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RESEARCH

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Refractive errors, amblyopia risk factors and vision screening in children aged 7–10 years in Aotearoa New Zealand

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ABSTRACT

Clinical relevance: Vision screening is important for detecting undiagnosed vision conditions that are common in school-aged children. However, current vision screening protocols are poor at detecting vision conditions that are most common in the Aotearoa New Zealand paediatric population.

Background: Uncorrected refractive error and amblyopia are the most common causes of visual impairment in children. The most appropriate vision screening method depends on the refractive error profile of the population. This study aimed to: estimate the prevalence of refractive errors and amblyopia risk factors among children living in Aotearoa New Zealand; describe previous participation in preschool vision screening and determine the diagnostic accuracy of potential screening methods.

Methods: Children aged 7–10 years received comprehensive eye examinations, including cycloplegic refraction, in their school. Eye examination results were assessed for refractive error and amblyopia risk factors. The sensitivity and specificity of individual vision tests for detecting any vision conditions was calculated to assess the most effective tests for vision screening.

Results: Eye examinations were completed for 237 children and cycloplegic refraction data was available for 220 of these children. Significant refractive error (need for glasses) was detected in 23.6% of children (7.7% myopia, 7.7% hyperopia, 15.0% astigmatism). Amblyopia risk factors were detected in 9.1% of children. Preschool vision screening had been completed by 78.5% of children. Distance visual acuity screening alone had a sensitivity of 39% for detecting vision conditions, with addition of the Spot Vision Screener improving sensitivity to 65%.

Conclusion: Astigmatism is the most frequent refractive error among children aged 7–10 years living in Aotearoa New Zealand. Distance visual acuity screening alone is ineffective in detecting refractive error in children in Aotearoa New Zealand. Further research investigating refractive errors across the paediatric population in Aotearoa New Zealand is required to determine the optimal timing and appropriate protocols for school-aged vision screening.

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Introduction

Uncorrected refractive error is the leading cause of visual impairment in children,[1] is associated with poorer academic outcomes[2] and can lead to vision loss from amblyopia, progressive myopia,[3] or keratoconus.[4] Correction of myopia and initiation of myopia control methods may reduce myopia progression and the potential ocular complications and vision loss resulting from high myopia.[3] Furthermore, as increasing astigmatism can be an early sign of keratoconus,[4] it is important that children with astigmatism receive regular follow-up to ensure appropriate detection and timely treatment. Therefore, early detection and correction of refractive errors is important.

Children frequently do not report visual symptoms.[5] Additionally, those living in areas of socioeconomic disadvantage are less likely to attend an eye examination than those living in more advantaged areas.[6] Therefore, vision screening plays an important role in detecting vision conditions in children.[7] Vision screening has been shown to be cost-effective,[8] and correction of refractive error has a significant return on investment.[9]

In Aotearoa New Zealand (NZ), children aged 4–5 years receive unilateral visual acuity (VA) screening (with the Parr vision test at 4 m)[10] as part of a nationwide well child check at that age. A further unilateral VA screening is completed at age 11–12 years, using a Snellen chart at 6 m.[11] Both screenings are performed by vision-hearing technicians (trained lay screeners). However, evidence for the effectiveness of Parr vision test used during preschool vision screening, and the use of VA screening in children aged 11–12 years is lacking.[12,13]

The most appropriate method of screening depends on the target conditions and the refractive error profile of the population.[14] Previous studies of NZ children aged 4–7 years have shown the primary refractive error in this age group is astigmatism.[15,16] However, the prevalence of vision conditions in older children is currently unknown.

Photorefraction, an automated method of screening for significant refractive error and strabismus has been shown to

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be more accurate than distance VA screening for detecting vision conditions in populations with high levels of astigmatism.[17] Furthermore, combining measures of distance and near VA,[18] or photorefraction and distance VA,[16,19] or stereoacuity,[20] improves sensitivity in detecting ocular conditions, compared with screening using only distance VA measurement.

Therefore, in this study of children aged 7–10 years living in Auckland, NZ we aimed to:

(1) determine the proportion of children with corrected and uncorrected refractive error and amblyopia risk factors; (2) examine previous participation in, and outcomes of, the NZ preschool vision screening programme; and (3) compare the efficacy of distance VA screening with near VA measurement, stereoacuity measurement and the Spot Vision Screener for detecting amblyopia risk factors and significant refractive error.

