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REVIEW ARTICLE | Pneumoconiosis Control

Measures to Control the Prevalence of Pneumoconiosis in Coal Mining: A Review of the Literature

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ABSTRACT

Background: There are enormous health problems associated with the use of coal as energy. Dust emitted during the mining processes is identified as a specific risk factor for Coal Worker Pneumoconiosis (CWP) and other respiratory health problems. There is little published evidence on various health measures and their effectiveness in controlling CWP. This review seeks to provide a summary of the published literature on various health measures taken to reduce CWP in coal mines.

Methods: We searched Google Scholar, PubMed, MEDLINE, EMBASE and occupational health databases for published research articles, evaluation reports, official documents and regulations. Reference lists of relevant papers were hand-searched. We retrieved a total of 1, 049 articles out of which 17 merited criteria for inclusion. Papers presenting evidence of the prevention of CWP among coal miners were included.

Results: Many technological interventions are currently available to promote primary prevention of CWP by ensuring reduction in inhalable dust. This review identified laws and regulations, surveillance, direct dust control measures, risk assessment and compensations as ways of minimizing exposure to dust among coal workers, as means of preventing CWP.

Conclusion and Implications for Translation: There is little evidence on the various measures stipulated in mining regulations that are adhered to and the extent to which they have been effective. The public health strategy that combines various health measures, including training of workers on safety measures, may be effective in preventing CWP.

Keywords: Pneumoconiosis • Coal Miner • Mining • Health Measure • Coal Worker • Control

1. Introduction

Coal mining is the extraction of coal from the earth for use as fuel. Coal may be found either as surface outcrops or in underground seams.[1] Burning coal is viewed as the single largest cause of global warming, which the world's leading medical journal, The Lancet, has described as "the biggest health threat of the 21st century." Health problems associated with using coal as an energy source in Australia alone have been estimated to cost $2.6 billion per year.[1] Dust emitted during the mining processes is identified as a specific risk factor for respiratory health among miners.[2] According to the US National Institute for Occupational Safety and Health (NIOSH) there is a considerable burden of pneumoconiosis in many countries, but stresses that underground coal miners were vulnerable to other lung diseases, notably chronic obstructive pulmonary disease (COPD), and asthma.[3]

Pneumoconiosis is a progressive disease whose severity depends primarily on the cumulative mass of coal mine dust inhaled and, to a lesser extent, on other factors such as dust composition, duration of exposure and age.[4] Pneumoconiosis is strongly related to excessive coal dust exposure exceeding the Maximum Permissible Exposure Limits (MPELs).[5] It occurs as a reaction of the lung tissue parenchyma to the foreign coal dust particles, which accumulate in lung parenchyma cells.[6]

Exposure to dust at the workplace is the major cause of other ailments. Occupational asthma, for example is the limited airflow related to workplace dust exposures.[7] In the developed world, occupational asthma is the most common occupational lung disease. This is evidenced by the results of physician notification schemes for occupational respiratory disease, established in several western countries, including the UK, Finland, Canada, the USA, South Africa and Australia. While reliable figures are difficult to find,[8] it has been estimated that up to 15% of new asthma in adults are directly attributable to occupational exposures.

According to the World Health Organization (WHO), COPD is "a disease state characterized by progressive development of airflow limitation that is not fully reversible. The airflow limitation is usually both progressive and associated with an abnormal inflammatory response by the lungs to, noxious particles or gases."[9] COPD prevalence is difficult to determine since the condition does not manifest until midlife. There is an estimated 90,000 diagnosed cases in England and Wales, and an estimated 2 million people are thought to have the disease but remain undiagnosed. Occupational agents reported to cause COPD with varying degrees of supporting evidence include coal mine dust, silica, asbestos, agricultural dust, dust from rubber, iron/steel and smelting, welding fumes, isocyanates and other chemicals.[10-12]

