EXTENDED REPORT

Socioeconomic status, systolic blood pressure and intraocular pressure: the Tanjong Pagar Study

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Background: Lower socioeconomic status (SES) is associated with higher morbidity and mortality in many countries. Present evidence suggests that glaucoma has similar risk factors to major chronic diseases such as cardiovascular disease. This study investigates the association between SES and intraocular pressure (IOP), an important risk factor for glaucoma.

Methods: The Tanjong Pagar Study was a population-based cross-sectional survey of Chinese people aged 40–79 years, who were randomly selected from the Singapore electoral register. Of the 2000 people selected, 1717 were considered eligible and 1090 were examined in clinic and included in the present study. IOP was measured using applanation tonometry. SES was assessed using a standardised questionnaire; education and income were used as the main explanatory variables. The effect of systolic blood pressure (SBP) was also examined.

Results: Participants with lower levels of education and income had higher mean IOP (both $p < 0.01$). These associations remained after adjusting for age and central corneal thickness, a strong independent predictor. SBP was strongly associated with both SES and IOP (both $p < 0.01$). Adjusting for SBP attenuated the association between SES and IOP.

Conclusion: Participants with lower education and income have a higher mean IOP. This effect may be mediated, in part, by an association of education and income with SBP. This is the first study to suggest that there is a social gradient in the distribution of the only major modifiable risk factor for glaucoma. Increasing similarities exist between the causation models of chronic diseases and that of glaucoma.

The association between socioeconomic status (SES) and disease have been well documented for many conditions.¹ This includes the correlation between lower SES and increased risk of coronary heart disease and its risk factors, notably increased blood pressure and higher body mass index (BMI—weight in kg/height in m²).^{2–3} Those in lower social groups also have higher mortality from different cancers.⁴ This plethora of evidence has led to important changes in public policy that deals with health inequalities in both the US⁵ and the UK.⁶ Increasingly, the focus is directed more at the mechanisms by which SES affects health,¹ such as endocrine responses, exposure to carcinogens and pathogens, health-related attitudes and resources, psychological and environmental influences. The World Health Organization has identified physical inactivity and unhealthy diet as two major modifiable risk factors to be targeted as a means of reducing chronic diseases via mechanisms relating to blood pressure, blood glucose and obesity.⁷ However, there have been relatively few investigations into the socioeconomic associations of ophthalmic diseases. An inverse relationship between SES and blindness rate has been detected on a regional scale from comparison of prevalence studies.^{8–9} This is largely due to diseases that are associated with deprivation, such as trachoma and vitamin A deficiency, or through poor access to healthcare services, such as cataracts. Health inequalities attributed to social factors are also evident in higher strata of SES, and in developed countries.^{10–11} Evidence suggests that these disparities are not primarily caused by differential access to healthcare, but are due to differences within the society.⁶ The mechanisms by which SES influences susceptibility to ocular disease are not clear.

Glaucoma is the commonest cause of irreversible blindness worldwide and the second most common cause of blindness overall after cataract. It affects approximately 70 million people,

of whom 7 million are blind.¹² Intraocular pressure (IOP) is widely regarded as the most important modifiable risk factor associated with the development of glaucomatous optic neuropathy.^{13–14} Therefore, factors that influence IOP and its measurement are of great relevance in understanding the pathogenesis of the disease and in reducing the burden of blindness. An association between systolic blood pressure (SBP) and raised IOP has consistently been shown in both cross-sectional and longitudinal studies.^{15–18} To our knowledge, no previous studies have examined the association between SES and IOP.

This study investigates the relationship between SES and IOP, and explores a possible mediating mechanism through SBP using data from a cross-sectional study of prevalence of glaucoma and risk factors in Chinese living in Singapore.