Methods

The research followed the tenets of the Declaration of Helsinki. Ethical approval was obtained from the University of Auckland Human Ethics Committee (Reference number: 020926). Written informed consent was obtained from each participant's parent or caregiver, and written assent was obtained from the child.

Participants

Children aged 7–10 years were recruited by convenience sampling in six primary schools in South Auckland, NZ. Children were purposely recruited from schools with decile ratings (a measure of the socioeconomic status of the community in which the school's residents reside), that were classified as high (deciles 8–10), moderate (deciles 4–7) and low (deciles 1–3). This ensured that the study sample included children from a range of socioeconomic areas.

Comprehensive eye examinations

All children received a comprehensive eye examination by an experienced paediatric optometrist, which was completed at their school. Distance and near VA were measured unaided and using the participant's habitual correction, where available. Distance VA was measured using the Electronic Early Treatment for Diabetic Retinopathy Study (e-ETDRS) protocol presented on an Electronic Visual Acuity testing system (JAEB Centre for Health Research) at 3 m.[21] Near VA was measured using the Sloan letter near logMAR acuity chart (Good-Lite Company) at 40 cm. Single line scoring was used in VA measurement and the child was considered to have successfully achieved a logMAR level if they correctly named four of the five letters for that level.

Binocular vision assessment included the cover–uncover test and alternating cover test performed at 6 m and 40 cm, and measurement of near stereoacuity using the Randot Preschool stereotest at 40 cm (2012, Stereo Optical Company Inc).

Non-cycloplegic photorefraction was performed using the Spot Vision Screener VS100 (Software version 3.0.04.02, Welch Allyn). Refractive error assessment was completed a minimum of 40 min after instillation of one drop of cyclopentolate 1% to each eye using retinoscopy. Cycloplegia was considered complete when the pupils had a minimum diameter of 6 mm and were unreactive to light.

Slit-lamp examination of the anterior segment and dilated fundus examination with binocular indirect ophthalmoscopic evaluation were performed to assess the health of the anterior and posterior segments of the eyes.

Preschool vision screening results

Results of the preschool vision screening[11] of each child were obtained from the Counties Manukau preschool vision screening team.

Definitions for vision conditions

Refractive error was classified using the cycloplegic retinoscopy results. Clinically significant refractive error (requiring glasses, Table 1) was defined according to the criteria described by the Refractive Error Studies in Children group.[22] Amblyopia risk factors (Table 1) were defined according to the American Academy of Ophthalmology guidelines.[23] Children who had more than one vision condition were included in the counts for each condition they had. Spectacle coverage was defined as children with significant refractive error that had refractive correction.

Vision tests as screening tools

Four of the vision tests employed in the comprehensive eye examinations (distance VA, near VA, stereoacuity and the Spot Vision Screener) were assessed as potential screening tools in this population. The results of these tests were compared against the full comprehensive eye examination results to determine their sensitivity and specificity for detecting the refractive error or amblyopia risk factors described in Table 1.

For each vision test, children were classified as failing vision screening if they met predetermined failure criteria in one or both eyes (Table 2). When assessing the diagnostic accuracy of two or more tests combined, children were considered to have failed vision screening when failure criteria for at least one of the vision tests were met. The failure criteria for VA measurement were those currently used in the NZ preschool vision screening programme.[11] For stereoacuity measurement, the failure

Table 1. Definitions for significant refractive error[22] and amblyopia risk factors.[23]

Significant refractive error	
Myopia*	≤ −0.50 D
Hyperopia*	≥ +2.00 D
Astigmatism	≥0.75 D
Amblyopia risk factors	
Visual pathway obstruction	Visual pathway obstruction present
Strabismus	Any manifest deviation
Anisometropia	
Myopia*	≥2.50 D
Hyperopia*	≥1.50 D
Astigmatism	≥1.50 D in any meridian
Bilateral refractive error	
Myopia*	≤ −2.50 D
Hyperopia*	≥ +3.50 D
Astigmatism	≥1.50 D

*Spherical equivalent
D = Dioptres

Table 2. Predetermined failure criteria for vision tests.

