Combined Effect of Cigarette Smoking and Occupational Exposures on Lung Function

A Cross-sectional Study of Rubber Industry Workers

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RESEARCH ABSTRACT

Workers in the rubber industry are exposed to pulmonary health hazards. The main purpose of this study was to assess the combined effect of cigarette smoking and occupational exposures on lung function. The exposed group consisted of tire manufacturing workers in production units and the non-exposed group included executives from the same factory. The researchers calculated the synergy index (SI) to determine the combined effect of exposures to cigarette smoke and pulmonary health hazards on lung function. A significant correlation was found between occupational exposures in the rubber industry and abnormal spirometric findings ($p < .05$). The synergistic effect of cigarette smoking and occupational exposures on lung function was significant (SI = 2.25; $p < .05$). This study demonstrated that occupational exposures and smoking may have a synergistic effect on the respiratory systems of tire manufacturing workers. The results suggest that tire manufacturing companies should consider establishing spirometric surveillance systems in their factories. Also, smoking cessation should be promoted, engineering controls applied, and respiratory protection provided to workers. [*Workplace Health Saf* 2013;61(5):213-220.]

Occupational exposures are one of the primary causes of respiratory symptoms and lung function impairment (Ghasemkhani et al., 2006). According to World Health Organization (WHO) estimates, pulmonary diseases are predicted to become the third leading cause of death by 2020 (WHO, 2002). Previous studies have demonstrated that 15% to 20% of chronic obstructive pulmonary disease (COPD) cases are caused by occupational exposures (Balmes, 2007). However, a recent study found limited evidence for an association between COPD and occupational exposures (Mehta et al., 2012).

The rubber industry frequently exposes workers to harmful dust particles (e.g., kaolin and talc), fumes, and vapors of organic solvents (e.g., toluene and benzene) (Neghab, Rahimi, Emad, & Rajaeei Fard, 2007). Based on the results of one study, occupational inhalation of talc dust causes obstructive lung disease (Neghab et al., 2007). In contrast, another study has concluded that talc can decrease vital capacity and total lung capacity (restrictive ventilatory defect) (Wild et al., 2002). Based on a study

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The authors have disclosed no potential conflicts of interest, financial or otherwise.

This study was conducted with support from the Deputy for Research at Tehran University of Medical Sciences.

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Received: June 20, 2012; Accepted: January 28, 2013; Posted: April 25, 2013.

doi:10.3928/21650799-20130418-66

Applying Research to Practice

Rubber industry workers are frequently exposed to harmful dust particles such as kaolin and talc, fumes, and organic solvents such as toluene and benzene. Cigarette smoking is common worldwide. This study showed that, in tire manufacturing, simultaneous occupational exposures and smoking may have a synergistic effect on workers' respiratory systems. Determining pulmonary health hazards in workplaces and preventing exposures must be a high priority, and simultaneously smoking cessation must be promoted.

by Neghab et al. (2007), workers exposed to talc had a significantly higher prevalence of pulmonary symptoms than controls. Also, pulmonary function tests showed that workers exposed to talc had significant decreases in their mean percentage predicted vital capacity (VC; i.e., the maximum amount of air an individual can expel from the lungs after a maximum inhalation), forced vital capacity (FVC; i.e., the volume of air that can forcibly be expelled after full inspiration), and forced expiratory volume in 1 second (FEV_1; i.e., the volume of air that can forcibly be expelled in 1 second, after full inspiration).

Inhaled talc causes granuloma formation and an interstitial inflammatory reaction. This inflammatory reaction may lead to interstitial fibrosis, emphysema, and progressive massive fibrosis (Loyola et al., 2010).

The results of a study by Weeks, Peters, and Monson (1981) suggested that rubber workers are frequently exposed to hazardous agents that may lead to acute or chronic pulmonary impairment.

