Astigmatism among children in Jeddah, Saudi Arabia: prevalence and associated factors

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Abstract

Background: Undiagnosed astigmatism among children may result in multiple unfavourable consequences, such as poor performance on cognitive and language tasks, reduced oral reading fluency, behavioural disorders, and amblyopia development. In contrast, astigmatism is easily correctable in young children, which highlights the need for periodic assessment of its prevalence among pediatric populations.

Purpose: This study aimed to assess the prevalence of astigmatism among the pediatric population in Jeddah, Saudi Arabia, and to assess the rate of newly detected cases (incidental astigmatism) and the associated risk factors.

Patients and methods: This cross-sectional study was conducted among visitors of the awareness campaign about amblyopia, which took place in the Red Sea Mall, Jeddah, Saudi Arabia, on January 29–30, 2016. Children aged 2–15 years were enrolled in the study to undergo noncycloplegic eye examination using an autorefractometer for measuring cylindrical refractive error (Cyl). The calculated sample size for the studied age group of the population of Jeddah, Saudi Arabia was 291. Astigmatism was defined as Cyl ≥1 diopter in either eye. Multivariate binomial regression was used to analyze the predictors of incidental astigmatism.

Results: We examined the eyes of 347 children, mean age = 7.788 (standard deviation = 2.69) years, females = 53.3%. The overall prevalence of astigmatism was 41.5%, whereas the prevalence of incidental astigmatism was 40.6% among 342 children without apparent astigmatism. The prevalence of incidental astigmatism was associated with a previous diagnosis of amblyopia, having a sibling known to have amblyopia, and wearing spectacles. However, only wearing spectacles was shown to predict incidental astigmatism in the multivariate analysis.

Conclusion: Astigmatism is highly prevalent among children in Western Saudi Arabia, with the majority being undiagnosed before this screening campaign. These findings urge for further nationwide, population-based studies to address the burden of refractive errors among children in Saudi Arabia.

Key words: amblyopia, incidental, population, refractive error, risk factors, Saudi

Introduction

Owing to its impact on various aspects of the visual system, there has been a great deal of research concerning astigmatism since the early reports of Thomas Young and George Airy in the early 1800s (1). Astigmatism is a common type of refractive error characterized by unequal curvature of one or more refractive surfaces leading to the formation of 2 distinct focal lines of light, rather than a single focal ray on the retina. The disorder can occur at the level of the 2 principal meridia of the anterior cornea (corneal astigmatism), the posterior corneal surface and the surfaces of the crystalline lens (internal or residual astigmatism), or a combination of both entities, involving all of the ocular system (total astigmatism) (2).

Notwithstanding the significant advances in ophthalmological instrumentation and technologies that enable effective and accurate measurements of optical and shape properties, the typical etiologies of astigmatism remain elusive. The contribution of genetic factors is mostly evident in studies that reported the impact of heritable corneal power characteristics and increased risk of astigmatism in monozygotic twins compared with dizygotic twins (3). However, these results were conflicting in the literature. Therefore, environmental triggers may play a role in astigmatism development through the modulation of the mechanical interaction between the cornea and the eyelids or extraocular muscles (2). Conducting future investigations may improve our knowledge about the potential risk factors and causes of astigmatism.

Noteworthy, high degrees of astigmatism can lead to the development of amblyopia, whereas others reported correlations between myopia and astigmatism (4,5). Besides, the impact of severity and subtypes of uncorrected astigmatism on different developmental aspects is still unclear. Despite the scarcity of available investigations, astigmatic effects on visual acuity seem to start as early as the year after the first year of life (6). Therefore, children with uncorrected astigmatism would experience multiple unfavorable consequences, such as poor performance on cognitive and language tasks, reduced oral reading fluency, and increased prevalence of behavioral disorders (7,8,9).