Screening method	Failure criteria
Visual acuity measurement	≥0.3 logMAR
Stereoacuity	>200 arcsec
Spot vision screener	Myopia ≤ −1.25 D
	Hyperopia ≥ +2.50 D
	Astigmatism ≥1.75 D
	Anisometropia ≥1.00 D
	Ocular misalignment

criteria were based on previously published normative data.[24] The failure criteria for the Spot Vision Screener were the pre-programmed referral thresholds for the instrument.

Analysis

Data analysis was conducted using SPSS Statistics (Version 27, IBM Corporation, New York, USA). Descriptive statistics were used to summarise the data and presented as medians and interquartile ranges (IQR) for non-parametric data. Receiver operator characteristic (ROC) curve analysis was performed using MedCalc (Version 22.030, MedCalc Software Ltd).

The sensitivity and specificity of each vision test assessed as a potential screening tool was calculated by comparing the outcome (pass/fail; Table 2) for any of the refractive error or amblyopia risk factors detected by the comprehensive eye examination (Table 1). Pairwise comparisons of sensitivity and specificity between vision tests were made using the McNemar chi-square test for correlated data. A two-tailed $p < 0.05$ was considered statistically significant. ROC curves were plotted for the different vision tests for detecting significant refractive error and amblyopia risk factors. The Spot Vision Screener measurements were plotted using the cylinder component and the positive and negative sphere components separately.

Results

Caregiver consent to participate in the study was obtained for 240 children. Two children had left their schools prior to testing and one child did not assent to testing. Therefore, the final sample consisted of 237 children (53.6% female) with a median (IQR) age of 9.3 (8.2–10.2) years. The ethnic composition of the participants was 8.4% Māori, 19.4% Pacific, 29.5% Asian and 39.2% European or other ethnicities.

Vision conditions

Cycloplegic refraction was completed for 220 children; 12 caregivers did not consent to the use of cycloplegic eye drops, and a further five children did not assent to instillation of drops on the day of examination. Of the children who completed cycloplegic refraction, 23.6% (52/220) had significant refractive error (Table 3) and 44.2% (23/52) of these were wearing refractive correction at the time of our assessment. Among the children wearing refractive correction, 18/23 (78.2%) passed the vision screening cut-offs with their habitual correction.

Amblyopia risk factors were detected in 20 children (Table 3). Of these, 85.0% (17/20) had significant refractive error. Twelve children (70.6%) with amblyopia risk factors and significant refractive error were wearing refractive correction at the time of our assessment. Six children (30%) with amblyopia risk factors had reduced corrected VA in one or both eyes. Of these, three children (50%) were corrected at the time of our assessment. No children in the study had ocular pathology detected.

Table 3. Prevalence of vision conditions.

Vision condition	n (%)
Refractive error (either eye) ($n = 220$)*	
Myopia	17 (7.7)
Hyperopia	17 (7.7)
Astigmatism	33 (15.0)
Any refractive error	52 (23.6)
Amblyopia risk factors ($n = 220$)†	
Strabismus	6 (2.7)
Anisometropia	7 (3.2)
Bilateral refractive error	12 (5.5)
Any amblyopia risk factor	20 (9.1)
Ocular pathology	0 (0.0)
Any vision condition ($n = 220$)	71 (30.0)
Spectacle coverage ($n = 52$)	23 (44.2)

*Seven children had both myopia and astigmatism and eight had both hyperopia and astigmatism.
†One child had both strabismus and anisometropia, three children had both strabismus and bilateral refractive error and two children had both anisometropia and bilateral refractive error.

Preschool vision screening

A preschool vision screening outcome was recorded for 79.3% (188/237) of the children (Figure 1). Of these, 153 (64.6%) children passed screening, 24 (10.1%) were referred and 6 (2.5%) were identified for rescreening. No preschool vision screening outcome was recorded for 49 (20.6%) children and two (0.8%) children declined vision screening. Three children (1.3%) were under the care of an eye care provider and therefore not eligible for vision screening at the time of the preschool vision screening. Four (20%) of the children with amblyopia risk factors had previously passed their preschool vision screening and five (25%) had not received preschool vision screening.