In addition to occupational exposures, cigarette smoking, common worldwide, also causes respiratory symptoms and impaired lung function. According to the WHO (2012), more than 1 billion individuals are addicted to nicotine. Smoking is common in all social classes, including the working class (Iribarren, Friedman, Klatsky, & Eisner, 2001). Smoking prevalence and tobacco-related mortality and morbidity rates appear to be increasing in developing countries (Abdullah & Husten, 2004). An Iranian survey found that 14.8% of the population currently used tobacco (Meysamie et al., 2010). Some studies have indicated that smoking is the primary cause of COPD, but exposure to workplace dust and fumes is also related to COPD (Balmes et al., 2003; Blanc et al., 2009). Cigarette smoking and occupational exposures to dust and fumes have been suggested to have a synergistic effect on pulmonary function (Blanc et al., 2009; de Meer, Kerkhof, Kromhout, Schouten, & Heederik, 2004; Jaakkola, 2009; Jaakkola, Sripaiboonkij, & Jaakkola, 2011; Neghab et al., 2007).

The objective of this study was to explore the combined effect of cigarette smoking and occupational exposures on pulmonary function.

METHODS

Study Design

A cross-sectional study was designed to assess the simultaneous effects of cigarette smoking and occupational exposures on lung function. The exposed group consisted of tire manufacturing workers in production units and the non-exposed group included executives from the same tire manufacturing company. Lung function was assessed using a simple spirometry test and the results for the two groups were compared.

Study Population

This study included workers from a tire manufacturing company in Yazd City, Iran, in 2010. The main tire factory units included compounding and banbury mixing (i.e., combining rubber stock, carbon black, and other chemicals to create a homogeneous rubber material), extruding and calendering (i.e., shaping rubber and creating tube-like rubber components), component assembly and building (i.e., assembling tires), curing (i.e., transforming rubber to a long-lasting state), and inspection and finishing (i.e., trimming excess rubber). Talc, benzene, toluene, formaldehyde, ethylene oxide, and phenol were the raw materials used by workers in tire production. In this process, workers are exposed to different concentrations of respirable and inhalable talc dust and vapors of organic solvents that may adversely affect their respiratory systems.

All the male production unit workers exposed to talc dust or organic solvents entered the study and comprised the "exposed" group. Male employees of the executive unit were the "non-exposed" group. Workers with less than 1 year of employment in their current jobs, with a second job or a previous job that included exposure to respiratory risk factors, with a positive history of respiratory diseases occurring prior to their current employment, with a history of thoracic surgeries, with a history of allergic diseases, who were ex-smokers, with a family history of allergies, or with acute respiratory infection in the 4 weeks prior to initiation of the study were excluded from the sample.

Four hundred sixty-one male workers were employed in the production unit and 180 male workers were employed in the executive unit of the factory. After applying the exclusion criteria, 453 workers remained in the exposed group and 178 in the non-exposed group. None of these workers used any type of respirator to prevent exposure to occupational respiratory health hazards.

All workers voluntarily participated in this study and signed informed consent forms in Persian. This study was approved by the Ethics Committee of Tehran University of Medical Sciences.

Instruments

Questionnaire and Clinical Examination. The respiratory questionnaire, a slightly modified version of the American Thoracic Society (ATS) standard questionnaire (Ferris, 1978), was completed for all study participants during face-to-face interviews. The questionnaire included demographic data, health history, family history, respiratory complaints (i.e., cough, sputum, dyspnea, and wheezing), history of allergy and asthma, medication use, smoking habits, respiratory complaints before accepting current employment, and detailed job descriptions (i.e., type of work, potential risks, previous jobs). The questionnaire was used during workers' periodic examinations. After completing the questionnaires, all study participants were clinically examined by two physicians who focused on their respiratory systems.

Spirometry. All study participants completed simple spirometry using a calibrated portable spirometer according to ATS guidelines (Miller et al., 2005a, 2005b; Pellegrino et al., 2005). The test was conducted by a trained physician between 9:00 a.m. and 11:00 a.m. every day of the study.

Before the spirometric measurements were recorded, the participants rested in a seated position for about 10 minutes. The mean percentage of predicted value was based on workers' age, weight, height when standing, gender, and ethnic group (e.g., Caucasian) as calculated and adjusted based on European Respiratory Society standards.

The researchers used the following spirometric indices for reporting results:

1. Forced expiratory volume in 1 second (FEV_1)
2. Forced vital capacity (FVC)
3. FEV_1/FVC (i.e., the proportion of individuals' vital capacity that they are able to expel in the first second of expiration)
4. Forced expiratory flow between 25% and 75% of the FVC ($FEF_{25\text{-}75\%}$)
5. Peak expiratory flow (PEF)

Study participants were categorized into four groups—normal, obstructive, restrictive, and mixed—based on spirometric findings (Pellegrino et al., 2005).

