REVIEW ARTICLE

Effect of Paint Exposure Among Paint Workers and DNA Damage: A Scoping Review

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ABSTRACT

Paint contains various complex chemical mixtures, such as aliphatic hydrocarbons, aromatic hydrocarbons (primarily toluene), ketones, and benzene as reported at previous studies. Toxicity from some chemicals can cause early DNA damage with various factors. A scoping review was conducted via literature review on relevant studies on the effect of paint exposure on paint workers and DNA damage. A systematic search was conducted in October 2021 via PubMed, Scopus, and Web of Science databases. The key terms used were paint, solvent-based paint, organic solvent, mixed organic solvent, occupational exposure and DNA damage, oxidative stress, genotoxicity on a painter, paint worker. From 561 articles, only 13 articles were finally selected based on the inclusion, exclusion criteria, and eligibility criteria. The literature showed that biomonitoring studies on painters were consistently reporting positive and significant DNA damage due to exposure to different types of compounds mixed in a paint. However, there were fewer studies on paint manufacturing factory workers compared to painters while paint manufacturing workers exposed various chemical everyday during the paint production which potentially susceptible to occupational toxicity. In conclusion, this review suggests that exposure to paints could induce early DNA damage among paint workers and further investigations on paint exposure among paint manufacturing factory workers and the DNA damage were needed in order to improve occupational health among paint workers in the future.
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Keywords: Paint exposure, Organic solvent exposure, Paint workers, DNA damage, Oxidative stress

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INTRODUCTION

The paints and coating industry is one of the world's major industrial bussiness in the manufacturing sector. Despite world market review on paint and coating market during Covid19(1) in year of 2020-2021 were decline, the market project to grow significantly on 2029. Therefore, production of paint and coating increases when there were high demand. Paints are usually used to adorn, maintain, and extend the life of natural and manmade materials, as well as to function as a protective layer against environmental conditions. Paints are classified into variety of uses such as ornaments paints are being used on-site to embellish and shield buildings and other items, whereas industrial coatings are used in factories to fix produced goods like vehicles, ships, and household appliances, among other things (2). Paints are finely split pigment particles suspended in a liquid comprised of a binder (resin) and a volatile solvent, occasionally with additives to give unique features (3). However, in paint production, the pigments, binders, extenders, solvents (sometimes called thinner), and additives that include a variety of chemical compounds can release hazardous gases that can be harmful to human health.

Therefore, workers can be exposed to occupational toxicity when a large number of chemicals are used in their workplace(4). Occupational exposure to chemicals typically occurs via inhalation, but in some workplaces, dermal exposure is also important, especially in the paint industry (5,6). Some substances present in paints have been classified as carcinogenic and are related to effects caused by dermal and inhalation exposure, such as eye irritation and problems with the respiratory tract's mucous membranes(7). Production of paints and paint applications will release a variety of gases, some of which may have negative effects on human health.

Thus, paint manufacturing workers and painters who are involved in paint production or paint application may be afflicted with chemical toxicity. Previous studies found significant health effects among paint workers compared to control workers, which workers in the paint sector have shown to be reliable exposed to occupational toxicity and at a high risk of developing negative health effects. The International Agency for Research on Cancer (IARC) had classified the painters' occupational exposure as a Group 1 carcinogen in 1989, leading to the paint and coating industries being regulated heavily all over the world.

Organic solvents such as aromatic hydrocarbons (mostly toluene), aliphatic hydrocarbons, ketones, alcohols, and esters, as well as metals such as aluminium, titanium, cobalt, chromium, and lead, are found in paints (8,9,10). However, although not all of these compounds are considered as carcinogenic the IARC, their mixture can impart a cancer risk (11,12), hearing loss (13), neurological issues(14), hepatic(15), and respiratory diseases. During paint production or paint applications, workers are exposed to volatile organic compounds (VOCs) that present in paint products. VOC exposure was prominently found to induce damage to nucleic acids, produce oxidative stress, genotoxicity, and inflammation (16). They can also have immunologic, cancer-causing, respiratory, reproductive, cardiovascular, and inflammatory effects. (9,15). Depending on food and smoking habits, exercise level, state of health, environmental exposures, age, stress level, or mood, humans also release various VOCs created by endogenous metabolism (17). Previous research on industrial solvents indicated that they harmed central nervous system function, as shown by a range of neurobehavioral tests, which were also used to assess any probable interactions with other neurotoxic chemicals. Many epidemiological investigations on painters found that they were exposed to a variety of harmful chemicals (9).