Of the children who did not participate in the preschool vision screening at 4–5 years of age, 23.5% (12/51) had significant refractive error at the time of our assessment (aged 7–10 years) including five (9.8%) with amblyopia risk factors. Of these, 50% (6/12) had refractive correction at the time of our assessment. Of the 24 children who had been referred from the preschool vision screening, 15 (62.5%) were identified with significant refractive error at our assessment, with spectacle coverage of 53.3% (8/15). Of the 153 children who had passed the preschool vision screening, 20 (13.0%) had significant refractive error at the time of our assessment, of

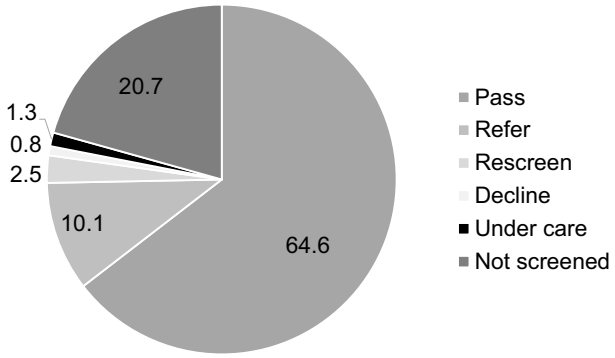

Figure 1. Preschool vision screening outcomes (%) for study participants.

whom 9 (45.0%) had myopia and 11 (55.0%) had hyperopia and/or astigmatism; 25% (5/20) were corrected.

Diagnostic accuracy of vision assessment methods

Table 4 presents sensitivity and specificity for the four vision tests, administered separately and in combination, for detecting any ocular condition as defined in Table 1, and also presents the *P*-values for pairwise comparison with distance VA testing alone. The sensitivity of the three alternative methods did not differ significantly from distance VA testing (near VA, $p = 0.41$; stereoacuity, $p = 0.31$; Spot Vision Screener, $p = 0.54$). However, near VA testing ($p = 0.02$) and stereoacuity ($p = 0.03$) had significantly lower specificity than distance VA testing. Each combination of vision tests had significantly higher sensitivity and lower specificity than distance VA alone. ROC curve analysis (Supplementary Table S2) gave optimal referral cut-offs. For each of the vision tests, a lower referral threshold increased sensitivity for detecting any ocular condition.

Discussion

This study provides contemporary data on vision disorders and vision assessment in children aged 7–10 years in NZ. Nearly 25% of the children in this study had significant refractive error, more than half of whom did not have refractive correction. Approximately 20% of the children had not previously participated in vision screening. Measurement of distance VA, the method currently employed for screening school-aged children in NZ, had sensitivity for detecting vision conditions that did not differ significantly to use of near VA, stereoacuity or Spot Vision Screener testing. Addition of the Spot Vision Screener to the current protocol increased the number of children correctly identified with refractive error (increased sensitivity).

Table 4. Diagnostic accuracy of vision assessment methods for detecting any ocular condition and *P*-values for pairwise comparison with distance VA testing alone.

Vision test	Sensitivity (*P*-value)	Specificity (*P*-value)
Single test		
Distance VA	0.39 (Ref)	0.96 (Ref)
Near VA	0.41 (1.00)	0.91 (0.02)
Stereoacuity	0.31 (0.30)	0.90 (0.03)
Spot Vision Screener	0.54 (0.06)	0.96 (1.00)
2 tests		
Distance VA and near VA	0.54 (0.01)	0.90 (0.004)
Distance VA and stereoacuity	0.49 (0.06)	0.87 (<0.001)
Distance VA and Spot	0.65 (<0.001)	0.92 (0.03)
Near VA and stereoacuity	0.47 (0.04)	0.84 (<0.001)
Near VA and Spot	0.59 (0.02)	0.87 (<0.001)
Stereoacuity and Spot	0.62 (0.01)	0.87 (<0.001)
3 tests		
Distance VA, near VA and stereoacuity	0.60 (<0.001)	0.84 (<0.001)
Distance VA, near VA and Spot	0.67 (<0.001)	0.87 (<0.001)
Distance VA, stereoacuity and Spot	0.69 (<0.001)	0.85 (<0.001)
Near VA, stereoacuity and Spot	0.64 (0.01)	0.81 (<0.001)
All four tests		
Distance VA, near VA, stereoacuity and Spot	0.71 (<0.001)	0.81 (<0.001)

