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Refractive error changes relative to age

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Abstract

Refractive error changes from infancy to late adulthood. Hyperopic state of refraction error was reported in infancy and early childhood. Most of the refractive changes occur mainly between 3 to 9 months of age which indicates emmetropization and it correlates significantly with axial length elongation. High prevalence of astigmatism is found in early life of infant but it decreases rapidly in the first year. More myopia/less hyperopia is associated with increased age in school-age children and the progression is related to genetic and environmental factors. Astigmatism is rather constant during school-age years. The young adults have the most stable refractive error compared to other age groups. Myopia onset and progression are the most common refractive changes in this group which could be caused by vitreous chamber elongation. Hyperopic shifts were observed after the age of 40 which could be due to decreasing lens power with aging or increasing optical density of the lens. Myopic shift associated with nuclear cataract were found in later adulthood and its onset is dependent on the origin of the population sample. Higher rates of astigmatism are found in older adults and conditions against the rule are the most common axis.

Keywords—emmetropization; myopia shift; hyperopia shift; astigmatism

I. INTRODUCTION

The leading cause of visual impairment worldwide is uncorrected refractive error (Guidmundsdottir et al., 2005). Refractive error is also known as ocular refraction and it changes continuously throughout one's life (Saunders, 1981). Understanding the changes of refractive error as a function of age will help to determine the need for proper refractive correction and the planning for better eye care services. Many studies have been conducted cross-sectionally (Brown, 1938; Slataper, 1950; Saunders, 1981) and longitudinally (Goss & Cox, 1985; Saunders, 1986) to investigate the changes of the refractive error from infancy up to late adulthood.

The cause of refractive changes with age is not fully understood, although it may be linked to the changes in biometric data such as corneal power and axial length (Ishii et al., 2013; Zadnik et al., 1993; Goss et al., 1985; Goss & Erickson, 1987; Grosvenor & Scott, 1991; Grosvenor & Scott; 1993; McBrien & Adams, 1997; Lin et al., 2001; Pan et al., 2012). In order to understand better the changes of the refractive error, the life span have been divided to four main stages: infancy and early childhood (≈ 0 to 5 year-old), school-aged years (≈ 6 to 18 year-old), young adulthood (≈ 20 to 40 year-old) and later adulthood (> 40 year-old). When comparing the refractive errors in these four stages, refractive error varies throughout the stages as shown by Saunders (1986). Comprehensive longitudinal studies have to be conducted to confirm and understand the association of refractive error with age. These would help to determine the type of correction for the refractive error especially surgical intervention which may help to achieve emmetropia only for a limited time (Xu et al., 2005).

II. Infancy and Early Childhood

Many studies reported hyperopic state of refractive error for infants and early childhood (Wood et al., 1995; Edwards, 1991; Hopkinson et al., 1992; Blomdahl, 1979; Mayer et al., 2001) with an average mean spherical error reported from +0.50 D to +3.60 D and myopic shift was observed towards their first year of life (Wood et al., 1995; Edwards, 1991; Mayer et al., 2001; Mutti et al., 2005; Zadnik, 2003; Mutti, 2007). As shown by Edwards (1991), a rapid decrease of mean spherical equivalent of the refractive error occurred between the first 10 and 40 weeks of infant growth.

The changes of the refractive error in infancy and early childhood are believed to be moving towards emmetropia in the first few years of life and it occurs for both myopic and hyperopic infants (Saunders et al., 1995; Ehrlich et al., 1995). Most of the refractive change was observed in the first year especially between 3 and 9 months of age (Goss & West, 2002; Mutti et al., 2004). This perhaps indicates emmetropization of the refractive error (Troilo, 1992; Wildsoet, 1997). Hyperopic defocus may guide eye growth and any interruptions of exposure to hyperopic defocus could affect the process of the emmetropization (Napper et al., 1995; Smith et al., 2002). The reduction of hyperopia in infants correlated significantly with axial length elongation but not with the changes in corneal and lenticular power although both showed significant changes during the period of emmetropization (Mutti et al., 2005; Ishii et al., 2013).