METHODS

The Tanjong Pagar Study

The Tanjong Pagar Study was a population-based, cross-sectional survey of the prevalence and risk factors of ocular disease carried out between October 1997 and August 1998 in the Tanjong Pagar district of Singapore. The demographic and socioeconomic characteristics of this region are similar to those of Singapore as a whole, and this has been described previously.¹⁹ The study was carried out in accordance with the Declaration of Helsinki. Detailed methods of the study have been published elsewhere^{20–21}; a summary is presented below. A total of 2000 people with Chinese names aged between 40 and 79 years was selected from the 1996 electoral register using a stratified, clustered sampling procedure (13% of the total of

Abbreviations: BMI, body mass index; CCT, central corneal thickness; IOP, intraocular pressure; SBP, systolic blood pressure; SES, socioeconomic status; SGD, Singapore dollars

15 081). The population was divided into four age strata: 40–49, 50–59, 60–69 and 70–79 years, and 500 people from each age stratum were randomly selected. The primary sampling unit was the street of residence. Electoral registration is a legal requirement in Singapore, and therefore provides a complete record of all residents aged ≥ 21 years in the country. The demographic and socioeconomic characteristics of this region are similar to those of Singapore as a whole. All subjects received a postal invitation for an eye examination in a research clinic, with a leaflet about glaucoma. All non-responders were sent two more postal invitations and received a telephone call. Subsequently, a fieldworker visited persistent non-responders twice to facilitate visits. Finally, an eye examination team performed a home visit.

Participant characteristics

The identity of all the participants was verified from their national identity cards. A previously described standardised questionnaire was used to record demographic and socioeconomic details.²¹ SBP was measured in the right arm of the participants by a trained nurse using a mercury sphygmomanometer. Educational attainment was graded as no formal education, primary school level (up to age 11 years), secondary school level (11–18 years) and tertiary schooling, which included participants who had completed pre-university level education or had attended university. Individual income was categorised into participants who had a monthly income of 0–1000 Singapore dollars (SGD), 1000–2000SGD, >2000SGD and retired.

Eye examination

The hospital clinic-based eye examination consisted of visual acuity and refraction, slitlamp examination of the anterior segment, applanation tonometry, gonioscopy, optical pachymetry measurement of central corneal thickness (CCT), dilated optic disc examination and visual field testing. IOP was measured with a slitlamp-mounted Goldmann applanation tonometer (Haag–Streit, Bern, Switzerland) after anaesthetising the cornea. Three readings were made and the median figure was taken as the measurement for that eye. CCT was measured with an optical pachymeter (Haag–Streit) using the “touch” method, and therefore represented the distance from the anterior epithelial to the posterior endothelial surfaces. A magnification of $\times 1.6$ and eyepiece addition of 2.5 D were used, with CTT read to the nearest 0.01 mm. CCT was also measured three, times, and the median was taken as the reading for that eye. All IOP and CCT readings were taken by the same examiner (PJF).

Statistical analysis

Linear regression was used to assess univariate association between IOP and SES, demographic, systemic and ocular factors. Participants diagnosed with glaucoma were not excluded from the analysis. A forward fitting approach was used to examine predictors of IOP in a multivariate model with SES parameters. Indicator variables were used with all categorical variables to relax underlying assumptions on linearity in multiple regression models. The effect of SBP as an intermediate variable was examined by fitting models with and without this parameter. SBP was included as a quantitative variable in the final models. Effect modification was examined in the final models by introducing interaction terms. All analyses were carried out using Stata (version 8) statistical software package survey commands to account for the complex survey design.

RESULTS

Of 2000 participants sampled, 283 people had died, moved away or were too unwell to participate in the survey, leaving a

total of 1717 eligible participants. Of these, 1090 people (63.5%) responded to the invitations and were examined in the clinic. IOP, blood pressure, height and weight measurements were carried out only in this group. Information on a further 142 people was obtained during home visits, giving a total of 1232 (71.6%) participants. The design effect for estimation of IOP was 1.15.

Non-responders

Information on the 283 participants excluded was not available for analysis. Of the initial 500 people per decade age group invited for examination, 52.2% of the 40–49-year age group, 56.8% of the 50–59-year age group, 59.4% of the 60–69-year age group and 49.6% of the >70-year age group responded to the initial invitation.

Participants in the oldest age group were least likely to respond and most likely to be examined at home, with the highest response in the 60–69-year age group. A strong association was shown between SES and clinic attendance. Participants were more likely to respond if they had lower levels of education and higher levels of income. People who lived alone were less likely to attend clinic. These associations remained strong after adjusting for age (all $p < 0.01$). There was no evidence that mean IOP differed between those who attended clinic and those who were seen at home.