Environmental Monitoring

Measurement of all respiratory hazards present in the work environment was completed by the factory's occupational hygiene team.

Measuring the Concentration of Organic Solvents. To detect solvent exposure in each location, the team of occupational hygienists gathered a set of job titles after completing a workplace survey. All measurements of time-weighted averages were done based on environmental sampling for each job title. Air monitoring was conducted by stationary sampling; the samplers were located at a 1.5-meter height (National Institute for Occupational Safety and Health [NIOSH], 2003) continuously during the entire shift. Air samples were collected on charcoal tubes using constant flow (100 ml/min) pumps at 43 stations in the production units and 8 stations in the executive units. Subsequently, gas chromatography was used to analyze the samples, and the average concentration of each solvent was identified. Environmental monitoring revealed that benzene, toluene, formaldehyde, ethylene oxide, and phenol were present in the factory. The occupational exposure to the organic solvents was evaluated according to an American Conference of Governmental Industrial Hygienists (ACGIH, 2006) equation. The equation used to assess the permitted limit of the mixture of organic solvents appears in the Sidebar.

Sidebar

Equation for Assessing Permitted Limit of Organic Solvents Mixture

$$Em = C1/L1 + C2/L2 + \ldots + Cn/Ln$$

where Em is the equivalent exposure for the mixture of organic solvents, C is the mean concentration of organic solvents in the air of the environment, and L is the exposure limit for the organic solvents. An Em value greater than 1 indicates the concentration of the organic solvents mixture in the work environment is higher than threshold limit values.

Measuring the Concentration of Dust Particles. To assess the extent to which workers were exposed to talc dust, personal dust monitoring for airborne total and respirable dust was completed in all parts of the production unit using standard methods (Health and Safety Executive, 2000). To measure total talc dust and respirable talc dust, researchers used a calibrated air sampling pump equipped with a filter holder containing a 25-mm membrane filter and a 0.45-μm (pore diameter) filter connected to the cyclone. Sampling occurred at the flow rate of 2 L/min in the breathing zone of workers. Dust concentration was analyzed using gravimetry. By weighing the filter before and after filtration of the air (SD = 0.1 mg), respirable dust concentrations were calculated; by weighing the cyclone contents, the total concentration of all dust particles was determined.

Statistical Analysis

SPSS, version 11, currently Predictive Analytics Software, was used for data analysis. Percentages, frequencies, means, and standard deviations were used for descriptive analysis. The t test was used to compare the means of quantitative variables; the chi-square test was used for categorical variables. Logistic regression analysis was used for precise evaluation of the correlation between spirometric parameters and occupational exposure. For all statistical tests, the confidence interval (CI) was 95%, the power was 80%, and a p value of less than .05 was considered significant. Biological interaction between two variables was calculated using the synergy index (SI), based on the ratio of the combined effects to the sum of the separate effects of two variables (Rothman & Greenland, 1998). An SI above 1 indicates synergy exists between two variables. The authors analyzed how occupational exposures and cigarette smoking individually and in combination were associated with abnormal spirometric findings.

RESULTS

This study included 631 employees of a tire manufacturing company; 453 (71.8%) worked in production units (the exposed group) and 178 (28.2%) were executives (the non-exposed group). The mean age was 36.31

Table 1

Comparison of Demographics Between the Exposed Group and the Non-exposed Group

	Exposed Group (n = 453)	Non-exposed Group (n = 178)	p
Age (years)	36.51 ± 5.68	35.81 ± 7.15	.19
Duration of employment (years)	10.86 ± 3.93	11.03 ± 4.74	.64
Height (cm)	172.39 ± 6.77	171.33 ± 8.03	.09
Weight (kg)	75.82 ± 12.04	76.02 ± 10.44	.84
Smoking (pack-years)	9.03 ± 5.21	7.89 ± 3.99	.30

Note. *Values are* M ± SD.

