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Effects of air pollutant exposure on lung function in exercisers: a systematic review and meta-analysis

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Abstract. – OBJECTIVE: The aim of this study is to systematically evaluate the effect of air pollutant exposure on lung function in exercisers.

MATERIALS AND METHODS: Computer search Web of Science, PubMed, EBSCO and Cochrane Library, MINORS scale for literature quality evaluation, and Stata 12.0 software for statistical analysis.

RESULTS: According to the literature inclusion and exclusion criteria, a total of 14 pieces of literature were screened and included in the Meta-analysis, and the literature quality was relatively high. Meta-analysis shows that air pollutant exposure has no significant effect on FVC, FEV_1 and PEF of exercisers (p>0.05); but it can significantly increase the FeNO level of exercisers [Z=2.26, p = 0.024, SMD=-0.228, 95% CI= (-0.426, -0.031)]. Egger linear regression analysis shows that FVC [β=-4.64, p = 0.004, 95% CI= (-7.32,-1.95)] has the possibility of publication bias; FEV_1, PEF and FeNO p>0.05 and 95% CI contains 0, there is no publication bias in the included literature. There is no sensitivity problem in the included literature, and the combined result is robust and reliable.

CONCLUSIONS: Exposure to air pollutants may cause allergic airway inflammation by increasing FeNO levels in exercised populations, and adversely affecting human health.

Key Words:
Air pollution, Exercise, Health, Lung function, Meta-analysis.

Introduction

As people pay more and more attention to the relationship between environmental pollution and their own health, air pollution has become a hot issue in recent years. Even, the World Health Organization (WHO) lists air pollution as the biggest environmental problem threatening human health[1]. A large number of epidemiological and toxicological studies[2-6] show that frequent exposure to gaseous pollutants such as NO_2 and O_3 and inhalable particles can increase the prevalence of cardiovascular diseases, respiratory diseases, some cancers, leukemia and metabolic diseases, resulting in the risk of premature death. In recent years, as people begin to pay attention to the health benefits of physical activity, stadiums are increasingly in short supply, and people have to choose parks, squares, streets and other places for physical exercise. Long-term exposure to air pollutants may cause certain damage to health. The effects of air pollutant exposure and exercise on health are in a contradictory state. Exposure to air pollutants can harm the body's health, while regular exercise can promote health. So, what is the combined effect of air pollutant exposure and exercise on health? Can exercise reverse the harmful effects of air pollutants? Zhao et al[7] believe that there may be a balance between the two, and it is particularly important to study the impact of air pollutant exposure on the health of exercisers.

Exposure to air pollutants has a negative effect on human lung function first, so a large number of studies mainly focuses on the impact of exposure to air pollutants on the lung function of exercisers. The adaptation of the respiratory system to exercise includes increased ventilation rate and continuous bronchiectasis after exercise. Due to these respiratory adaptations, the proportion of air inhaled and air pollution particles deposited in the respiratory tract during exercise is much higher than the body's respiratory response in the resting state[8,9]. Exercise improves the metabolic level of the body, and the heart rate, stroke volume and gas exchange speed increase during ex-

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ercise, leading to the increase of pollutant deposition rate. Wijnen et al[10] and Watt et al[11] showed that compared with people exercising indoors or in rural areas, people who exercise in urban environment will face higher risk of exposure to air pollutants. McCreanor et al[12], Mu et al[13], Knibbs et al[14] believed that exercise in a heavily polluted urban environment can significantly increase the dose of toxic gases such as SO_2, O_3, and ultrafine suspended particulate matter, resulting in the decline of lung function of susceptible people and healthy adults. In conclusion, strenuous exercise exposed to air pollutants can cause the body to inhale more pollutants, which can reduce lung function and increase the incidence of lung infections. However, many studies disagree with the above studies, that is, exercise can resist the harm of air pollutant exposure. Giles et al[15] believed that the positive health benefits of exercise were greater than the negative effects of exposure to air pollutants. Matt et al[16] has proved that exercise can reduce the negative impact of suspended particulate matter in the air on the respiratory tract, and exercise can significantly improve the function of upper respiratory tract in a short term even in a highly polluted environment. Tena et al[17], Heyder et al[18] pointed out that due to the increase of pulmonary ventilation during exercise, the embedded deposition of pollutants decreased accordingly.