Univariate analysis

Mean IOP increased with age from 14.0 mm Hg in participants in their 40s to 15.1 mm Hg in participants in their 70s (table 1). Lower education and income levels were associated with higher IOP. People who had tertiary level education had the lowest mean IOP of 13.4 mm Hg, whereas participants who had no formal education and those who had only primary level education had the highest mean IOP of 14.7 and 14.8 mm Hg, respectively. Similarly, those who earned the most (>2000SGD) also had the lowest mean IOP of 13.8 mm Hg. Retired people had the highest mean IOP.

Participants in the younger age groups were more likely to be in the highest levels of SES (tertiary education and income >2000SGD). Within age groups in each decade, the trends in IOP were less clear. For education and income, only those in the youngest age group showed the same trends as in the general analysis. In all other age groups, the associations varied. However, in all age groups other than the oldest, the mean IOP was found to be lower in people who had tertiary education compared with those who did not have education beyond the secondary level. There was no evidence of interaction was shown between age and the effects of SES on mean IOP (all $p > 0.1$). As all variables were associated with age, this was accounted for in further analysis.

Mean SBP decreased with higher levels of education ($p < 0.01$; table 2) and higher monthly income ($p < 0.01$).

Multivariate analysis

Table 3 shows the estimates of effect of SES on IOP after allowing for the effects of both age and CCT. We adjusted for CCT as it is a strong independent predictor of IOP. Lower education was associated with higher IOP ($p < 0.01$ in the right eye, $p = 0.05$ in the left). People who had a university level education had a mean IOP that was 0.8 mm Hg lower (95% confidence interval (CI) -1.66 to 0.10 right eye; -1.82 to 0.15 left eye) than those without any formal schooling. After adjusting for SBP, the effect of education on IOP was attenuated by approximately 50%, which eliminated the statistical evidence of a genuine association in the left eye data ($p = 0.04$ in the right eye and $p = 0.27$ in the left eye). A less marked relationship was found between monthly income and

Table 1 Mean intraocular pressure by socioeconomic status, body mass index and systolic blood pressure in each age group

Age group, years	Education				Income (SGD)		BMI (kg/m ²)		SBP (mm Hg)										
	Overall	None formal	Primary	Secondary	Tertiary	MV Retired	0–1000	1000–2000	>2000	MV	<18.5	18.5–23	23–27	>27	MV	<125	125–150	>150	MV
40–49	n	261	21	121	43	1	99	84	74	3	19	130	86	24	2	147	91	21	2
	Mean IOP (SE)	14.02 (0.18)	14.15 (0.84)	14.04 (0.32)	13.16 (0.38)	17	14.32 (0.40)	14.27 (0.37)	13.33 (0.31)		14.05 (0.54)	13.74 (0.21)	14.15 (0.31)	14.96 (0.55)		13.29 (0.21)	14.85 (0.38)	15.48 (0.6)	
50–59	n	284	60	87	15	1	171	62	33	1	20	116	125	23	0	91	110	81	2
	Mean IOP (SE)	14.96 (0.14)	14.92 (0.47)	15.11 (0.37)	14.27 (0.60)	15.69 (1.38)	14.98 (0.22)	14.60 (0.38)	15.12 (0.56)		13.63 (0.59)	14.48 (0.28)	15.37 (0.32)	16.30 (0.59)		13.90 (0.21)	14.96 (0.24)	16.15 (0.32)	
60–69	n	297	93	48	14	2	48	37	19	6	19	139	111	27	1	46	123	124	4
	Mean IOP (SE)	14.92 (0.26)	14.51 (0.30)	15.42 (0.61)	13.35 (0.51)	15.29 (0.53)	14.87 (0.34)	14.75 (0.5)	16 (1.48)		12.94 (0.53)	15.09 (0.34)	15.17 (0.53)	14.26 (0.27)		14.59 (0.51)	14.36 (0.44)	15.64 (0.31)	
>70	n	248	103	31	8	4	54	3	1	8	37	124	71	10	6	31	70	141	6
	Mean IOP (SE)	15.06 (0.23)	14.98 (0.45)	15.06 (0.49)	16.12 (0.75)	15.2 (0.47)	15.07 (0.30)	11.33 (1.81)	17		14.03 (0.62)	15.07 (0.27)	15.58 (0.41)	15.4 (0.65)		13.58 (0.75)	14.54 (0.53)	15.67 (0.38)	
Total	n	1090	277	287	80	8	120	186	115	18	95	509	393	84	9	317	396	369	14
	Mean IOP (SE)	14.54 (0.11)	14.68 (0.25)	14.46 (0.37)	13.44 (0.40)	15.4 (0.47)	14.76 (0.17)	14.38 (0.34)	13.75 (0.35)		13.80 (0.31)	14.30 (0.35)	14.85 (0.37)	15.2 (0.43)		13.53 (0.16)	14.76 (0.2)	15.78 (0.19)	
p-Value		<0.001	0.002			0.004					0.002					<0.001			

