of England, described a simple optometer in a book derived from his lectures to the Central London Ophthalmic Hospital.

In 1882, Berteling of San Francisco patented a Compound Optometer that was a near point test that utilized two circular disks, one containing spherical lenses and the other cylindrical lenses in front of an opening in which the observer saw the target monocularly. A similar instrument was introduced by Bucklin in 1884 called the Ophthalmoscopic Test Lens. DeZeng's Refractometer received a patent December 3, 1895. Other similar instruments included the Stigmatometer, the Ametropometer, Thomson's Ametrometer, the Hair Optometer, and the Punctometer. Campbell has provided a through description of many of these optometers (10). None of these optometers gained a significant foothold in clinical practice.

A significant development in the automation of refractors was the introduction of the Bausch & Lomb Ophthalmetron in 1971. Since the time of its introduction automated refractors have become increasingly numerous and sophisticated and are used as a starting point for subjective refraction or in some situations as a substitute for the same. Some of these instruments are based on the principles of retinoscopy such as the Ophthalmetron introduced by Bausch & Lomb in 1971. Others depend on evaluating conjugacy of the retinal image to determine the far point while others use the double pinhole principle of Scheiner (11).

Phorometer

As interest in learning refraction increased in America, many correspondence courses and later schools emerged, many being proprietary in nature. The background of students in these programs or schools varied. They included ophthalmologists, oculists, opticians, jewelers, watchmakers, pharmacists and others who wish to make "optics" their life's work (12). Besides teaching refraction some of the schools began to teach methods for determining binocularity problems. To better detect and diagnosis these muscle imbalances, devices were made to measure muscle imbalances. In 1888, Dr. George T. Stevens of New York introduced one such device called a phorometer which consisted of two prisms geared together so they could be rotated simultaneously in opposite directions. Patients with their lens correction placed in a trial frame, would view through the prisms at either near or distance targets. The phorometer could be mounted on a table or floor and contained a level to ensure there was no vertical misalignment when measuring vertical imbalances (13).

Later instruments incorporated Steven's phorometer attachment in combination with a forehead rest, Risley prisms, a graduated pupillary adjustment, Maddox rods, a spirit level, trial lens cells, and a near point rod. These devices could be used for not only measuring muscle incoordination or imbalances but also a trial frame for retinoscopy and/or trial frame refraction. These instruments would serve as the forerunner to the phoropter (14).

Taking a number of separate, uncoordinated, optically inaccurate and uncalibrated pieces, DeZeng designed the optometer or Phoro-Optometer No. 574, for which he applied for a patent on December 29, 1908. He received basic patent No. 941,766 on November 30, 1909 (15). This was the first self-contained instrument employing those correct, scientific principles and mechanical movements in the field of ocular instrumentation. This instrument contained many firsts; including the first radical dioptric scale applied to double rotary prisms, first ground Maddox multiple rod, first two-part double rotary prism cell, and the first refraction and muscle testing instrument. This instrument, as drawn, was never manufactured but served as a stimulus for later designs. Other manufacturers of phorometers in addition to DeZeng included the Wolff Ski-Optometer Model 235 and the B & L Phorometer Trial Frame. Perhaps the best known of these American ophthalmic instruments ultimately was the DeZeng Phorometer-Trial Frame No. 560. This instrument was based on the 1909 patent but little resembled the original drawings when introduced in 1917 (15).

Refractor or Phoroptor

Some sources have credited the German Monk Johann Zahn (1641-1701) with describing the first rudiments of a refracting unit. Zahn, in 1685) and Hertel (1683-1743), in 1716, described a polysphere lens (7, 8). This description was overlooked until the 20th century when von Rohr (1923) and later Bennet (1966) referred to this as the first refracting unit (8). This lens was made of portions of a plano-convex spherical lens and portions of a plano-concave spherical lens. It was termed a polysphere because each portion of the lens consisted of a single piece of glass with a total of six concentric zones of different power. The zones of different power could be sequentially brought in front of the eye to estimate spherical refractive error (8).