In China, the State Administration of Work Safety[13] estimated an unprecedented 4,648 cases of casualties caused by 105 coal dust explosions from 1970 to 2014.[14] Many of these explosions resulted in Coal Worker's Pneumoconiosis (CWP) which is estimated as the most common disease caused by coal dust.[15,16] Again, the China National Health and Family Planning Commission[17] revealed that more than 105 thousand coal miners developed CWP from 2009 to 2013, accounting for 94.5% of the total increase of pneumoconiosis victims. The most intriguing part of the situation is, longwall mining has increasingly been adopted due to its high productivity, neglecting the risk it poses to the miners. What is more alarming is the absence of inhalable dust concentration limits in Chinese mining regulations compared to their Australian counterparts. The Australian regulation limits the concentration of inhalable dust to 10 mg/m^3.[18]

In general terms, the body of evidence is stronger for coal mine dust, silica, grain and textiles and less strong for the other identified exposures.[19] Workers in numerous occupations (other than exposure-type) are at increased risk of COPD, supported by varying levels of evidence.[20] A study conducted by Goldyn, and colleagues,[21] revealed micro-nodular opacities along with restrictive pattern of pulmonary function in simple pneumoconiosis among coal miners whereas in Pakistan, an increased prevalence of pneumoconiosis was found among coal miners of Cherat district Nowshera.[22] The study revealed that 71% had signs and symptoms of Occupational Respiratory health problems and 49.50% of the Coal Miners showed prevalence of pneumoconiosis.[22] The overall situation of Occupational Safety & Health Measures in Cherat coal mines does not foster a safe and healthy working environment leaving miners under hazardous conditions.[22] In Baluchistan, a study to determine the health impacts of coal mining showed that higher concentration of coal dust (Carbon and Quartz) resulted in asthma, drowsiness, shortness of breath and pneumoconiosis, and other respiratory illnesses.[23]

In spite of these revelations, there is little published evidence to assist employers and workers in coal mines when considering either how best to reduce the risk of COPD, asthma and pneumoconiosis related to work, or how best to identify and retain those with COPD, asthma and pneumoconiosis in the work environment. Miners must be made aware of the potential health risks associated with breathing excess respirable dust as well as the controlling hazards to eliminate illnesses and injuries, including those that arise from changing mining conditions. The aim of this study is to review the existing literature on measures to control pneumoconiosis in coal mining.

2. Methods

The target population consisted of mineworkers from both high and low-income countries. The healthcare measures included all forms of measures undertaken to prevent the CWP and asbestosis. The targeted sources of evidence included reports, journal articles, conference proceedings, legal documents etc. The search was conducted in PubMed, Medline, Embase, Google Scholar and database of occupational health and injuries. Information was synthesized from any of the aforementioned sources provided it met the inclusion criteria. Out of the 1,049 articles extracted, 17 were included for review after meeting the inclusion criteria (Figure 1). We conducted our search using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). This study did not focus on quantifying the interventions but presenting the qualitative evidence of prevention of CWP among coal miners globally.

3. Results

3.1. Health measures

Dust exposure and resulting ailments have been a major health concern since the inception of coal mining. The pneumoconiosis is primarily caused by the exposure to dust during the mining process. Primary disease prevention therefore aims at efforts that minimize or eliminate completely the exposure to dust in coal mining. Exposure to dust during coal mining does not only lead to pneumoconiosis, but could also cause other illnesses such as bronchitis. This review identified key measures being taken to control dust exposure as an effective health care measure in coal mining. The identified measures included laws and regulations, health survey and assessment, direct exposure control through appropriate technological applications, research and development and instituting risk management systems.

3.2. Enactment of laws and regulations

Enactment of laws and regulations has been a widely used means of ensuring miners' safety. With regard to dust control, these regulations ensure that mining processes are structured to minimize dust emissions, institute procedures to detect health risks at the early stages as well as equip the miners to operate safely. This review found that most countries have instituted Mine Acts as a form of regulatory tool for mining operations. In the United States of America, the "Mine Act of 1977" gives authority to the Mine Safety and Health Administration[25] to write standards, inspect mines and impose sanctions in case of non-compliance. Similar acts were identified in South Africa,[26-28] and in Ghana. These Acts ensure miners' safety mainly through regulating mining operations, providing technical assistance, ensuring provision of surveillance systems, research and training of miners on health and safety.