Table 2

Occupational Exposure Concentrations Measured in the Air of Production Units

Unit	Total Dust (mg/m^3)	Respirable Dust (mg/m^3)	Organic Solvents Mixture (Em)	Respiratory Exposure Severity
Compounding and banbury mixing	10.33	5.23	1.65	Low
Extruding and calendering	52.24	35.31	1.13	High
Component assembly and building	37.34	21.70	1.36	High
Curing	41.32	27.20	3.67	High
Inspection and finishing	15.65	9.36	1.11	Low
ACGIH TLV	10	3	1	-

Note. *Values are* M. *ACGIH TLV = American Conference of Governmental Industrial Hygienists threshold limit value.*

years (range = 20 to 62 years), the mean duration of employment was 10.90 years (range = 1 to 25 years), the mean height was 172.09 cm (range = 152 to 197 cm), and the mean weight was 75.88 kg (range = 45 to 107 kg). Of the sample, 103 were smokers (16.3%) and 528 were non-smokers (83.7%).

Demographic variables were compared for the two groups (Table 1). No significant differences were found between the two groups for mean age, mean duration of employment, mean height, mean weight, or smoking habits ($p > .05$).

In the production units, the Em ranged from 1.11 to 3.67 (median = 1.78), indicating a higher than permitted concentration of the mixture of organic solvents. The mean Em values of the different production units are listed in Table 2. The mean talc dust concentrations in the production units are also listed in Table 2. The talc dust concentrations in all production units were above the maximum exposure limit (ACGIH, 2006). The mean respirable talc dust concentrations in the production units ranged from 5.10 to 37.20 mg/m^3 (median = 14.20 mg/m^3). Exposed workers were categorized into two groups: a low exposure group, defined as a mean respirable dust concentration of 5.10 to 14.20 mg/m^3 or an Em of 1.11 to 1.78; and a high exposure group, defined as a mean respirable dust concentration greater than 14.20 mg/m^3 or an Em greater than 1.78. Dust and organic solvent concentrations were insignificant in the executive units.

One hundred twenty-eight (28.2%) of the workers in the exposed group and 26 (14.6%) in the non-exposed group had respiratory complaints. Chi-square test revealed the frequency of respiratory complaints was significantly higher in the exposed group ($p < .001$, odds ratio [OR] = 2.302, 95% CI = 1.448–3.660) compared to the non-exposed group. The frequency of all respiratory complaints (i.e., dyspnea, cough, sputum, and wheezing) was significantly higher in the exposed group compared to the non-exposed group ($p < .05$; Table 3).

The frequency of respiratory complaints was 33.98% (35 workers) in the smoking group and 22.53% (119 workers) in the non-smoking group ($p < .05$). Chi-square test revealed that the frequency of respiratory complaints was significantly higher in the smoking group ($p < .05$, OR = 1.769, 95% CI = 1.121–2.791) than the non-smoking group.

In this study, 549 (87%) of the workers had normal and 82 (13%) of the workers had abnormal spirometric

Table 3

Frequency of Respiratory Symptoms in the Exposed Group and the Non-exposed Group

	Exposed Group (n = 453)		*Non-exposed Group (n = 178)*		
Symptom	**N**	**%**	**N**	**%**	**p**
Dyspnea	126	27.8	19	10.7	< .001
Cough	88	19.4	19	10.7	< .05
Wheezing	38	8.3	3	1.7	< .001
Sputum	73	16.1	15	8.4	< .05

Table 4

Spirometric Parameters in the Exposed Group and the Non-exposed Group

Parameter	*Exposed Group*	*Non-exposed Group*	p
FEV_1 (%)	86.99 ± 8.24	89.85 ± 12.32	< .001
FVC (%)	87.36 ± 9.63	90.77 ± 13.09	< .001
FEV_1/FVC (%)	87.06 ± 11.09	89.34 ± 7.22	< .05
$FEF_{25-75\%}$ (%)	79.05 ± 20.12	85.31 ± 20.15	< .001
PEF (%)	80.11 ± 13.23	83.77 ± 14.65	< .05

Note. *Values are* M ± SD. *FEV_1 = forced expiratory volume in 1 second; FVC = forced vital capacity; FEF = forced expiratory flow; PEF = peak expiratory flow.*

findings. Nine (5%) of the workers in the non-exposed group and 73 (16.1%) of the workers in the exposed group had abnormal spirometric findings. The frequency of abnormal pulmonary function was significantly higher in the exposed group ($p < .001$, OR = 3.607, 95% CI = 1.763–7.380) compared to the non-exposed group. In the exposed group, 46 workers (10.15%) had obstructive pulmonary function, 23 (5.77%) had restrictive pulmonary function, and 4 (0.88%) had mixed patterns. Among the non-exposed group, 7 (3.93%) had obstructive and 2 (1.23%) had restrictive patterns.