Therefore, because astigmatism is easily correctable in young children, periodic assessment of its prevalence among pediatric populations is necessary. In addition, given that astigmatism can be compounded by the existence of multiple risk factors that increase severity degrees, it is important to get deeper insights into the risk profile and the associated triggers. This would ensure the safety of children by developing suitable interventions targeting the vulnerable risk factors to assist in reducing the burden of such a preventable disorder. In this context, this study aimed to investigate the prevalence of astigmatism among the pediatric population in Jeddah, Saudi Arabia, taking advantage of screening children while conducting a local awareness campaign about amblyopia. In addition, we aimed to assess the rate of newly detected cases (incidental astigmatism) and the associated risk factors.

Materials and Methods

Design and settings

This cross-sectional study was conducted among children who visited the awareness campaign about amblyopia, which took place in the Red Sea Mall, in Jeddah, Western region of Saudi Arabia, on January 29–30, 2016. The campaign was conducted by a group of specialized optometrists and ophthalmologists, including consultants and residents, supported by medical students and nurses. The campaign aimed to raise awareness about amblyopia among parents and companions to prompt voluntary screening and improve early detection. It was followed by a free examination of the children's eyes to screen for astigmatism or any other detectable eye disease. Written informed consent was obtained from all parents. The study was approved by the Biomedical Ethics Research Committee at King Abdulaziz University, Jeddah, Saudi Arabia.

Sampling

Sample size was calculated to determine the prevalence of astigmatism, ranging between 3.6% and 25.3%, per review of the national data,(10-15) among a target population of 850,000 children (aged 2–15 years) in Jeddah according to its most updated census conducted in 2010 by The Saudi Authority for Statistics in Saudi Arabia (www.stats.gov.sa), with 80% statistical power, 95% confidence interval, and 0.05 type I error. The largest sample size (N = 291) was considered, corresponding to the detection of highest prevalence (25.3%) (15). The sample size was increased to 400 to adjust for eventual incomplete participation or dropouts.

Using a convenience sampling method, all children aged 2–15 years were enrolled by approaching their parents or companions. The study aims and procedure were explained, and the consenting companions were invited to submit the accompanied child to an ophthalmological screening examination. Children with multiple eye surgeries or with severe chronic eye diseases (e.g. cataract, glaucoma, and congenital eye malformations) were excluded.

Data collection procedure

Two stands equipped with autorefractor KR-8900 (Topcon Corp., Tokyo, Japan) were set up in one of the mall's lobbies. Moreover, 2 consultant ophthalmologists, 2 optometrists, and 3 ophthalmology residents performed the noncycloplegic eye examination. Cylindrical refractive error (Cyl) were measured. Findings were reported in an individual sheet for each child.

Other study data were collected in the same individual datasheet and comprised the child's sociodemographic and clinical characteristics such as age; gender; spectacle wearing; history of amblyopia, myopia, astigmatism, or hyperopia; amblyopia in a sibling; and the mother's and father's ages, educational level, profession and nationality. These data were analyzed as factors and predictors of incidental astigmatism.

Outcome definition
Astigmatism was defined as Cyl of ≥1 diopter (D), and a child screened positive if astigmatism was found in any of the 2 eyes, whereas mild levels of Cyl (0–0.75 D) were considered nonastigmatism. The severity of astigmatism was further categorized into moderate (Cyl = 1.00–2.00), severe (Cyl = 2.25–3.00), and extreme (Cyl > 3.00). Where both eyes of a given child were astigmatic, the eye with the highest Cyl (more severely affected eye) was considered to determine the severity level. Incidental astigmatism was defined as positive screening for astigmatism in a participant with unknown astigmatic status, that is, by exclusion of children who are already known astigmatic.

Statistical methods
The Statistical Package for Social Sciences version 21.0 for Windows (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. The participants' characteristics and Cyl measurements were analyzed using descriptive statistics. Categorical variables were summarized as frequency and percentage, and numerical variables were summarized as mean ± standard deviation (SD), and eventually median, centile (P75), and range. The prevalence of astigmatism was calculated as the percentage of children who screened positive for astigmatism during the campaign; the results are presented with 95% confidence interval (CI). The factors associated with incidental astigmatism (Cyl≥1 D) were analyzed using chi-square test or Fisher's exact test, as appropriate, for categorical variables and independent t-test for discrete variables, including the child's and parents' ages. Multivariate binomial regression was used to analyze the predictors of incidental astigmatism; results are presented as odds ratio (OR) with 95% CI. P < 0.05 was considered statistically significant.