VA = visual acuity, Spot = Spot Vision Screener

Refractive error and amblyopia risk factors

Significant refractive error was detected in 23.6% of children in the current study. This proportion was lower than reported in the Welcome To School study (31.6%) which evaluated refractive error and visual impairment of NZ children aged 6–7 years from an area of socioeconomic disadvantage.[15] Astigmatism was the most common refractive error, in both the Welcome to School study (25.4%) and the current study (15.0%). The proportion of children with hyperopia (7.7%) in the present study is comparable to the proportion of hyperopia reported in the Welcome to School study (6.1%). The proportion of children with myopia (7.7%) in the present study was larger than that reported in the Welcome to School study (3.5%).[15]

These disparities may be due to differences in study recruitment, and in the ages and ethnicities of the children participating in each study. Children in the Welcome to School study were recruited to take part in a multidisciplinary study without a specific vision focus. In contrast, for the current study, children were recruited to specifically take part in a study about visual function and reading. Some parents may have declined participation due to known vision problems that were considered adequately corrected.

Studies of refractive error in children living in urban areas in Australia at ages 6 and 12 years, found the prevalence of astigmatism comparable to that found in the current study (10.3% at 6 years and 13.6% at 12 years). In contrast, the prevalence of myopia (1.4% at 6 years and 12.5% at 12 years) was higher and the prevalence of hyperopia (9.4% at 6 years and 2.8% at 12 years) were lower than the present study.[25]

A study of Australian children aged 5–13 years from schools with large numbers of Indigenous children, found a lower prevalence of astigmatism than the present study (3.4% and 1.9% in Indigenous and non-Indigenous children, respectively).[26] The prevalence of hyperopia was similar to the current study (5.1% and 8.1% in Indigenous and non-Indigenous children, respectively) and the prevalence of myopia was lower (1.7% in Indigenous and 4.0% in non-Indigenous children).[26]

In contrast, specific populations of children in the Americas have a prevalence of astigmatism of 30% to 40%, as do those in studies with high myopia prevalence.[27,28] Population studies of children in East Asian countries demonstrate higher prevalence of the myopia (5–20.4%) and lower prevalence of hyperopia (1.3–5.9%).[28] These differences in refractive error prevalence reflect that ethnicity and socioeconomic differences influence refractive error development.

Preschool vision screening outcomes

One in five children in the present study had no recorded preschool vision screening outcome which is higher than seen in previous studies.[15,29,30] This lower attendance rate at preschool screening in our sample may be partly explained mobility of families; data from the 2018 census found 4.7% of children aged 0–15 years did not reside in NZ 5 years previously.[31]

Although children who do not receive vision screening at 4 years of age are targeted for screening on school entry, the cut-off for new entrant vision screening is at the end of Year 3

(age 7–8 years). Therefore, children who move to NZ after this age may not have previously received screening and do not receive formal vision screening until the Year 7 screening at 11–12 years of age.

More than half of children with significant refractive error (54.0%) and four children (33.3%) with amblyopia risk factors had previously passed their preschool vision screening. Due to the time that had elapsed between the preschool vision screening (age 4–5 years) and our assessment (age 7–10 years), it is not possible to determine if these children had significant refractive error at the time of their preschool vision screening. Nine children had myopia which is likely to have developed after preschool vision screening. The remaining 11 children had hyperopia and/or astigmatism that may have been present at the time of preschool vision screening.

The aim of the current preschool vision screening programme is detection of amblyopia. However, non-amblyogenic levels of hyperopia and astigmatism have been associated with poorer results on tests of academic performance.[2] Therefore, improvements to the screening protocol are necessary to ensure that NZ children with significant refractive error that may affect classroom learning are being detected through vision screening. Furthermore, as most (77.8%) of children with myopia did not have spectacle correction, further vision screening at an older age may be indicated to ensure NZ children have the spectacle correction they need for learning.