Twenty-nine (28.15%) of the workers in the smoking group and 53 (10.03%) of the workers in the non-smoking group had abnormal spirometric findings. The frequency of abnormal pulmonary function was significantly higher in the smoking group ($p < .001$, OR = 3.512, 95% CI = 2.099–5.877) compared to the non-smoking group.

The mean spirometric parameters were significantly lower in the exposed group compared to the non-exposed group ($p < .05$; Table 4). Logistic regression analysis was used for precise evaluation of the correlation between abnormal spirometric findings and occupational exposures in the factory (Table 5).

In this analysis, spirometric findings (normal or abnormal) were considered the dependent variable and occupational exposures, cigarette smoking, age, and work duration were considered independent variables. Occupational exposures were categorized as exposure to organic solvents or exposure to particle dusts at low and high levels. Table 5 shows that even after adjusting for the variables of age, duration of employment, and cigarette smoking, a significant correlation existed between abnormal spirometric findings and occupational exposures ($p < .05$).

The researchers also found that the OR demonstrated an increasingly abnormal trend with increasing exposure levels. With increasing concentrations of occupational exposures, the frequency of abnormal spirometric findings also increased. A significant relationship between age, work experience, and cigarette smoking and abnormal spirometric results was also found ($p < .05$). This analysis showed that the abnormal spirometric OR increased with more pack-years of smoking.

The estimated SI was greater than 1. A significant SI was found for smoking and occupational exposures (SI = 2.25, 95% CI = 1.95–2.39). When analyzed alone or in combination, smoking and occupational exposures were positively associated with abnormal spirometric findings ($p < .05$). ORs for the effects of smoking and occupational exposures on lung function are presented in Table 6. The estimated effect on lung function was greater when these factors were combined than isolated.

DISCUSSION

This study demonstrated the combined effect of cigarette smoking and occupational exposures on lung function. No significant difference was detected between the

Table 5

Relationship Between Spirometric Results and Study Variables on Logistic Regression Analysis (*N* = 631)

Variable	*Adjusted OR*	*95% CI*	p
Age (years)			
⩽ 36 (*n* = 295)	1	-	
> 36 (*n* = 336)	2.08	1.03–4.21	< .05
Duration of employment (years)			
⩽ 11 (*n* = 316)	1	-	
> 11 (*n* = 315)	2.04	1.04–4.00	< .05
Smoking (pack-years)			
Non-smoker (*n* = 528)	1	-	-
⩽ 7 (*n* = 56)	2.40	1.14–5.06	< .05
> 7 (*n* = 47)	7.76	2.43–24.78	< .001
Occupational exposure group (mg/m^3 or Em)			
Non-exposed (*n* = 178)	1	-	-
Low exposed (*n* = 234)	2.43	1.07–5.51	< .05
High exposed (*n* = 219)	4.35	2.02–9.38	< .001

Note. *OR = odds ratio; CI = confidence interval.*

Table 6

Effects of Smoking and Occupational Exposures on Lung Function

Variable[a]	*Number (N = 631)*	*%*	*OR*	*95% CI*
Occupational exposures = 0, smoking = 0	151	23.9	1.00	-
Occupational exposures = 1, smoking = 0	377	59.7	3.45	1.76–9.50
Occupational exposures = 0, smoking = 1	27	4.3	3.48	1.42–8.33
Occupational exposures = 1, smoking = 1	76	12.0	12.12	3.35–37.87