The average cycloplegic spherical-equivalent (SEQ) refractive error (RE) of human infants has been found to be about +2.00 diopter (D) at 3 months, decreasing to+1.00 to +1.50 D at 12 months of age with significant decreasing hyperopia and its standard deviation with age during emmetropization (Wood et al., 1995; Mutti et al., 2005).

High prevalence of astigmatism is also found in infants (Mayer et al., 2001; Mutti et al., 2004; Howland & Sayles, 1984), which is more common in the early life of infants (3 months old) and decreases in prevalence with age (Mutti et al., 2004; Ehrlich et al., 1997; Atkinson et al., 1980). Astigmatic power decreases rapidly in the 1st year (Chan & Edwards, 1993) and astigmatism in infancy appeared to be unrelated to emmetropization of spherical error (Mutti et al., 2004).

Some studies have reported that with-the-rule astigmatism is more common in infancy (Wood et al., 1995; Edwards, 1991; Saunders, 1988). Almost 70 % of astigmatism is with-the-rule astigmatism in the first year of life (Saunders, 1988) and the average astigmatism was less than 1 dioptre cylinder (Wood et al., 1995). Conversely, Mayer et al. (2001) has reported that against-the-rule was more common in infants and high cylindrical error (2 D or more) was uncommon. Mutti et al. (2004) reported with-the-rule was more common at 3 months but against-the-rule at 36 months of age. There is also a report stating that a higher prevalence with-the-rule astigmatism was found after 4½ years of age as increased eyelid pressure could produce greater flattening in the horizontal meridian of the cornea (Gwiazda et al., 1984). The incidence of astigmatism gradually declines from 12 months of age onward (Wood et al., 1995). The prevalence of astigmatism ≥1.00 DC decreases rapidly during the first year of life and falling at 18 months to a level found in childhood of less than 10% (Atkinson et al., 1980; Mohindra et al., 1978). Emmetropization of astigmatism can be up to 36 months compared to only 9 months for the spherical equivalent (Mutti et al., 2004). The cornea and anterior lens surface was observed to become more spherical with age, contributing to reduced astigmatism (Mutti et al., 2004).

III. School-Age Years

As mentioned earlier, hyperopia continues to decline with increased age (Saunders, 1986; Mayer et al., 2001; Chan & Edwards, 1993; Rezvan et al., 2012) in school-age children. More myopic/less hyperopic refractive error was associated with advanced age groups (Twelker et al., 2009; Dandona et al., 2002; Zadnik et al., 2002). There was an age-related shift in refractive error from hyperopia in young children (15.6% in 5-year-olds) towards myopia in older children (10.8% in 15-year-olds) (Murthy et al., 2002). Basically, previous findings have indicated that children with hyperopia decrease in hyperopia and children with myopia increase in myopia in a slightly higher rate per year among school-aged children (Mantyjarvi, 1985). In addition, during the first year of life, rapid refractive shifts in hyperopic power were also particularly observed during the sixth to the tenth years of life (Chan & Edwards, 1993). In Shunyi district of China, myopic shift was observed in children at the ages of 5 to 13 years which was associated with the female sex, older age, and higher myopic or hyperopic refractive error at baseline (Zhao et al., 2002). However, another study found no significant difference in average refractive error between girls and boys despite girls tending to have steeper corneas, stronger lens power and shorter eyes compared with boys (Zadnik et al., 2002). The rate of the refractive change varies among ethnicities with Asians reported as having more myopic eyes with increased age (Twelker et al., 2009) while the peak age of myopia onset is younger in the South East Asian population compared to the UK-based population (Williams et al., 2013; Lin et al., 2004).