There are different studies on the effects of air pollutant exposure on lung function of exercisers, and it is urgent to analyze the combined effects. At present, the published review discusses the toxicity of air pollutants, the negative effects of air pollutant exposure on health, and the negative effects of exercise to compensate for air pollutant exposure[7,19,20]. The simple listing of literature content and results lacks unified standards for inclusion, literature quality evaluation, and strict data statistical analysis process, so it is impossible to quantitatively analyze the total effect of air pollutant exposure on lung function of exercisers, and the research conclusion is greatly influenced by the subjective influence of the author. Qin et al[21] studied the combined effect of outdoor exercise and exposure to air pollutants on lung function through meta-analysis, but due to inadequate retrieval, only 2-3 studies were analyzed for the combined effect of each outcome variable. In addition, the study did not evaluate the literature sensitivity, and the combined effect was greatly affected by individual studies, so the accuracy of the results was questioned. However, it is also enough to prove the impact of air pollutant exposure on the lung function of the exercisers has gradually become a hot issue, which can help guide how people in developing countries with large population density, lack of sports facilities and serious air pollution to exercise. Therefore, this study systematically reviews the previous literature in this field, discusses the impact of air pollutant exposure on lung function of exercisers, discusses whether air pollutant exposure will offset the fitness benefits of outdoor sports, and discusses its related physiological mechanisms, in order to provide guidance for outdoor sports.

Materials and Methods

Literature Search and Data Sources

Two researchers searched the database independently and obtained consistent results. Combine "outdoor sports", "exercise", "physical activity", "fitness", "physical training" with "air pollution" "air quality" "nitrogen dioxide (NO_2)" "sulfur dioxide (SO_2)" "ozone (O_3)" "carbon" monoxide (CO)""particulate matter (PM)" for mixed search. Boolean operator "AND" is used to connect search keywords. The retrieval databases are Web of Science, PubMed, EBSCO and Cochrane Library. The retrieval period is from the establishment of the database to September 2021. Import the retrieved documents into Endnote X9 document management software for preservation and deduplication.

Inclusion and Exclusion Criteria of Literature

The inclusion and exclusion criteria of literature were designed according to PRISMA statement (Figure 1). Two researchers independently screened literature according to the inclusion and exclusion criteria of literature and included literature that met common requirements. For literature with disputed judgment results, they discussed with the third person to decide whether to include them. Inclusion criteria: (1) Subjects: exercisers without respiratory and cardiovascular diseases, without age and gender restrictions; (2) Exposure factors: exposure to air pollutants, including gaseous pollutants and inhalable particles; (3) Outcome variables: one, part or all of FVC (forced Vital Capacity), FEV_1 (Forced Expiratory Volume in 1 second), PEF (Peak Expiratory Flow) and FeNO (Fractional exhaled Nitric

Oxide); (4) Study design: intervention studies; (5) Literature type: English literature. Exclusion criteria: (1) Conference abstracts, letters to the editor, literature reviews; (2) literature published repeatedly with the same set of data; (3) Comprehensive intervention experimental studies; (4) Retrospective studies; (5) Animal experiments; (6) Literature with incomplete report data.

Literature Quality Evaluation

Two researchers independently evaluated the methodological quality of the included literature, and the items with serious differences were discussed and decided with the third person. The MINORS scale was used to evaluate the original research included in the meta-analysis. The MINORS scale is applied to the evaluation of non-randomized controlled trials. The scale has 12 items, each item has 0-2 points, a total of 24 points, of which 0 indicates "not reported"; 1 point means "reported but insufficient information"; A score of 3 means "reported and provided sufficient information". The MINORS scale also involves the evaluation criteria used to evaluate the comparative group, including 4 items, so only Stieb et al[22] are suitable for the evaluation of 12 items.

Literature Data Extraction

Two researchers independently extracted and coded the basic features of the included literature, and the items with serious differences were discussed and decided with the third person. The contents of the literature extraction were the first author, publication year, research design, participant characteristics (sample size, age, gender, and country), air pollutant exposure factors, exercise content, and outcome variables. The extracted content is stored in Excel 2010 software.