Note. *OR = odds ratio; CI = confidence interval. [a]Occupational exposures: 0 = not exposed to organic solvents and/or dust, 1 = exposed to organic solvents and/or dust. Smoking: 0 = non-smoker, 1 = smoker.*

exposed group and the non-exposed group regarding mean age, mean duration of employment, mean weight, mean height, or smoking habits. Therefore, the correlation between exposure to occupational pulmonary health hazards and respiratory disorders among workers was not affected by these potential confounding factors. The researchers noted a statistically significant increased prevalence of respiratory complaints (i.e., cough, sputum, wheezing, and dyspnea) among production unit workers compared to executive employees. These results are similar to those of Neghab et al. (2007), Ghasemkhani et al. (2006), Jaén, Zock, Kogevinas, Ferrer, and Marín (2006), and Jaakkola et al. (2011). In contrast, in the study by Meijer, Heederik, and Kromhout (1998), rubber workers with chronic respiratory symptoms were not found to have higher rates than the control group. In another study, an association was found between exposure to dust, gases, and fumes and respiratory complaints, with ORs of 1.3 and 2.5 for exposed and non-exposed workers, respectively (Vermeulen, Heederik, Kromhout, & Smit, 2002).

This study demonstrated increased frequency of respiratory complaints among smokers. This finding is in accordance with the results of studies conducted by Boggia, Farinaro, Grieco, Lucariello, and Carbone (2008) and Jaakkola et al. (2011).

In this study, the spirometric parameters were significantly lower in the exposed group compared to the non-exposed group. These results are in agreement with the results of studies conducted by Neghab et al. (2007) and Jaén et al. (2006). In the study of talc-exposed workers conducted by Neghab et al. (2007), pulmonary function tests revealed that exposure to this lubricating agent was associated with significant decreases in the mean percentage predicted VC, FVC, and FEV_1.

In this study, a significant correlation was found between exposure to occupational pulmonary health hazards and abnormal spirometric findings, even after adjusting for age, employment duration, and smoking habits. These findings corroborate the results of studies conducted by Neghab et al. (2007) and Jaén et al. (2006). Honda et al. (2002) found a general tendency for some parameters of pulmonary function to become smaller as estimated cumulative exposure increased. A similar result was reported in this study.

A significant correlation was found between aging and abnormal pulmonary function, similar to the results of the study conducted by Dehghan, Mohammadi, Sadeghi, and Attarchi (2009). Also, a significant correlation was found between cigarette smoking and abnormal pulmonary function, which was expected based on studies by Meijer et al. (1998) and Jaakkola et al. (2011). In this study, a significant correlation was also found between employment duration and abnormal pulmonary function, which was supported by the results of the studies conducted by Neghab et al. (2007) and Jaakkola et al. (2011). Exposure to occupational respiratory health hazards and cigarette smoking was related to spirometric abnormalities, a finding supported by the study conducted by Jaakkola et al. (2011).

The current study shows that the concurrent effects of cigarette smoking and occupational exposures might have a synergic impact on lung function. Smoking workers and those exposed to occupational pulmonary health hazards had a 3.48-fold and 3.45-fold higher risk of abnormal spirometric findings, respectively, than non-smoking workers in the executive unit. Also, smoking workers exposed to occupational pulmonary health hazards had a significantly increased risk of abnormal spirometric findings compared to non-smoking workers in the executive unit. These findings corroborate the findings of Boggia et al. (2008) and Jaakkola et al. (2011).

The cross-sectional design of this study is a limitation. With cross-sectional studies, temporal and causal relationships cannot be clearly ascertained. Therefore, longitudinal, industry-based studies with sample size and determination of occupational exposure are necessary to evaluate the causal relationship between occupational exposures and lung function impairment. Another limitation of this study is that in evaluating occupational respiratory hazard exposure, the researchers relied on environmental monitoring alone rather than individual or biological monitoring.

This study showed a significant correlation among occupational exposures to pulmonary health hazards, decreased spirometric parameters, and increased frequency of respiratory complaints among workers in the rubber industry. Employing engineering controls and personal protective equipment and establishing a respiratory protection program should prevent, or at least minimize, occupational exposure to organic solvents and talc dust.

This study suggested a synergistic effect between occupational exposures and cigarette smoking on lung function among rubber industry workers. Therefore, determination of pulmonary health hazards in workplaces and prevention of exposures must be a priority. The results suggest that tire manufacturing companies should consider measures to reduce exposure to respiratory health hazards by establishing pulmonary surveillance systems in factories. Smoking cessation should also be promoted to prevent additional harmful respiratory effects of occupational exposures in tire manufacturing companies.

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