It was also reported that prevalence of myopia increases from under 2% until about the age of 7 or 8 years to 20% by the age of 15 (Zadnik, 2003). Myopia progresses at a higher rate than hyperopia with vitreous chamber elongation and reduced crystalline lens power found between the ages of 6 to 12 (Zadnik et al., 1993). Children that have greater corneal powers and greater axial length to corneal radius (AL/CR) are at risk of myopia onset during this period (Goss & Jackson, 1995). Myopia with an onset in the childhood could increase until it slows down or stops in the mid to late teens (Goss & Winkler, 1983). These myopia progression rates in childhood were similar between boys and girls with -0.40 D/yr and -0.43 D/yr respectively (Goss & Cox, 1985). The progression of myopia is very much related to genetic and environment factors such as age and gender (Donovan et al., 2012), ethnic origin (Twelker et al., 2009), time spent on reading or near work (Saw et al., 2001; Saw et al., 2002) and outdoor activities (Guggenheim et al., 2012; Guo et al., 2013; Goss, 1998), as well as between urban and rural children (Ahuama & Atowa, 2004). The onset and progression of myopia may also be related to height spurts which correlate to the onset of puberty (Yip et al., 2012; Hyman et al., 2005).

Astigmatic power is rather constant during the school-age years (Chan & Edwards, 1993) with almost zero astigmatic error change in 28 months for children aged from 5 to 13 years (Zhao et al., 2002). A very low average rate of the astigmatic increment ranging from 0.03 to 0.06 D/yr was also reported among school-aged children (Goss & West, 2002). Over 80% of the astigmatism was with-the-rule in children aged between 6 to 17 years (Rezvan et al., 2012) and also another group of Icelanders aged between 0 to 19 years (Janasson & Thordarson, 1990).

IV. YOUNG ADULTHOOD FROM LATE TEENS TO PRE-PRESBYOPIA

Young adults are having the most stable ocular refraction compared with other age groups (Goss, 1998; Grosvenor, 1991). Myopia onset and progression are the most common refractive changes found in this age group and their rates of myopia progression are less than the rates in children (Goss & West, 2002; Lin et al., 1996; Kinge & Midelfart, 1999; Jorge et al., 2007). A recent study by Williams et al.(2013) showed that almost half of the myopes in a British population based research had adult-onset myopia with the mean myopia onset being more than 18 years.

Myopia progression in young adulthood has been suggested to be associated with corneal steepening where corneal power increased (Goss et al., 1985; Goss & Erickson, 1987; Grosvenor & Scott, 1991) but longitudinal changes in corneal radius are poorly correlated with refractive changesn (Fledelius, 1998). As myopia is a complex multifactorial condition (Hyman, 2007), corneal steepening cannot be the only contributor to myopia progression (Grosvenor & Scott, 1993). Steeper corneas are seen in smaller eyes but such eyes are not universally myopic (Grosvenor, 1991). Vitreous chamber depth and axial length also were associated with myopia progression in adulthood (Grosvenor & Scott, 1991). McBrien and Adams (1997) also showed that the structural cause of the myopia onset and myopia progression in this age group is vitreous chamber elongation. There was an initial belief that the eye has achieved its full growth by the age of 13 to 15 years (Sorsby et al., 1992; Larsen, 1971; Kent, 1963) and any myopia onset beyond this period is unlikely due to elongation of axial length. There are several studies which have shown that the eye can still grow into adulthood (Grosvenor & Scott, 1991; Grosvenor & Scott, 1993; McBrien & Adams, 1997; McBrien & Millodot, 1987; Bullimore et al., 1992) which links to the possibility of scleral stretching in this adult-onset and adult-progression myopia (Bell, 1978).