BMI, body mass index; IOP, intraocular pressure; MV, missing values; SBP, systolic blood pressure; SGD, Singaporean dollars.
p-Values from test for association.

IOP. Trends in the left eye were significant, with people in the highest income bracket having a mean IOP of 0.97 mm Hg (95% CI –1.65 to –0.30, $p < 0.01$) less than those with the lowest income. Again, adjusting for SBP attenuated the effect of income on IOP, and the association was no longer significant (right $p = 0.35$, left $p = 0.09$).

DISCUSSION

These results show that higher levels of education and income are associated with lower measured IOP in a Chinese population. These effects are largely related to SBP.

This is the first report, to our knowledge, of an association between SES and IOP. Previous studies on SES in ophthalmology mostly examined the relationship between SES and blindness⁸ or visual impairment¹⁰ in people of lower SES who had worse vision. These assessments encompass both the health of the individual and the access to and usage of health services. Fraser *et al*²² showed that deprivation is associated with presentation of advanced glaucomatous optic neuropathy to hospital clinics, an important risk factor for blindness from glaucoma. This association could be attributed to differences in health seeking behaviour, access to healthcare or disease characteristics. Our investigation into SES and IOP was focused on the individual health status and potential risk for disease. High IOP is the major modifiable risk factor for glaucoma²³; therefore, those at risk of higher IOP also have a higher risk of glaucoma. However, we found no evidence from this study that people in lower SES groups had a higher prevalence of glaucoma (data not shown). We identified small differences in mean IOP associated with SES. Because of the relatively small number of cases of glaucoma ($n = 45$) in this study, the power of this study is insufficient to detect an association between SES and glaucoma.

The Baltimore Eye Survey has shown that African Americans have a higher prevalence of glaucoma, although there is no difference in the distribution of IOP.^{24–25} This study also showed that race and SES were associated with visual impairment.¹⁰ The relationship between race, SES and health in the US has been extensively explored, and it is well recognised that African Americans experience poorer health than Americans with European heritage.²⁶ Evidence also shows that it is differences in socioeconomic and cultural factors between races rather than genetics that are important determinants in these health inequalities.^{27–28} In the Baltimore Eye Survey, the authors excluded differential health access as a source of difference in glaucoma prevalence, and although the relationship between

Table 2 Mean systolic blood pressure and body mass index by socioeconomic status

	Age adjusted, mean SBP, mm Hg (SE)	Age adjusted, mean BMI, kg/m ² (SE)
Education		
None formal	119.0 (3.11)	24.80 (0.61)
Primary	117.1 (1.96)	24.31 (0.35)
Secondary	114.7 (2.42)	23.97 (0.41)
Tertiary	106.2 (2.75)	23.94 (1.70)
p Value	<0.01	<0.01
Monthly income (SGD)		
Retired	117.4 (2.73)	23.99 (0.44)
0–1000	118.1 (2.37)	24.08 (0.68)
1000–2000	114.7 (2.41)	23.66 (0.45)
>2000	109.5 (2.14)	24.43 (1.19)
p Value	<0.01	0.58

BMI, body mass index; SBP, systolic blood pressure; SGD, Singaporean Dollars.
p-Value from test for association.