Results

Participants' characteristics
A total of 401 parents or companions participated, of whom 347 (86.5%) allowed their children to undergo ophthalmological assessments. Children and parents' characteristics related to the 347 participations are presented in Tables 1 and 2. The mean age of the participating children was 7.788 (SD = 2.69) years, wherein a majority (57%) were classified in the age group 5–<10 years and 53.3% were female. Clinical data revealed that 15.6% of the children wore spectacles, with a history of amblyopia (8.1%), myopia (2.7%), and astigmatism (1.4%). A history of amblyopia in a sibling was found in 50 cases (14.4%).

Astigmatism levels as measured by cylinder curvature
Measurements of the cylinder curvature (Cyl) in pooled right (n = 317) and left (n = 307) eyes of the participating children revealed mean of 0.98 and 1.02 D, respectively, with median of 0.75 and range of 0.25–5.00 D in both eyes. By considering the worst eye in each child, the overall prevalence of moderate to extreme astigmatism was 41.5% (95% CI = 36.3–46.9), distributed as follows: moderate (26.5%), severe (8.4%), and extreme (6.6%) astigmatism. After excluding children with known astigmatism, the prevalence of incidental astigmatism was 40.6% (95% CI = 35.4–46.1%), distributed as moderate (26.3%), severe (8.5%), and extreme (5.8%) (Table 3).

Factors and predictors of incidental astigmatism
After excluding children with known diagnosis of astigmatism, the prevalence of incidental astigmatism was higher among children with a history of amblyopia (72.0% vs 38.2%, P = 0.001), those who wore spectacles (70.0% vs 32.5%, P < 0.001), and those who had a sibling afflicted with amblyopia (55.1% vs 38.2%, P = 0.026) compared with their counterparts, respectively. However, no significant difference in astigmatism detection rates was found across the age categories.

Regarding the parents' factors, low maternal educational level was associated with a higher prevalence of incidental astigmatism (51.9%) vs high educational level (38.2%), albeit not statistically significant (P = 0.063) (Table 4).

Multivariate binary regression model including significant factors indicated that incidental astigmatism was independently associated with spectacle wearing (OR = 3.60, P = 0.003) (Table 5).

Discussion

Refractive error testing during vision screening is of great diagnostic utility to identify children with visual disorders. That is, school children with mere screening results of 20/20 are still vulnerable to be diagnosed as having astigmatism and hyperopia as sources of visual discomfort (16). Therefore, this study investigated diagnostically confirmed and newly incident cases of astigmatism. The prevalence of incidental astigmatism among children was 40.6%, and it was associated with a previous diagnosis of amblyopia, having a sibling known to have amblyopia, and wearing spectacles. Furthermore, low maternal educational level was relatively associated with a higher prevalence of astigmatism. However, only wearing spectacles was shown to predict incidental astigmatism in the multivariate analysis.

The prevalence rate of astigmatism in children in our study, defined as Cyl of ≥1 D, is higher than other rates reported in the literature among the Saudi population. A review of these studies revealed prevalence rates of 20%, 3.6%, and 11% in Riyadh, Dammam, and Jazan, respectively (10,11,12). Considering astigmatism diagnosis at ≥0.75 D, Aldebasi found a 9.8% prevalence among 5,176 primary school children in Qassim province, whereas Al Wadaani et al reported a 24.5% rate in Al Hassa region (13,14). A study conducted in Medina, which defined astigmatism as >2 D in children aged 3–6 years and >1 D in children aged 6–10 years, found a prevalence of 25.3% with significant variation by age, increasing among older children (15).