Most mining acts entail prescriptions for the mining practice. These include ventilation requirements, roof support and the required level of dust produced. In the "USA Mine Act" for example, statutory permissible limits are set for exposure to respirable coal mine dust.[29] The Mine Acts also

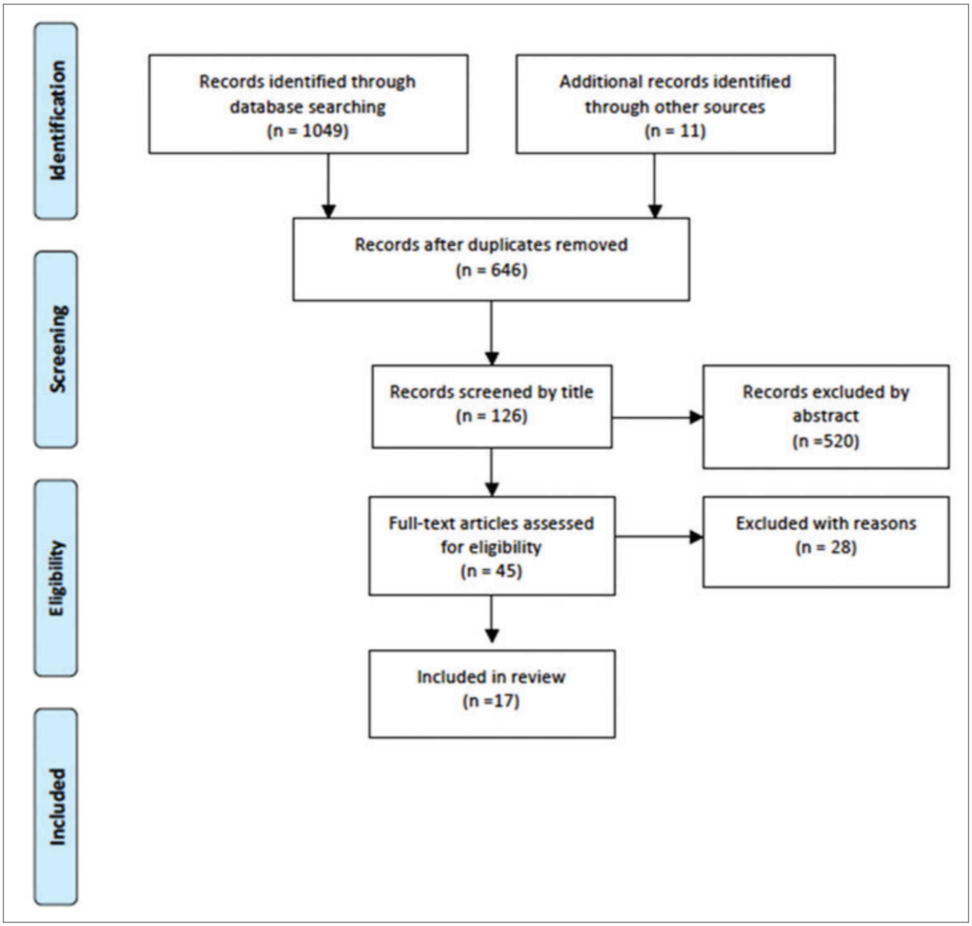

Figure 1: Flow diagram of the review process, measure to control pneumoconiosis in coal mining (adopted from PRISMA tool)[24]

make provision for regular monitoring to ensure compliance with these standards. In the United States, the Mining Safety and Health Administration is required to conduct frequent inspections. These include quarterly inspections of underground mines and semi-annual inspections of surface mines. The "Mine Health and Safety Act of South Africa" also stipulate the establishment of regional inspectorate divisions for the purposes of administering the act and ensuring compliance.[27] The administrators of these Acts are sometimes even empowered to shut the mine if they fail to comply.[29] In Ghana, for instance, the Inspectorate Division (ID) of the Minerals Commission was established following the 2006 Minerals and Mining Act to enforce the Mining Regulations, 1970.[28] The ID is empowered to review proposed mining projects and, if satisfied with the instituted health and safety measures, issue an operating permit.