Table 3 Multivariate adjusted effects of socioeconomic status on intraocular pressure

	Adjusted for age and CCT		Adjusted for age, CCT and SBP		Adjusted for age, CCT and BMI		Adjusted for age, CCT, SBP and BMI	
	Coefficient (95% CI)	p Value	Coefficient (95% CI)	p Value	Coefficient (95% CI)	p Value	Coefficient (95% CI)	p Value
Right eye								
Education								
Intercept	5.37 (2.06 to 9.08)		1.32 (-2.29 to 4.92)		4.82 (1.12 to 8.51)		1.2 (-2.51 to 4.89)	
Primary	0.37 (-0.26 to 1)		0.37 (-0.25 to 0.99)		0.42 (-0.2 to 1.04)		0.4 (-0.22 to 1.02)	
Secondary	0.16 (-0.69 to 1)		0.24 (-0.55 to 1.02)		0.23 (-0.63 to 1.08)		0.26 (-0.54 to 1.07)	
Tertiary	-0.78 (-1.66 to 0.1)		-0.43 (-1.25 to 0.38)		-0.59 (-1.51 to 0.32)		-0.37 (-1.24 to 0.49)	
		<0.01		0.04		0.02		0.06
Monthly income (SGD)								
Intercept	5.89 (2.52 to 9.26)		1.55 (-1.90 to 5)		5.1 (1.51 to 8.69)		1.43 (-2.14 to 5.02)	
1000-2000	-0.19 (-0.89 to 0.51)		-0.1 (-0.74 to 0.55)		-0.17 (-0.86 to 0.52)		-0.1 (-0.76 to 0.56)	
>2000	-0.72 (-1.52 to 0.08)		-0.44 (-1.19 to 0.3)		-0.68 (-1.47 to 0.11)		-0.44 (-1.2 to 0.32)	
		0.12		0.35		0.13		0.36
Left eye								
Education								
Intercept	4.55 (0.9 to 8.21)		0.24 (-3.47 to 3.96)		3.95 (0.19 to 7.72)		0.23 (-3.48 to 3.95)	
Primary	0.02 (-0.49 to 0.54)		0.02 (-0.47 to 0.52)		0.04 (-0.48 to 0.55)		0.01 (-0.49 to 0.51)	
Secondary	0.08 (-0.71 to 0.87)		0.16 (-0.57 to 0.88)		0.1 (-0.67 to 0.87)		0.14 (-0.58 to 0.85)	
Tertiary	-0.84 (-1.82 to 0.15)		-0.49 (-1.43 to 0.46)		-0.75 (-1.73 to 0.24)		-0.51 (-1.46 to 0.43)	
		0.05		0.27		0.09		0.27
Monthly income (SGD)								
Intercept	4.70 (1.19 to 8.21)		0.53 (-3 to 4.06)		4.03 (0.43 to 7.64)		0.43 (-3.12 to 3.98)	
1000-2000	-0.45 (-1 to 0.12)		-0.37 (-0.88 to 0.15)		-0.44 (-0.99 to 0.11)		-0.38 (-0.9 to 0.14)	
>2000	-0.97 (-1.65 to -0.3)		-0.71 (-1.34 to -0.08)		-0.96 (-1.60 to -0.32)		-0.72 (-1.34 to -0.09)	
		0.02		0.09		0.02		0.08

BMI, body mass index; CCT, central corneal thickness; IOP, intraocular pressure; SBP, systolic blood pressure; SGD, Singaporean dollars.

p Value from test for association.

Coefficient, difference in mean IOP between people in higher levels of explanatory variable (education, primary, secondary or tertiary; income = 100-2000SGD or >2000SGD) and baseline level (education, no formal education; monthly income, 0-1000SGD), with all other adjusted parameters held constant.

SES and glaucoma or IOP has not been explored, the association between race and glaucoma may indicate a relationship between SES and glaucoma.

We have provided evidence to suggest that part of the effects of education and income is dependent on SBP. An underlying assumption in the analysis of SBP is an intermediate factor in the causal chain rather than a confounder. Although this study is based on cross-sectional data, which provides weak evidence for causality, there is consistent evidence in the literature that supports the intermediate relationships between SES and blood pressure, and also between SBP and IOP. A large systematic review based mostly on survey data showed that lower SES was associated with higher mean blood pressure in developed countries. Findings from birth cohort studies have also shown that lower childhood SES is associated with higher blood pressure in adulthood.²⁹⁻³⁰ The correlation between high SBP and high IOP has been well established in prevalence studies.^{15-17, 18-31, 32} There are also longitudinal data from developed countries suggesting that baseline SBP is directly associated with mean IOP measured at follow-ups of 4³³, 34 and 8 years.³⁵ These studies give good support for the assumptions made about SBP. Therefore, our estimates of effects of education and income on IOP adjust only for age and CCT and do not adjust for the assumed intermediate variables.³⁶