The Vision in Preschoolers Study, which is a multicenter study that enrolled 4,040 participants, conducted in the United States, and defined astigmatism as ≥1.5 D, found the prevalence of astigmatism as 17% (17). They found

Table 1: Participants' characteristics (N = 347)

Parameter	Category	Frequency	Percentage
Child's data			
Age	Mean, SD	7.78	2.69
	0–<5	44	12.7
	5–<10	198	57.0
	10–15	105	30.3
Gender	Male	162	46.7
	Female	185	53.3
Has spectacles	No	266	76.7
	Yes	54	15.6
Previously diagnosed with amblyopia	No	319	91.9
	Yes		
Ophthalmological history§	None	262	75.5
	Amblyopia	28	8.1
	Myopia	9	2.7
	Astigmatism	5	1.4
	Strabismus	5	1.4
Amblyopia in a sibling	No	297	85.6
	Yes	50	14.4
Guardian	Mother	180	51.9
	Father	145	41.8
	Other	22	6.3

Because of missing data, some values do not sum up to the total.
SD, standard deviation.
§A participant may have >1 condition.

Table 2: Participants' parents characteristics (N = 347)

Parameter	Category	Frequency	Percentage
Mother's data			
Age	Mean, SD	34.53	5.58
Educational level	Illiterate	3	0.9
	Primary	16	4.6
	Secondary	35	10.1
	Diploma/college	8	2.3
	University	278	80.1
	Not specified	7	2.0
Profession	Housewife	201	57.9
	Employed	90	25.9
	Retired	1	0.3
	Not specified	55	15.9
Nationality	Saudi	176	50.7
	Non-Saudi	130	37.5
Father's data			
Age	Mean, SD	40.53	6.54
Educational level	Illiterate	3	0.9
	Primary	6	1.7
	Secondary	32	9.2
	Diploma/college	21	6.1
	University	281	81.0
	Not specified	4	1.1
Profession	Unemployed	1	0.3
	Employed	337	97.1
	Retired	3	0.9
	Not specified	6	1.7
Nationality	Saudi	174	50.1
	Non-Saudi	133	38.3

Because of missing data, some values do not sum up to the total.
SD, standard deviation.

Table 3: Assessment of astigmatism in the study population

Parameter/Statistics	Population			
	Right eye (n = 317)	Left eye (n = 307)	Child§ (Overall, N = 347)	Child§ (Incidental, N = 342)
Cyl (diopter)				
Mean	0.98	1.02	-	
SD	0.90	0.91	-	
Median	0.75	0.75	-	
P75	1.25	1.25	-	
Range	0.25, 5.00	0.25, 5.00	-	
Astigmatism (Cyl, diopter)				
None (0.00)	1 (0.3)	1 (0.3)	0 (0.0)	0 (0.0)
Mild (<1.00)	202 (63.7)	187 (60.9)	203 (58.5)	203 (59.4)
Moderate (1.00–2.00)	72 (22.7)	75 (24.4)	92 (26.5)	90 (26.3)
Severe (2.25–3.00)	26 (8.2)	29 (9.4)	29 (8.4)	29 (8.5)
Extreme (>3.00)	16 (5.1)	15 (5.0)	23 (6.6)	20 (5.8)

§The eye with the worst level of astigmatism was considered per child. Values in the lower part of the table are frequency (percentage); percentages were calculated by the specified number in each population.

that the risk of astigmatism varies by ethnicity, being higher in Hispanic, African American, and Asian races than non-Hispanic white Americans. They also found that astigmatism was higher in older children. Moreover, Hashemi et al.(18) did a systematic review and meta-analysis to estimate the global prevalence of refractive errors. They estimated the global astigmatism prevalence in children as 14.9% with considerable variation among different studies (0.3% to 91%). When the estimated pooled prevalence was calculated according to the World Health Organization regions, the highest was seen in the Americas (27.2%), followed by the Eastern Mediterranean region (20.4%), and the lowest was seen in Southeast Asia (9.8%). They reported that astigmatism was the most common refractive error in children.

The variation in astigmatism prevalence figures in children across different global and local studies may be attributed to the differences in cutoff definitions of astigmatism, ethnic variations, socioeconomic conditions, and environmental factors. We used a cutoff astigmatism definition of 1 D according to a study conducted by Wang et al.(19) which found that visual acuity impairment occurred with astigmatism at ≥1.00 D and suggested a cutoff Cyl of ≥1.00 D for clinically significant astigmatism. Because astigmatism prevalence increases with age, the inclusion of older children in our study (the majority being aged ≥5 years) may partly explain the higher prevalence than those reported in local studies with younger pediatric populations (13,15,17). Another possible explanation is that our study was conducted in Jeddah, Saudi Arabia, wherein most residents come from different ethnic backgrounds compared with other regions in Saudi Arabia. Another factor that might explain this high prevalence is the presence of a selection bias, that is, the awareness campaign might have been more attractive to parents who have children with eye complaints and/or eye diseases.