In China, the government enacted the "Occupational Safety and Health Regulations in Plant" as far back as 1956.[30] This called for the closure of equipment, which sends out dust, harmful steam and gases, and possible installation of ventilation equipment and dust workers operating under wet conditions. In this regulation, the factories were also mandated to provide dust-proof masks, protective glasses and gas masks for workers who engage in dust and other harmful steams. Chinese State Council also issued the "Prevention and Cure Regulations on Pneumoconiosis in 1987."[31]

As part of this regulation, there is a call on mining operators to ensure that dust density does not exceed the national sanitary standard. It also empowered workers to refuse operating when dust density exceeds national sanitary standard. The Industrial and Commercial Hygiene Standards sets limits for mine dust concentration and the Safety Regulations in Coal Mine stipulate that all coal mines should take active measures to ensure that mining dust does not exceed these limits.[18] However, there is little evidence of the level of compliance of these Acts, especially in low and middle-income countries. It could be deduced from the rising level of pneumoconiosis in many countries globally, that these regulations might not fully adhere.

The mining regulations in most countries call for a provision for surveillance of CWP. Under these regulations, workers are required to report all injuries to help compute crude rates and to identify near-miss incidents. The "Mine Health and Safety Act" of USA states that safety managers should establish systems of medical surveillance and keep records of hazardous work and medical surveillance. Operators are required to make provision of chest x-rays for underground miners when first employed and during regular intervals. It further states that these x-rays facilities should be certified by the National Institute for Occupational Safety and Health (NIOSH). This was to monitor the progress of CWP and offering miners with positive films the opportunity to be transferred to a less dusty job.

Training and employee empowerment is another key aspect of most Mining Acts. Employers are required to equip employees with the requisite knowledge to be able to work safely and avoid risk and exposure to hazardous materials. Training coal mineworkers on how to minimize dust exposure for instance, is a major prevention strategy for CWP. The South African Mine Health and Safety, for example, requires that mine operators ensure that every employee is properly trained to deal with risk pertaining to their health or safety associated with any work they have to perform.

3.3. Public health measures

3.3.1. Surveillance

Surveillance is an effective way of detecting and controlling disease occurrence and spread in the mining industry. It is important to ensure regular health surveillance for all workers in the coal mining industry. However, although stipulated in most Mining Acts, there were few identified surveillance programs being rolled out. In the United States, an x-ray surveillance program in the coal mining industry was initiated in 1970. Evidence shows marked reduction in the prevalence of CWP since the inception of the program (drop-in prevalence from 28.2% to 3.3% from 1973 to 1999 among workers with over 25 years or more experience).[3]

Health surveillance provides the avenue for unraveling current levels of disease prevalence. CWP is a progressive disease, which could be detected and dealt with earlier if there are proper surveillance and screening mechanisms. The Center for Disease Control[2] also reported a two-month health screening program conducted in five mine sites in bituminous coalfields in western Pennsylvania (Altoona, Clearfield, Farmington, Indiana, and Somerset) and, in June 1997, at three mine sites in anthracite coalfields in eastern Pennsylvania (Centralia, Pottsville, and Wilkes-Barre) found a prevalence of 83 (6.7%) of 1,236 screened miners and marked differences between eastern and western sites. These surveillance programs expose the risk levels of CWP among miners and pave way for necessary preventive and curative actions. In Africa, the mining sector is marked by weak surveillance systems. There is scarce evidence of implemented surveillance programs across mining sectors in Africa, and in areas where efforts have been made, there are few or no policy implementations to this effect.[32]

3.3.2. Exposure control

Efforts to control exposure to dust at mining sites are key to controlling CWP among coal miners. This involves providing appropriate data on the dust levels at the mine site and instituting appropriate technological and safety interventions to minimize them. The study by Fishwick et al.[33] identified risk assessment and application of principles of good practice as key to minimizing exposure to hazardous substances in the mining industry. The study identified the "hierarchy of control" as mostly used to decide the most appropriate controls. The hierarchy involves elimination (completely removing the agent from the workplace); substitution (replacing harmful agent with an alternative); instituting engineering controls such as total enclosure, partial enclosures with local exhaust ventilation and general ventilation; and administrative controls (including segregation of workers, job rotation to minimize potential exposure time, good cleaning and maintenance practices, providing hygiene facilities) and providing personal protective equipment.[33]

The study by Joy[34] also identified a four-stage process approach to risk management. These include risk identification (identifying the potential hazard); risk analysis (assessing the magnitude of risk); risk control (deciding on appropriate measures to reduce or control unacceptable risk); and implementation and control of the measures to ensure effectiveness.