Low participation rates are a major cause of selection bias in prevalence surveys, as the participants may not be representative of the population. In this study, 63.5% of those eligible were examined in clinic. Comparisons between patients examined at home and those in clinic can give some indication of the characteristics of non-responders; however, this group is not completely representative of true non-responders. Therefore, we compared the levels of exposure and education of our survey participants with those obtained from the national census.³⁷ We found no statistical difference in education levels between study participants and the population. This would suggest that the education levels were representative of the population and reduce the effects of a participation

bias. We used education as one of our measures of SES; as education is completed early in life, the association between education and IOP assessed here would not be subject to reverse causality. Education and individual income are crude indicators of SES; further investigations using finer techniques such as consumption and assets may strengthen or refute our hypothesis.

SES affects health through many different pathways.¹ A physiological mechanism that may explain higher IOP in those with low SES is that exposure to chronic stress associated with relative differences in SES induces increased levels of corticoids that can have long-term effects on the cardiovascular and immune systems.³⁸⁻³⁹ Increased IOP is also observed in participants with ocular or systemic administration of glucocorticoids.⁴⁰ SES could also mediate an effect through lifestyle factors that increase SBP, such as diet and physical activity.⁴¹ Therefore, the association between SES and IOP remains, but as suggested here, the effect is largely through changes in SBP.

University education was the only stratum that showed a clear difference compared with other levels of education in mean IOP. This may suggest a threshold effect for lower IOP and higher SES. This analysis indicates that people who had tertiary education had a mean IOP 0.80 mm Hg lower than those without formal education. Although this small reduction may not seem clinically significant, small shifts in population mean values of important risk factors may have a significant effect on the rate of disease. It has been estimated that a 3% reduction in the average population blood pressure could result in a 25% reduction in the prevalence of clinical hypertension.⁴²⁻⁴³ Although the diagnosis of glaucoma is made independently of IOP,⁴⁴ a population reduction in IOP would reduce the number of people at greatest risk of glaucoma, as IOP is strongly linked to the risk of glaucoma. Therefore, potential intervention strategies such as modifying diet or increasing physical activity as a means of reducing SBP and IOP may have multiple health benefits on the population level. These interventions have already been advocated by the World

Health Organization as a means of reducing morbidity and mortality from chronic disease.⁷ The postulated model identified here closely resembles causation models for chronic diseases such as heart disease and stroke. This study shows a social gradient in the distribution of major risk factors in glaucoma, a major cause of blindness in older people worldwide. In addition, in a randomised controlled trial of glaucoma management, the difference in mean IOP between one group of people with progressive disease and another group without the disease was 2.4 mm Hg.⁴⁵ This association could therefore explain how people with lower SES could be at increased risk of visual impairment and blindness from glaucoma.²⁰

Eliminating health inequalities is a major goal of recent health policies in developed countries where these gradients are evident.⁵⁻⁴⁶ This includes dealing with the disparities in healthcare, but SES also contributes to the causes of health inequalities. This study proposes a mechanism by which SES can cause differences in mean IOP through its effects on blood pressure. A logical extrapolation from these results is that overcoming disparities in cardiovascular disease and hypertension caused by social factors may also reduce mean IOP. How this influences the risk of glaucoma in an unaffected population and in those people with established disease is a controversial issue. A large, population-based study in the US has previously shown a modest positive association between SBP and primary open-angle glaucoma. However, this study also detected a stronger association between lower perfusion pressure (blood pressure – IOP) and a significantly increased risk of glaucoma.⁴⁷ It was hypothesised that glaucoma may be associated with an autoregulatory failure of circulation at the optic nerve head. It is a plausible extrapolation from this work that reducing blood pressure may reduce mean IOP and also the risk of glaucoma. It is a justifiable concern that reduction of blood pressure may reduce perfusion pressure and increase the risk of glaucoma, although this effect should be negligible in those with normal autoregulatory function. The important missing information needed to validate either theory is regarding the temporal relationship between the purported risk factor (SBP or perfusion pressure) and development of glaucoma. Further studies are necessary to corroborate these findings and assess whether there are higher frequencies of glaucoma in people of lower SES.

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