Research conducted in Indonesia did not show myopia progression in this age group where a reduction of myopic refractive error of 0.17 D was found between the age group of 21 to 29 years to 30 to 39 years (Saw et al., 2002). The Handan Eye Study in China reported that the mean refractive error became less myopic (hyperopic shift) with increasing age from 30 to 40 years old (Liang et al., 2009). This cross sectional study showed similar changes reported by a longitudinal study of Saunders (1986) in this age group. Adults that are associated with myopia onset or progression during adulthood are most likely currently smoking, spend more hours in reading, diabetic and have more number of family members with myopia (Liang et al., 2009). A recent paper also showed that besides having myopic parents and spending more time in reading, factors such as older age, higher educational level, nearer reading distance, less outdoor activity and higher urbanization were associated with myopia for young adults aged 18 to 24 years (Lee et al., 2013).

There is also stable astigmatism found in this age group (Liang et al., 2009; Saw et al., 2002). It was reported that an average change of 0.1 to 0.3 D was observed between 20 and 40 years of age (Goss &West, 2002). With-the-rule astigmatism is also found more common than against-the-rule in this age group (Goss & West, 2002).

V. LATER ADULTHOOD

Hyperopic shifts of the refractive error continue to be observed after the age of 40 years (Xu et al., 2005; Goss & West, 2002; Liang et al., 2009; Wu et al., 2005; Shimizu et al., 2003; Attebo et al., 1999; He et al., 2009) up to the age group of 60 to 64 years in rural populations and 70 to 74 years in urban populations (Xu et al., 2005) with a mean spherical equivalent of up to 0.41 D in 5 years reported in a longitudinal study (Gudmundsdottir et al., 2005). Bengtsson et al. (1999) showed that a true hypermetropic shift did exist between 55 and 70 years of age. Another study showed an increment of mean spherical error +1.2 D in person aged more than 80 years (Attebo et al., 1999). The trend of the hyperopic shift also showed an increased prevalence of hypermetropia up to 68.5% with increasing age in this age group (Anton et al., 2009; Wang, et al., 1994; Lam et al., 1994). This age-related increase in hypermetropia with an associated age-related decrease in myopia could be due to decreasing lens power with aging or increasing optical density of lens cortex making the lens more uniformly refractive (Shimizu et al., 2003; Wang et al., 1994; Garner et al., 1998). The changes in vitreous depth and axial length may be associated with the refractive shift as significant correlations were found between age and these two biometric parameters (Lam et al., 1994) whereas corneal curvature was found as age-independent in this population (Gudmundsdottir et al., 2005). Grosvenor and Skeates (1999) used the results of their analysis of refraction data collated from optometric practice records which indicated that there were very few myopic individuals who showed a hyperopic refractive shift during presbyopia but rather remained stable or became more myopic. They postulated that this was the result of myopic axial elongation countering the recognised age-associated decrease in the gradient index of the lens.

Women older than 40 years of age have consistently shorter axial length compared with men and the increment of lens thickness with age tended to be greater in women (He et al., 2009). These could be associated with the different refractive error found among men and women older than 40 years of age (Kempen et al., 2004).

The change of refractive error starts to have a ‘U-turn’ or reverse effect by as early as 60 years of age with a myopic shift being observed (Gudmundsdottir et al., 2005; Liang et al., 2009; Wu et al., 2005; He et al., 2009). This refractive shift was associated with the development of nuclear cataract (Liang et al., 2009; Guzowski et al., 2003) and a higher rate of myopic shift of -0.65 D which was especially found in eyes with higher level of nuclear lens opacification (Gudmundsdottir et al., 2005). The severity of lens nuclear opacity was positively associated with the prevalence of myopia and negatively associated with the prevalence of hypermetropia (Cheng et al., 2003; Saw et al., 2008; Wong et al., 2000; Tarczy-Hornoch et al., 2006). A study conducted in Japan also showed that the prevalence of myopia decreased with age up to 70 to 79 years but increased slightly in patients who were 80 years and older and the prevalence of hypermetropia showed an opposite trend (Sawada et al., 2008). There are also a number of studies showed that the prevalence of myopia in adults was indicated as initially declining with age and then increasing in the upper age groups (Wang et al., 1994; Katz et al., 1997; Wensor et al., 1999).