Statistical Analysis

Stata 12.0 software was used for statistical analysis. Through the heterogeneity test, select the combined effect model for the main effect test. The publication bias test was performed by Egger linear regression analysis. The sources of literature heterogeneity were discussed by univariate Meta regression analysis. Literature sensitivity analysis was performed by "metainf" command. Q test and I^2 statistics were used to test the heterogeneity between studies. If $I^2 < 50\%$, $p > 0.1$, it can be considered as homogeneity between studies, and the fixed effect model was selected for analysis; If $I^2 \geq 50\%$, $p < 0.1$, it can be considered as heterogeneity between studies, and the random effect model is selected for analysis. The effect size of air pollutant exposure on pulmonary function of exercisers was expressed by SMD and 95% CI. The heterogeneity test level is set as α=0.1, and the other test levels are set as α=0.05.

Results

Literature Search and Screening Results

A total of 1675 articles were retrieved, and 958 articles were obtained after deduplication. After literature screening, a total of 14 articles were included for Meta-analysis. The literature screening process is shown in Figure 1.

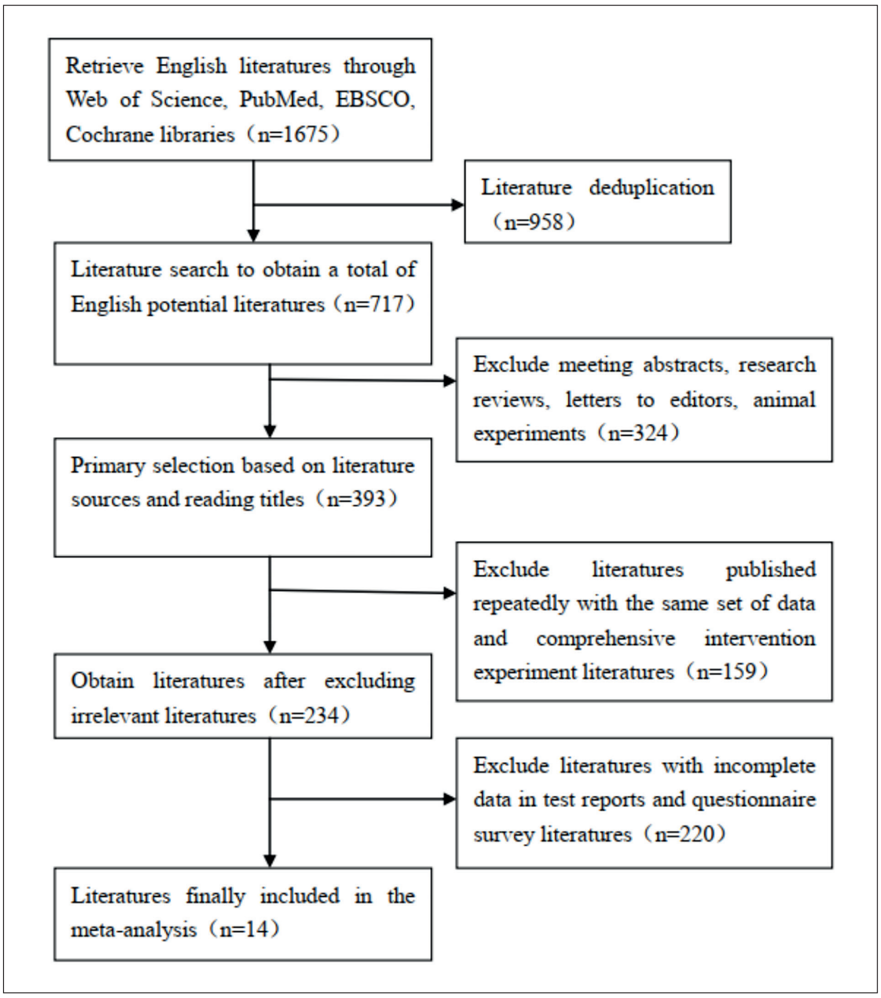
Basic Characteristics and Quality Evaluation of Literature