A prototype of what might be considered a phoropter was developed by French ophthalmologist, Marc Antoine Girard-Teulon (1816-1887). However, it was Henry L. De Zeng, Jr. (1866-1929) who developed the phoropter as we have come to know it today (16). This instrument could be utilized for both distance and near testing, with such accessories as rotary prisms, cross cylinders, and Maddox rods. De Zeng had begun work for an optical company in 1885. Later he attended Hobart College, studied medicine in Chicago, and took refracting and optics courses (17).

Between 1895 and 1915 De Zeng patented 41 inventions, including, in the ophthalmic domain, a refractor, phoropter, an electric ophthalmoscope, the first battery-handle ophthalmoscope, retinoscope, and other diagnostic instruments (16). De Zeng's first phoropter was patented in 1909, which was then later produced in a somewhat altered form by the De Zeng Standard Company in 1917 (16). In the 1917 form the cylindrical lenses had been removed but the lenses were covered front and back in shields. De Zeng produced later improvements as his invention went through a variety of iterations progressing from the phorometer to the phoropter. He published a manual in 1917 entitled "The Modern Phorometer: Including the Phorometer-Trial Frame, Phoro-Optometer, and the Rotary Cross-Cylinder". Around 1920 the design of the Phoro-Optometer No. 574 was improved and the shields housing the spherical lens units were reduced in size. In 1922 DeZeng Standard began production of the Phoropter No. 584 (16).

De Zeng sold his company to American Optical Company in 1925 (15). In collaboration with some of the best known authorities in ocular refraction, improvements were made to the Model 584 and it was named the Wellsworth DeZeng Improved Phoropter No. 588. This phoropter was introduced in 1927. The Additive Power Phoropter was introduced in 1935 as Model No. 589 and the American Optical Model 590 Phoropter was introduced in 1948. The now familiar AO Rx Master was introduced in 1956. De Zeng also invented other diagnostic eye instrumentation such as the rotary cross cylinder, perimeter, corneal microscope, and transilluminator. DeZeng also invented otolaryngology instruments such as the otoscope and laryngoscope. He developed instrumentation for urologic and other fields of medicine (18, 19)).

A competing phoroptor was Bausch & Lomb Green's Refractor, developed in the 1930's by Clyde L. Hunsicker, Aaron S. Green, Louis D. Green and M. I. Green. This very durable phoroptor was reliable but had a cross cylinder that required manual manipulation for both cylinder power and axis (20). Several other American Companies manufactured phoroptors but they never achieved significant market share (21). Likewise, several foreign phoroptors were manufactured but were not frequently purchased for utilization in the United States (22).

Subjective Refraction

Although some sources have credited the German Monk Johann Zahn (1641-1707) with describing the first rudiments of a subjective refracting unit as early as the 1685, Zahn was also aware of the relationship of the distance of the *punctum remotum* to the focal length of the power of a correcting lens for myopia. So there existed some notion of the relationship of the power of a lens focal length to the distance of the *punctum remotum* in some regions of Europe (7, 8).

The concept of approaching the final sphere power from the most plus or least minus power had been discussed as early as the mid-seventeenth century. This had evolved no doubt from prescribing for presbyopia but made equal sense for myopia and later hyperopia. It also made common sense to always guard against giving more power than necessary regardless of the condition.

Perhaps the real stimulus to refraction was Donders' book that brought some clarity to an understanding of hyperopia both clinically and scientifically. For refracting opticians, in addition to Donders, and other medical books published in the latter half of the 19th century, several booklets or books were published by opticians as early as 1866. Several more books on refraction were published in the 1880's. An in depth understanding of refractive methods was gained from the 1896 publication by Queen and Company of the book *The Human Eye – How to correct its Defects by Properly Fitting Glasses* (23). This is the company that had originally been started by James Queen (1811-1890). Additional discussion of Donders and these early optometric books is included in this chapter in the section on *Early Books Related to Optics, Prescribing, and Instrumentation*.

As a result of the unique manner in which astigmatism was discovered, its discovery in two countries at approximately the same time, and the evolution of its correction the reader is directed to the section on Optical Correction of Astigmatism

Obviously, these were men of science who used their understanding of science and reasoning to establish many of the early percepts related to the clinical understanding of refractive errors and vision science.