3.3.3. Dust controls measures

Water sprays and ventilating air have been identified as the primary controls used for protecting mineworkers from being over-exposed to respirable dust. Water spray is an important primary dust control mechanism among longwall face workers. Although longwall mining has improved over the years, significant increase in coal extraction rates have led to increase in dust production. Longwall mining equipment operates with shearers and all shearer-cutting drums in operation since the late 1970s have been equipped with drum-mounted water sprays. All shearers in the US are equipped with water sprays and these have shown to be very effective in moving air and entraining dust in the direction of airflow. Current inventions, including spray equipped miners known as "wet head" miners have also been underway in the US and evaluation report shows that these could reduce dust at the mine operator ranging from 0.2 to 0.5 mg/m^3.[35] Previous evidence suggests the effectiveness of water spray technologies in reducing dust exposure, as a way of preventing CWP. The study by Courtney and Cheng[36] reported that a typical water spray operating at 100 psi and 1-2gpm gives no more than 30% airborne capture of respirable dust. Raising the pressure of the sprays was even shown to improve its effectiveness in dust capture. A high-pressure system (2,300 psi, 3gpm), for instance, gave 30% respirable dust reduction just as conventional spray (100psi, 19gpm) but with much less water.[37]

Ventilation ensures reduction in dust levels by diluting generated dust and transporting dust away before it can migrate to breathing zones. This was described as the most effective method of dust control because it ensures the main work entry and the continuous miner, as well as the shuttle car, are exposed to fresh air. This involves bringing in fresh air to the face in the working entry and installing tubing within the entry to create an air separation and further drawing dust-laden air from the face through the tubing. Other reported ventilation measures include equipping miners with fan-powered, flooded-bed scrubbers, which mainly collect dust with water droplets and removing them from the air stream when a demister captures the droplets. In the United States, miners are also equipped with external sprays located on top of the miner booms, with the purpose of wetting the coal as it is being cut and prevent dust from being airborne. These measures help to minimize the respirable air to the mineworker and help prevent CWP.

Dust avoidance is another effective way to control dust exposure. This refers to the movement of either the dust cloud or the workers so they are upwind of the dust. One effective means of avoiding dust on mining machinery is the use of remote control. Evidence shows that this control measure enabled shearer operators to move upwind 15-20ft, and reduced dust exposure by 68% by avoiding direct contact with dust from the head gate-end shearer.[38] In another study by Divers et al.,[39] this measure enabled the operator to step back 12ft from intake and reduced dust exposure level by 50%.

3.3.4. Compensation

Mineworkers' compensation is a very important issue related to the control of health issues such as CWP. Mining Acts emphasize the need for operators to institute appropriate compensatory schemes for mineworkers in the advent of disease, disabilities or death due to their involvement in mining activities. In South Africa for instance, there is statutory provision for compensation under two pieces of legislation; the "Compensation of Occupational Injuries and Diseases Act" (Coida) and the "Occupational Diseases in Mines and Works Act" (Odimwa), with the Odimwa being specifically applicable to the mining industry.[26,27] In the United Kingdom, there exist the Coal Health Claims, which are two claims run by the Government and exist to compensate UK coal miners and their families in relation to respiratory diseases. Previous evidence suggests that most mineworkers, especially from low-income countries, do not benefit from compensations in times of injuries or disabilities. A study by Roberts[40] among 205 former miners in Eastern Cape, South Africa reported that about 85% of respondents did not receive the statutory medical compensation when leaving the mine and about 99% were not aware of the existence of the Compensation Acts and its benefits. Another study by Steen[41] on 304 former gold miners living in Thamanga, Botswana also reported that only a few eligible miners had been compensated and in the study by Trapido et al.[26] on former gold miners living in Eastern Cape, South Africa only 2.5% had been fully compensated with 62% of those eligible not compensated.

In China, the government included asbestos pneumoconiosis in the list of legal occupational diseases under "Law of the People's Republic of China on Prevention and Control of Occupational Diseases" from 2001. Under this law, pneumoconiosis patients could receive free medical treatment catered for by the insurance fund of the occupational injury. In the same vein, the Insurance Regulations of the Occupational Injury issues in 2003 by the State Council also highlight various treatment rights and interests due to the occupational disease patients.