The included literature spans from 1986 to 2021, including 3 single group pretest and posttest designs, 8 self-control experiments, 2 randomized crossover designs and 1 quasi experimental study. Meta-analysis explored the effects of air pollutant exposure on lung function among exercisers in 711 subjects. The subjects were over 18 years old, and the subjects were from the United States[23-29], Poland[30-31], United Kingdom[32], China[33], Greece[34], Belgium[35] and Canada[22]. Two studies[30,32] explored the impact of air pollutant exposure on the lung function of male exercisers; no research aimed at female exercisers; the remaining studies did not distinguish between genders. The exposed air pollutants include UFPM, $PM_{2.5}$, PM_{10}, BC and other air suspended particles and CO, NO, NO_2, NO_X, SO_2, O_3, HNO_3 and other gaseous pollutants. Exercise content includes aerobic exercise, high-intensity exercise and other forms. Outcome variables include FVC (11), FEV_1 (11), PEF (4) and FeNO (6). Except for Stieb et al[22] (the quality evaluation result was 19), the literature quality evaluation results included in meta-analysis (Table I) had an average score of 12.14, ranging from 11 to 16, indicating high literature quality.

Heterogeneity Test and Main Effect Test

The literature included in FVC, FEV_1 and PEF showed heterogeneity (I^2>50%, p<0.1), so random effect model was used for analysis; the literature included in FeNO showed homogeneous (I^2=34.5%, p=0.178), so the fixed effects model is used for analysis (Table II). The main effect test results (Table II) showed that air pollutant

Figure 1. Flow chart of literature screening.



exposure had no significant effect on FVC, FEV_1 and PEF in exercise group (p>0.05). However, exposure to air pollutants can significantly increase FeNO level in exercisers [Z=2.26, p=0.024, SMD=-0.228, 95% CI= (-0.426, -0.031)], which may cause allergic airway inflammation and have adverse effects on human health.

Literature Publication Bias Test

The reliability of meta-analysis results depends on whether the included literature is biased. In this study, Egger linear regression was used to test the publication bias of literature. Egger linear regression is a method of quantitatively testing whether there is publication bias, to make up for the insufficiency of the funnel chart subjectively unable to judge the situation[36]. The Egger linear regression model uses the standardized effect size as the Y variable and the accuracy of the effect estimator as the X variable to construct a linear regression equation. The intercept of the regression equation is the offset. The closer it is to 0, it indicates that there is a publication bias. The smaller the value, if p >0.05 and 95% CI contains 0, it means that there is no publication bias. Egger linear regression analysis results (Table III) show that: in FVC β=- 4.64, p = 0.004, 95% CI = (- 7.32, - 1.95), that is, the included literature may have publication bias; p > 0.05 and 95% CI included 0 in FEV_1, PEF and FeNO, that is, there was no publication bias among the included literature, and the meta-analysis results were stable and reliable.

Sources of Literature Heterogeneity

The literature heterogeneity test shows that there is serious heterogeneity in the four outcome variables of lung function. Therefore, it is necessary to conduct a Univariate Meta regression analysis on the research characteristics that may cause heterogeneity to explore the source of the heterogeneity between studies. In this study,

Table I. The basic characteristics and quality evaluation results of the literature included in the meta-analysis.