In this study, a tabletop autorefractor was used to measure astigmatism in children without cycloplegia. This will not likely affect the results of measured astigmatism prevalence than that measured by cycloplegic retinoscopy, as there are many studies that have suggested that noncycloplegic autorefraction may have a role as a screening tool for astigmatism among young children (20,21,22,23). These studies found that there is minimal difference between the cylinder power when measured with noncycloplegic autorefraction (tabletop or handheld) and that measured with cycloplegic retinoscopy. This is likely explained by the fact that accommodation, which is triggered by the autorefractor near stimulus, does not affect the cylinder magnitude.

In the current study, astigmatism was associated with a personal history of amblyopia, which is consistent with the literature documenting astigmatism as a risk factor of developing amblyopia. Sjostrand and Abrahamsson (24) found that children with constant or increased astigmatism between 1 and 4 years of age were more likely to develop amblyopia. Similarly, in more recent cross-sectional investigations, astigmatism has been considered a risk factor of subsequent amblyopia (25,26). It was suggested that astigmatism during early visual development (>2 years of age) may lead to a specific form of meridian visual deprivation (meridional amblyopia) and visual cortex alterations. Based on the magnitude of astigmatism and the following meridional variations, patients may experience reductions in Vernier acuity, grating acuity, and contrast sensitivity (27). Therefore, young infants with astigmatism who do not undergo emmetropization

Table 4: Factors associated with incidental astigmatism (N = 342)

Factor	Category	Astigmatism				*P* value
		None or mild		Yes (moderate+)		
		Frequency	%	Frequency	%	
Child's factor						
Age category	0–<5	22	51.2	21	48.8	
	5–<10	118	60.2	78	39.8	
	10–15	63	61.2	40	38.8	0.452
Gender	Male	94	59.1	65	40.9	
	Female	109	59.6	74	40.4	0.934
Previously diagnosed with amblyopia	No	196	61.8	121	38.2	
	Yes	7	28.0	18	72.0	0.001*
Has spectacles	No	179	67.5	86	32.5	
	Yes	15	30.0	35	70.0	<0.001*
Sibling afflicted with amblyopia	No	181	61.8	112	38.2	
	Yes	22	44.9	27	55.1	0.026*
Mother's factors						
Age	Mean, SD	34.42	5.93	34.82	4.98	0.545
Educational level	Low	25	48.1	27	51.9	
	High	175	61.8	108	38.2	0.063
Professional status	Housewife	121	60.2	80	39.8	
	Employed	55	64.7	30	35.3	0.474
Nationality	Saudi	100	58.1	72	41.9	
	Non-Saudi	83	63.8	47	36.2	0.315
Father's factors						
Age	Mean, SD	40.45	6.54	40.70	6.57	0.756
Educational level	Low	25	64.1	14	35.9	
	High	176	58.9	123	41.1	0.531
Nationality	Saudi	100	58.8	70	41.2	
	Non-Saudi	81	60.9	52	39.1	0.714

Because of missing data, some values do not sum up to the total.
SD, standard deviation.
*Statistically significant result (P < 0.05).

Table 5: Predictors of incidental astigmatism (N = 342)

Predictor	OR	95% CI		*P* value
Previously diagnosed with amblyopia	1.17	0.36	3.79	0.796
Has spectacles	3.60	1.55	8.35	0.003*
Sibling afflicted with amblyopia	1.43	0.70	2.93	0.325

Multivariate binary regression; dependent variable: presence of incidental astigmatism.
*Statistically significant result (P < 0.05).
CI, confidence interval
OR, odds ratio

during the first years of life would typically develop meridional amblyopia.