Effective screening programmes require that treatment is available, affordable and accessible.[32] Refractive error is correctable with glasses or contact lenses and correction results in improved VA and/or reduced asthenopic symptoms.[33] In the current study, only 44.2% of the children with significant refractive error and only 53.3% of those children previously referred from preschool vision screening were wearing spectacle correction. Similar compliance levels are seen internationally.

A recent meta-analysis found an overall compliance with spectacle use of 40.1% in children, with lost or broken spectacles, forgetfulness and parental disapproval being the main reasons for non-compliance.[34] Further research is required to identify barriers to caregivers accessing eye care for their children and reasons for non-compliance with spectacle wear in the NZ paediatric population.

Diagnostic accuracy of vision assessment methods

Measurement of distance VA, the testing method currently employed in vision screening programmes for children in NZ had good specificity for correctly classifying children with normal vision. However, 60% of children with a vision condition would not be identified.

The appropriate balance between sensitivity and specificity depends on the availability of eyecare resources. Where eyecare resources are limited, high specificity (>90%) is important to reduce the number of false positive referrals. However, where eyecare resources are accessible, increasing the number of children correctly identified with an eye condition and referred for assessment and treatment will improve equity for children living in lower socioeconomic areas. Previous studies have shown that combining screening tools increases sensitivity in detecting ocular conditions.[16,18,19]

In the current study, combining vision screening tools increased sensitivity, and decreased specificity, for detecting a vision condition. Addition of the Spot Vision Screener to distance VA testing significantly improved the detection of ocular conditions while maintaining specificity higher than 90%. These results are in agreement with a previous study of preschool-aged NZ children,[16] and other studies that found that autorefraction is more effective than VA screening in detecting refractive error in populations with a high prevalence of astigmatism.[17,35]

A study assessing screening for amblyopia risk factors in Australian children also found that adding the Spot Vision Screener to VA testing increased sensitivity of the screening.[19] Furthermore, for each of the screening tools, the optimal referral cut-off was lower (i.e. a better level of VA, lower refractive error) than the current referral criterion (distance VA) or pre-programmed referral criteria (Spot Vision Screener). Changing to these lower referral thresholds would result in an increased sensitivity, but decreased specificity, in detecting children with an eye condition.

The lower overall participation in preschool vision screening in the current study compared with previous studies, and an increasing prevalence of myopia with age in NZ children, supports the need for further vision screening at a later age following preschool vision screening. To maximise efficacy, this screening should be targeted towards refractive errors that have the highest prevalence in the NZ paediatric population. Therefore, inclusion of the Spot Vision Screener is likely to improve efficacy of school-aged vision screening as more children will be correctly identified with an ocular condition.

This study has several potential limitations. The children recruited into this study are not a representative sample of the NZ paediatric population, as all resided in Auckland in an urban setting, which may limit the generalisability of the results for children in rural areas. However, the schools invited to participate comprised a range of school deciles to ensure that the study sample included children from a range of socioeconomic backgrounds.

A further limitation is that the data could over-estimate the prevalence of vision conditions as the proportion of children of Asian ethnicity was higher in the study population (29.5%) than the general population (15.1%).[31] There is a need for a population-based paediatric eye health survey in NZ to determine the prevalence of refractive error and other visual conditions. This will in turn inform the most appropriate methods and timings for vision screening.

The data used to calculate the sensitivity and specificity of the vision tests in the current study were collected as part of the comprehensive eye examinations and not specifically as a diagnostic accuracy study. Distance VA measurements were made by a trained lay screener, but all other data was collected by a paediatric optometrist. Nonetheless, the results are consistent with those of a previous diagnostic accuracy study of NZ preschool children,[16] suggesting the results will be applicable to screening by lay screeners in the community.

Participation in this study by Māori children was relatively low (8.4%), compared to the general population (16.5%).[31] This is despite recruitment across a range of school deciles including those with a high proportion of Māori children. Future research should employ Kaupapa Māori methodologies to improve Māori participation and thus ensure that future policy changes benefit Māori children and improve equity.

Conclusion

The most common refractive error in NZ children 7–10 years of age was astigmatism. Less than half of children with refractive error were wearing correction. One in five children had not previously received vision screening. The addition of the Spot Vision Screener to current VA screening is likely to improve the number of children correctly identified with a vision condition.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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