Included studies	Research design	Participant characteristics	Exposure factors	Sports content	Outcome variables	Quality assessment
Aris et al[23], 1991	Single group pretest and posttest design	N: 10 Age: 21-39 Sex: M 6/F 4 Country: United States	Acidic Fog (HNO_3), O_3	2 h exercise	FVC FEV_1	12
Jacobs et al[24], 2010	Self-control experiment	N: 10 Age: 21-31 ex: M 6/F 4 Country: United States	PM_{10}, $PM_{2.5}$, UFPM	20 min cycling	FeNO	13
Daigle et al[25], 2003	Self-control experiment	N: 12 Age: 18-52 Sex: M 6/F 6 Country: United States	UFPM	15 min moderate intensity exercise, bicycle dynamometer	FVC FEV_1	12
Gomes et al[26], 2010	Randomized crossover design	N: 10 Age: 24±6 Sex: M 10/F 0 Country: United Kingdom	O_3	8 km run	FVC FEV_1 PEF	13
Wagner and Clark[27], 2018	Self-control experiment	N: 16 Age: 31.5±11.3 Sex: M 5/F 11 Country: United States	$PM_{2.5}$	20 min cycling, try to ride as hard as possible	FVC FEV_1 FeNO	12
Jarjour et al[28], 2013	Self-control experiment	N: 15 Age: 32.20±6.67 Sex: M 11/F 4 Country: United States	UFPM, CO, PM2.5, BC	40 min cycling	FVC FEV_1	16
Pun and Ho[29], 2019	Self-control experiment	N: 30 Age: 20.6±2.2 Sex: M 13/F 17 Country: China	O_3, BC	30 min moderate intensity running	FVC FEV_1 PEF FeNO	15
Kocot and Zejda[30], 2021	Self-control experiment	N: 30 Age: 22.8±2.2 Sex: M 30/F 0 Country: Poland	SO_2, NOX, PM10, PM2.5	15 min maximum intensity cycling	FVC FEV_1 FeNO	14
Gong et al[31], 1986	Self-control experiment	N: 17 Age: 24.4±3.2 Sex: M 15/F 2 Country: United States	O_3	60 min maximum intensity cycling	FVC FEV_1	11
Kocot et al[32], 2020	Self-control experiment	N: 76 Age: 20.9±2.6 Sex: M 42/F 34 Country: Poland	$PM_{2.5}$, PM_{10}, SO_2, NO_2, NOX, NO	45-60 min exercise training (high-level physical activity)	FeNO	14

Continued

Table I ***(Continued).*** The basic characteristics and quality evaluation results of the literature included in the meta-analysis.

Included studies	Research design	Participant characteristics	Exposure factors	Sports content	Outcome variables	Quality assessment
Flouris et al[33], 2012	Randomized crossover design	N: 16 Age: NA Sex: M 8/F 8 Country: Greece	CO	VO_2max test	FVC FEV_1 PEF	12
Girardot et al[34], 2006	Single group pretest and posttest design	N: 354 Age: 43.2±12.6 Sex: M 200/F 154 Country: United States	O_3, $PM_{2.5}$	6.7 km alpine hiking	FVC FEV_1 PEF	12
Bos et al[35], 2013	Single group pretest and posttest design	N: 38 Age: 43.0±8.6 Sex: M 28/F 10 Country: Belgium	UFPM	12 weeks of aerobic training, 3 times/week, 1 h/time	FeNO	14
Stieb et al[22], 2018	Quasi experiment	N: 36/41 Age: 63±5/65±6 Sex: M 30/F 47 Country: Canada	CO, NO_2, O_3, $PM_{2.5}$, SO_2	10 weeks outdoor activities, 7 times/week, 30 min/time	FVC FEV_1	19

Note: UFPM, Ultrafine PM; BC, Black Carbon.

Table II. Results of heterogeneity test and main effect test of outcome variables.

Outcome variables	Number of studies	Heterogeneity test				Main effect test	
		I^2	*p*	Z	*p*	SMD	95% CI
FVC	11	94.1%	< 0.1	0.09	0.871	-0.047	(-0.616, 0.522)
FEV_1	11	93.97%	< 0.1	1.73	0.084	0.357	(-0.048, 0.762)
PEF	4	84.8%	< 0.1	0.70	0.481	-0.229	(-0.866, 0.408)
FeNO	6	34.5%	0.178	2.26	0.024	-0.228	(-0.426, -0.031)

the standardized effect size was used as the Y variable, and the publication year, research design, age of participants, proportion of women, country of the participants, exposure factors, exercise content, and literature quality were coded respectively, and then set as the X variable for Univariate Meta regression analysis. The results of Univariate Meta regression analysis (Table IV) showed that none of the above research characteristics were the source of heterogeneity (p >0.05).

Table III. Egger linear regression publication bias test.

Outcome variables	β	SE	*t*	*p*	95% CI
FVC	-4.64	1.109	-3.91	0.004	(-7.32, -1.95)
FEV_1	-1.30	1.40	-0.93	0.378	(-4.47, 1.87)
PEF	3.34	0.93	3.61	0.069	(-0.65, 7.34)
FeNO	0.43	1.84	0.24	0.824	(-0.466, 5.31)

Table IV. Univariate Meta regression analysis.