The age of onset for this myopic shift in later adulthood is dependent on the origin of the population sample and the incidence of nuclear cataract as some of the studies reported the myopic shift to begin in 7th decade (Liang et al., 2009; Saw et al., 2002; Saw et al., 2008; Wong et al., 2000) and some could be before the age of 50 years (Raju et al., 2004; Bourne et al., 2004; Dandona et al., 1999). The increasing level of nuclear opacity was an important determinant of the age-related increase in myopia after 70 years (Lee et al., 1999). There are also some risk factors that were shown to be associated with developing myopia in adults older than 50 years of age such as high school or higher education, diabetes, nuclear opacity and number of family members with myopia (Liang et al., 2009) whereas Gudmundsdottir et al. (2005) did show that factors such as years of education, smoking, corneal thickness, height, or body mass index had no significant effect on the amount of change in spherical equivalent.

As the changes in the crystalline lens contributed to the refractive shift the older age, Truscott and Zhu (2010) suggested that chronic incubation of the lens at high temperatures results in changes to the lenses macromolecular structure and induce the development of presbyopia and age-related nuclear cataract. These could indicate higher rate of myopic shift in older age population of hot climate countries but a study conducted in Nigeria involving 1,362 subjects concluded that little impact of temperature on crystalline lens was found (Kragha, 1985).

Mean astigmatism increased significantly with increasing age in later adulthood (Xu et al., 2005; Attebo et al., 1999; Anton et al., 2009; Gupta et al., 2008) with mean change of 0.13 D in the against-the-rule astigmatism during 5 years (Gudmundsdottir et al., 2005). These higher rates of astigmatism in older adults especially for the age group of more than 50 years could be associated with increasing levels of lens opacities with age (Wang et al., 1994; Wong et al., 2000; Katz et al., 1997; Dandona et al., 1999). The most common axis is against the rule (Attebo et al., 1999). More astigmatism eyes shift toward against-the-rule astigmatism from 40 years of age onward. It could be due to the changes of lid tension. The lid tension is responsible for with-the-rule astigmatism (Goss, 1989) and as lid tension reduces with age, the with-the-rule astigmatism decreases and shifts toward against-the-rule (Dandona et al., 1999). There was about 66.5% of eye of those with astigmatism 43 years and older had astigmatism against-the-rule (Jonasson & Thordarson, 1987). The prevalence of astigmatism was also higher in the older age population (Sawada et al., 2008). The Blue Mountains Eye Study in an older population of 49 years or older showed very small changes of mean cylinder power over the 5-year period, irrespective of baseline refraction. The axis of astigmatism remained stable in most cases (64%) and only 12% changed to against-the-rule and 11% to with-the-rule (Guzowski et al., 2003).

VI. CONCLUSION

Ocular refraction changes relative to age. It starts mostly with hyperopic eyes due to smaller eyes and flatter cornea at birth. Emmetropization takes place in the first few years with most refractive change found in the first year of life. The myopic shift continues in the school-age years with the genetic and environmental factors playing a role in myopic progression rate. The ocular refraction is most stable in young adulthood with the myopic progression rate being much lower than in school-age years and reports have shown hyperopic shift being observed after 30 years of age. The hyperopic shift of ocular refraction continues in later adult years with decreasing lens power which may be the reason behind it. The development of the nuclear cataract influences the refractive changes in later adulthood when the onset of the myopic shift differs in different origins of the population sample and where the level of the nuclear opacity determines the increment in myopia.

Astigmatism takes a longer time for the emmetropization compared with spherical error while more with-the-rule astigmatism was found during early childhood with increasing lid pressure on the vertical meridian of the cornea. Very little change of astigmatism were found throughout school-age years and young adulthood. Decreased lid pressure and the development of nuclear cataract increased the prevalence of against-the-rule astigmatism among the population in later adulthood.

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