Optical Correction of Astigmatism

Testing for the Optical Correction of Astigmatism

No discussion about the correction of astigmatism would be complete without mentioning Chamblant's crossed cylinder lenses. Stedman Whitwell, an English architect, had been introduced to Chamblant's cross cylinder in 1815, in Paris. This lens was invented by Galland de Chervaux but Chamblant held the patent. These cylindrical lenses were of the same power but placed at right angles, and reunited with their axes and surfaces in opposition. The lenses were developed to eliminate the aberrations and deformities produced by spherical lenses. There was no mention of using this lens for the correction of astigmatism (24).

Brewster's suggestion, offered in 1837, of observing the reflected corneal image appears to be overlooked until when, in 1846, Airy discussed examination of the cornea by a reflection technique. This observation eventually led to the invention of the hand keratoscope (25). Henry Goode, in turn, corrected astigmatism in his, and several other eyes, and described it in a paper published in 1847 (25).

Goode's contemporary George Stokes (1819-1903) subsequently, in 1849, devised a simple method for determining the degree of astigmatism. The "Stokes Lens" consisted of a variable cylinder consisting of plus and minus plano-cylinders of the same power, crossed at right angles, and so arranged that they rotated in equal and opposite directions. It was first described at a meeting of the British Society for the Advancement of Science in 1849. In his opening remarks, Stokes noted besides long sight and short sight, there existed a defect not very uncommon (26). The lens Stokes described was most valuable when it was restricted to relatively high degrees of astigmatism.

It would be almost 50 years before the cross cylinder technique was popularized by Edward Jackson (1825-1952). With various modifications by Javal, Dennett, and other investigators, this lens culminated in the elegantly simple refinements that made this technique so popular (26). Jackson was an American ophthalmologist who published several papers between 1897 and 1929 that advocated for and described testing procedures to determine the axis and power of the cylinder necessary for correcting astigmatism (27-33). Slowly over the course of the next three to four decades of the 20th century, the cross cylinder test as described by Jackson became the preferred subjective method of astigmatism measurement (34). The technique was widely accepted as it became an integral part of the modern phoroptor. As recently as 1932 Crisp stated he doubted if the cross cylinder test was really familiar to more than five percent of ophthalmic surgeons (35).

Astigmatism Charts

It appears doubtful that Airy knew about any of the following advances regarding the examination techniques of astigmatism.

Gerson Hirsch Gerson (1788-1843) received his university education at Berlin and then proceeded to Gottingen, for his medical education in 1809. Gerson was a student of Fischer and his early interest in vision derived and developed from Fischer. As early as 1808 had used a series of horizontal and vertical lines, plus a rectangular target for detecting astigmatism (36).

On July 12, 1852, Goulier, Professor of Topography at the Military School at Metz presented his observations on astigmatism to the Academy of Sciences. Included in his account was an illustration comprising a series of vertical and horizontal lines, grids, etc., which successfully employed for the determination of the presence of astigmatism. The chart was also designed to detect astigmatism in oblique meridians as well. Goulier was also familiar with the usage of plano-cylindrical lenses (36).

John Green, in 1867, published a paper entitled "Detection and Measurement of Astigmatism", in which he included three illustrations of his astigmatic dials one of which comprised 60 radiating lines (36). Green's charts set the pattern for modern astigmatic dials still in use in contemporary practice. During the period of projected visual acuity charts a knob was included in the chart that allowed for the determination of the darkest line in the clock dial. There are now many charts and slides available for the detection and measurement of astigmatism. However, for most patients the use of the cross cylinder as described by Jackson is used almost universally for those capable of responding to directions given by the examiner.

SUMMARY

The above description is not a comprehensive description of the history of the development of ophthalmic instruments. It does, however, provide some degree of understanding related to the evolution of instruments used in the early period of eye care. The latter half of the 20th century gave birth to more sophisticated instrumentation such as the indirect ophthalmoscope, applanation tonometry, pre-corneal lenses, and many automated instruments. This development continues at an even more rapid pace in contemporary practice most notably with the development of such instrumentation as ocular computed tomography, the visual evoked potential and electroretinography. Much of eye care is driven by new technology and that will continue to be the case in the future.

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