Research characteristics	β	SE	*t*	*p*	95% CI
Publication year	1.081	0.118	0.71	0.493	(0.845, 1.383)
Research design	1.609	1.870	0.41	0.962	(0.116, 22.299)
Age of participants	1.019	0.097	0.20	0.847	(0.822, 1.264)
Proportion of women	3.259	17.02	0.23	0.826	(0.000,439609.500)
Country of the participants	1.814	1.183	0.91	0.385	(0.415, 7.929)
Exposure factors	0.638	1.026	-0.28	0.786	(0.017, 24.289)
Exercise content	8.651	20.824	0.90	0.393	(0.037, 2004.785)
Literature quality	0.526	0.475	-0.71	0.495	(0.068, 4.062)

Literature Sensitivity Analysis

Literature sensitivity analysis is an important method used to evaluate the robustness and reliability of consolidation results in meta-analysis. It can evaluate whether the consolidation results have significant changes due to the influence of a study. In this study, the sensitivity of each study included in each outcome variable was analyzed with the help of the "metainf" command. By excluding a study one by one, it is found that the SMD and 95% CI of the research results have not changed significantly, so there is no literature sensitivity problem.

Discussion

The research results are similar to the meta-analysis results of Qin et al[21]. It is also considered that air pollutant exposure combined with exercise has little effect on FVC and FEV_1, but this study believes that air pollutant exposure combined with exercise has no significant effect on FeNO, which is different from our study. Outdoor exercise can increase the sensitivity of the body to air pollutants. Especially in the process of high-intensity exercise, breathing changes from nasal breathing to oral breathing, and lung ventilation increases, making air pollutants bypass the nasal filtration system and potentially increase the dose of air pollutants into the body[15]. In addition, exercise increases the proportion of ultrafine particles deposited in the respiratory tract that are not exhaled, which may increase the adverse effects of air pollutant exposure[25,37]. However, Jarjour et al[27] believes that the increase of air pollutant concentration will not have a negative impact on physically active people; Weichenthal et al[38] concluded through empirical research that there is no significant difference in lung function between exercise in high pollution and low pollution environment; Laeremans et al[39] believes that exercise can counteract the adverse effects of air pollutant exposure on lung function; Cole et al[40] also found no significant changes in lung function under the interaction of air pollution and exercise; even Matt et al[16] found that exercise can significantly improve FVC and FEV_1 indicators under the exposure of higher concentrations of air pollutants. Exercise induced bronchiectasis may be due to the activation of endogenous catecholamine's β 2 receptor, which is well known β 2 receptor agonists are the first choice for airway spasm[41]. Researchers have extensively discussed the controversy about the impact of air pollution exposure on the lung function of the exercisers. Pieters et al[3] believes that the age and disease conditions of the subjects are important sources of differences between the studies. Exposure to air pollutants will further reduce the lung function of people with various diseases (myocardial infarction, diabetes, chronic obstructive pulmonary disease), aging, and drugs (β-blockers) users. The subjects included in our study are all healthy people without respiratory and cardiovascular diseases, so they are inconsistent with the results of some studies. FeNO is produced by airway cells, and its concentration is highly correlated with the number of inflammatory cells. Exposure to air pollutants may lead to oxidative stress, enhanced bronchial reactivity, increased airway resistance, and increased airway inflammatory cells, thereby affecting lung function[42,43]. Even healthy people may develop lung inflammation due to exposure to air pollutants. Long-term acute exposure can cause inflammatory cells to flow into the airway, which significantly increases airway inflammation markers, so FeNO rises[23,44]. Qin et al[21] only combined two studies to draw relevant conclusions, and Gomes et al[32] accounted for 85.58% of the weight in this meta-analysis, which will inevitably affect the statistical test power. However, our study evaluated the bias and sensitivity of the included study to ensure the robustness of the research results.

Egger linear regression analysis showed that FVC may have the possibility of publication bias, and the limited number of original studies may have a certain impact on the accuracy of the research results. However, on the whole, exposure to air pollutants may have a negative effect on the lung function of the exercisers, which suggests that we should try to avoid exercising under severe air pollution.

Conclusions

Overall, our study systematically reviewed 14 interventional studies on the impact of air pollutant exposure on the lung function of the exercisers and found that air pollutant exposure can significantly increase the FeNO level of the exercisers, but the effect on FVC, FEV_1 and PEF is not significant. It may cause allergic airway inflammation and adversely affect human health.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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