Spectacle wearing was another significant factor and the only predictor of incidental astigmatism. Actually, this was not surprising because spectacle lens correction is the most common method used for the clinical correction of astigmatic eyes. However, an intriguing finding in our study is that corrective spectacles predicted incidental astigmatism, which may be explained by the fact that some parents might not know the nature and type of refractive error that the glasses were dispensed to correct, owing to either lack of understanding or poor education by the ophthalmologist or optometrist who prescribed the glasses.

The functional and clinical implications of uncorrected astigmatism during a specific critical period (early childhood) underscore the importance of targeting the factors that may influence the lack of correction of these visual problems. First of all, it is imperative to enhance knowledge among families and in the community to support regular vision screening in infants and children. Notably, we found that low maternal educational level was associated with relatively higher percentage of newly diagnosed incident astigmatism, and the result approached statistical significance. This indicates that mothers with a higher educational level and subsequently who are more knowledgeable are more likely to consult an ophthalmologist and detect visual problems in their children at an earlier age. Therefore, it is necessary to establish suitable interventional programs to raise awareness and knowledge levels among low-educated parents, to screen children for astigmatism and other refractive errors at easily correctable ages. Besides, late detection of refractive errors, for example, in children older than 10–12 years, would result in poorer prognosis, because the children may have developed incurable amblyopia (15). Other factors that should be considered for optimal refractive error correction include facilitating affordable corrective lenses, enhancing adherence to wearing spectacles, and promoting affordable refractive services.

In this cross-sectional study, we were unable to investigate other potential confounders that might have affected the outcomes. Parent-reported outcomes are subject to bias or misunderstanding, which could affect the associated factors of astigmatism. Because of the study design where data was collected from participants at a mall during a 2 days awareness campaign concerning amblyopia, there is potential selection bias, which adds to this study's limitations. Therefore, conducting further studies would overcome such limitations and help reveal the potential relationships between a comprehensive panel of genetic and environmental factors and the development of astigmatism. Besides, in line with the scarce studies in Saudi Arabia, the impact of compliance to prescribing guidelines about spectacle use and need should be thoroughly investigated on the local level.

Conclusion

Astigmatism was highly prevalent among screened children in Jeddah, Saudi Arabia, and was associated with a history of amblyopia, wearing spectacles, and having a sibling with amblyopia. The reported rate (41.5%) was higher than most figures reported at the local, regional, and international levels. Besides, newly detected children with astigmatism represented 40.6% of children without apparent astigmatism. This underscores the importance of conducting additional population-based screening campaigns to address the prevalence and associated risk factors of astigmatism at a national level and to explore the levels of compliance to spectacle prescribing guidelines. Regular vision screening and educational campaigns are required to increase awareness and knowledge levels of parents and teachers at schools regarding the functional and clinical consequences of uncorrected astigmatism during visual development in children.

Ethics approval and consent to participate
Written informed consent was obtained from all parents. The study was approved by the Biomedical Ethics Research Committee at King Abdulaziz University, Jeddah, Saudi Arabia, and conducted in accordance with the ethical standards of the Declaration of Helsinki (Reference No 216-16).