4. Discussion

Pneumoconiosis was a major occupational health burden globally, that caused about 260,000 deaths in 2013.[42] This review was conducted to explore healthcare measures aimed at preventing CWP and asbestosis mainly resulting from exposure to dust at the mine. Laws and regulations were by far the most identified control measure for occupational injury and improved the health of workers. It provides an avenue for setting up regulatory bodies and empowers them to monitor, evaluate and ensure that coal mining operators work within set up regulatory standards to ensure hygienic working environments. Some mining acts stipulate the requisite operating requirements for setting up mines and ensure these are in place before operation begins and provide avenues for training of staff on appropriate health and hygienic measures. In the industrialized world, adherence to mining regulations has reduced inhalation exposure in the past decade. The passage of the Mine Act in the United States for instance, led to marked reduction in fatal injuries at the coal mine.[43] On the other hand, there is little evidence of miners' cooperation and enforcement of mining regulations by appropriate authorities. Most mine regulations also do not set a limit for inhalable dust concentration. A recent review of dust control practices in China and Australia identified that Chinese regulations have no limit in inhalable dust concentration whereas in Australian regulations, the concentration is limited to 10 mg/m^3.[44] Regulatory bodies mandated under these acts should ensure thorough enforcement of these regulations, which could help improve the hygienic standards of coal mines.

This review also identified practical measures such as improved technologies targeted to reduce respirable air at the coal mine. Exposure control measures that eliminate or substitute harmful agents and other control measures are enforced in most industrialized settings. Wetting and ventilation technologies are available in most industrialized settings and these are effective in reducing exposure to dust. In China, application of water infusion before mining operations has been shown to reduce dust up to about 60%.[45] This technology has also been successfully applied in Australia since 1987. In the United States, miners are equipped with fan-powered, flooded-bed scrubbers, and these are helpful in collecting exposable dust during mining operations. There are currently ongoing efforts to further improve these technologies but the extent to which they are used and evidence of their effectiveness is not much known. More interventional research is needed to show the effectiveness of these technologies especially in middle- and low-income countries.

Compensation mechanisms could compel mining operators to institute appropriate public health measures to prevent CWP. Evidence, however points to the fact that miners, especially from low resource settings are not aware of the existence of compensations and most benefactors do not get the compensations due to them. This points to gaps in workers' right and enforcement of legislation to ensure payment of compensations. Enforcing mining regulations together with appropriate technologies to control mine dust could go a long way in ensuring the safety of coal workers.

5. Limitations

The strength of this review reflects the various themes identified and their consistency with previous studies. Although we tried to search for all appropriate studies, we might have missed some and that may affect the generalization of our findings. However, we believe that the results identified are compelling and show consistent pattern scarcity of findings and inadequate public health measures to ensure mine safety, especially in limited-resource settings.

6. Conclusion and Implications for Translation

In conclusion, this review shows varied efforts to control respirable dust in coal mining. Many technological interventions are currently available to promote primary prevention of CWP by ensuring reduction in inhalable dust. These, however, could be better implemented through the enforcement of mining regulations. Health and environmental surveillance systems, which are stipulated in most mining regulations, are important in unraveling levels of exposure and infections among coal workers. There is, however, a scarcity of evidence to this effect, especially in low-income countries. The public strategy that combines various health measures, including training workers on safety measures, will be much more effective in preventing CWP. More research is required on the effectiveness of public health interventions and safety measures in mining to improve the level of evidence and make room for improvement.

Compliance with Ethical Standards

Conflicts of Interests: *The authors declare no competing interest.* ***Financial Disclosure:*** *Nothing to declare.* ***Funding/Support:*** *There was no funding for this study.* ***Ethical Statement:*** *This study is a review of existing literature and did not require ethical approval.* ***Acknowledgment:*** *This study was partially supported by the National Natural Science Foundation of China (81573119). The authors express a profound gratitude to all who helped in making this review possible especially Daniel Boateng. We also thank the authors of all the works cited in this study.* ***Disclaimer:*** *None.*

Key Messages

- Little evidence exists in the literature on the level of adherence to and effectiveness of mining regulations.
- A combination of public health strategies that include health measures and training may be effective in preventing coal worker pneumoconiosis.
- Efforts to control exposure to dust at mining sites are important in controlling coal worker pneumoconiosis.

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