References

1. Levene JR, Hartley HB. Sir George Biddell Airy, FRS (1801-1892) and the discovery and correction of astigmatism. Notes Rec R Soc Lond. 1966;21(2):180–199.
2. Read SA, Collins MJ, Carney LG. A review of astigmatism and its possible genesis. Clin Exp Optom. 2007;90(1):5–19.
3. Parssinen O, Kauppinen M, Kaprio J, et al. Heritability of corneal refraction and corneal astigmatism: a population-based twin study among 66- to 79-year-old female twins. Acta Ophthalmol. 2013;91(2):140–144.
4. Pascual M, Huang J, Maguire MG, et al. Risk factors for amblyopia in the vision in preschoolers study. Ophthalmology. 2014;121(3):622–629.e1.
5. Wu L, Weng C, Xia F, et al. Internal astigmatism and its role in the growth of axial length in school-age children. J Ophthalmol. 2018;2018(1686045-.
6. Dobson V, Harvey EM, Clifford-Donaldson CE, et al. Amblyopia in astigmatic infants and toddlers. Optom Vis Sci. 2010;87(5):330–336.
7. Harvey EM, McGrath ER, Miller JM, et al. A preliminary study of astigmatism and early childhood development. J Aapos. 2018;22(4):294–298.
8. Harvey EM, Miller JM, Twelker JD, Davis AL. Reading fluency in school-aged children with bilateral astigmatism. Optom Vis Sci. 2016;93(2):118–125.
9. Aghai G, Dibajnia P, Ashkesh E, et al. Behavior disorders in children with significant refractive errors. J Curr Ophthalmol. 2016;28(4):223–225.
10. Alsaqr AM, Ibrahim G, Sharha AA, Fagehi R. Investigating the visual status of preschool children in Riyadh, Saudi Arabia. Middle East Afr J Ophthalmol. 2017;24(4):190–194.
11. Al-Tamimi ER, Shakeel A, Yassin SA, et al. A clinic-based study of refractive errors, strabismus, and amblyopia in pediatric age-group. J Family Community Med. 2015;22(3):158–162.
12. Al Bahhawi T, Makeen AM, Daghreeri HH, et al. Refractive error among male primary school students in Jazan, Saudi Arabia: prevalence and Associated Factors. Open Ophthalmol J. 2018;12:264–272.
13. Aldebasi YH. Prevalence of correctable visual impairment in primary school children in Qassim Province, Saudi Arabia. J Optom. 2014;7(3):168–176.
14. Al Wadaani FA, Amin TT, Ali A, Khan AR. Prevalence and pattern of refractive errors among primary school children in Al Hassa, Saudi Arabia. Glob J Health Sci. 2012;5(1):125–134.
15. Alrahili NHR, Jadidy ES, Alahmadi BSH, et al. Prevalence of uncorrected refractive errors among children aged 3-10 years in western Saudi Arabia. Saudi Medical Journal. 2017;38(8):804–810.
16. Fotouhi A, KhabazKhoob M, Hashemi H, et al. Importance of including refractive error tests in school children's vision screening. Arch Iran Med. 2011;14(4):250–253.
17. Huang J, Maguire MG, Ciner E, et al. Risk factors for astigmatism in the Vision in Preschoolers Study. Optom Vis Sci. 2014;91(5):514–521.
18. Hashemi H, Fotouhi A, Yekta A, et al. Global and regional estimates of prevalence of refractive errors: systematic review and meta-analysis. J Curr Ophthalmol. 2017;30(1):3–22.
19. Wang LL, Wang W, Han XT, He MG. Influence of severity and types of astigmatism on visual acuity in school-aged children in southern China. Int J Ophthalmol. 2018;11(8):1377–1383.
20. Cordonnier M, Dramaix M. Screening for refractive errors in children: accuracy of the hand held refractor Retinomax to screen for astigmatism. Br J Ophthalmol. 1999;83(2):157–161.
21. Miller JM, Harvey EM, Dobson V. Visual acuity screening versus noncycloplegic autorefraction screening for astigmatism in Native American preschool children. J AAPOS. 1999;3(3):160–165.
22. Oral Y, Gunaydin N, Ozgur O, Arsan AK, Oskan S. A comparison of different autorefractors with retinoscopy in children. J Pediatr Ophthalmol Strabismus. 2012;49(6):370–377.
23. Zhao J, Mao J, Luo R, Li F, Pokharel GP, Ellwein LB. Accuracy of noncycloplegic autorefraction in school-age children in China. Optom Vis Sci. 2004;81(1):49–55.
24. Sjostrand J, Abrahamsson M. Risk factors in amblyopia. Eye (Lond). 1990;4(6):787–793.
25. Chia A, Lin X, Dirani M, et al. Risk factors for strabismus and amblyopia in young Singapore Chinese children. Ophthalmic Epidemiol. 2013;20(3):138–147.
26. Mocanu V, Horhat R. Prevalence and risk factors of amblyopia among refractive errors in an Eastern European Population. Medicina (Kaunas). 2018;54(1).
27. Read SA, Vincent SJ, Collins MJ. The visual and functional impacts of astigmatism and its clinical management. Ophthalmic Physiol Opt. 2014;34(3):267–294.