Occupational exposure to chemical solvents and certain metals may cause induced oxidative stress (8,18,19) and DNA damage (20,21,22,23,24). Toluene, xylenes, ethylbenzene, and styrene have been linked to oxidative and genotoxic effects on paint workers and painters in various studies (6,9,18,20,25). Meanwhile, DNA damage was found in industrial painters exposed to low levels of toluene through comet assays on lymphocytes (9). Similarly, Oliveira et al. (26) also reported the induction of DNA damage on buccal cells and lymphocytes in Brazilian paint industry workers via the comet assay method. Oxidative DNA damage was also found in car painters via the evaluation of formamidopyrimidine-glycosylase (Fpg) on lymphocytes(20). In a study among Turkish painters, micronucleus induction on exfoliated buccal cells, which indicated DNA damage, was also found(27). Another recent study on Brazilian car painters using buccal micronucleus cytome (BMCyt) assay also showed the occurrence of cytotoxic and genotoxic effects.

Despite these findings, the exact mechanism of the DNA damage is not fully understood since occupational exposure is still poorly studied. Even so, paint composition changed significantly over the years due to increasing awareness about the adverse health effects of the chemicals used and improved scientific knowledge on their toxicity. To our knowledge, no comprehensive scoping review on the impact of paint exposure on paint workers and DNA damage has ever been published. As a result, the goal of this research is to summarise the effects of paint exposure on DNA damage in paint workers, as well as the compounds involved and other derivatives that may worsen the negative effects.

METHOD

This review followed the methodological framework for scoping reviews established by Levac et al. (28), Colquhan et al. (29), and a member of The Joanna Briggs Institute [Peter et al. (30)], who introduced the Preferred Reporting Items for Systematic Reviews and Meta-Analysis extension for Scoping Reviews (PRISMA SCR) (31). In this review we further research on workers that occupational exposure to paint or chemical involved in paint. This review also would like to discover more on their exposure on paint which contain various chemical can induce their health on DNA damage or cause oxidative stress.

Searching Strategy

The following were selected as relevant terms related to the study questions: 'paint exposure', 'solvent exposure', 'organic solvent exposure', 'mixed solvent exposure', 'occupational exposure', 'paint workers', 'painters', 'DNA damage' and 'oxidative stress'. The key terms used in the search strategy were MeSH (Medical Subject Headings) terms, and systematic searches were conducted in October 2021 using three electronic databases, namely PubMed, Scopus, and Web of Science. Search terms used with combination of Boolean Operators OR and AND To wider search coverage, the only limit applied was to include research articles in the English language. Grey literature and review articles were not included. The bibliographies of the research included in this review were also examined to ensure that all of the papers included were relevant for this evaluation. The search strategy is provided in table I.

Eligibility Criteria and Study Selection

The following criteria were used to identify studies: (1) the study sample were worker that exposed to paint example car painters, industry painters, construction painters and many more (2) the study selected was related with workers that exposed with paint or chemical used in paint and affected to DNA damage or oxidative stress, (3) the articles must be an original research, and (4)

Table I: Search strategy

ITEM	DETAILED	
Electronic databases	PubMed	Paint exposure **OR** Solvent exposure **OR** Organic solvent exposure **OR** Mixed solvent exposure **OR** Occupational exposure **AND** Paint Worker **OR** Painter **AND** DNA damage **Or** oxidative stress
	Scopus	Paint exposure **OR** Solvent exposure **OR** Organic solvent exposure **OR** Mixed solvent exposure **OR** Occupational exposure **AND** Paint Worker **OR** Painter **AND** DNA damage **Or** oxidative stress
	Web of Science	Paint exposure **OR** Solvent exposure **OR** Organic solvent exposure **OR** Mixed solvent exposure **OR** Occupational exposure **AND** Paint Worker **OR** Painter **AND** DNA damage **Or** oxidative stress
Searching category	Mesh term included in title and abstract	
Article selection (year)	2011-2021	

Source: Researcher's compilation (2021)

the articles selected were in English in a peer-reviewed journal. Qualitative studies, case series or case reports, reviews, conference presentations or dissertations, editorial or proceeding writings, book chapters, and letters were all eliminated. We also excluded studies with no available abstract or full text. This review also only included human studies that were reporting the effects of paint exposure and DNA damage.

The selection process started with the searching of relevant articles on the online databases, followed by a screening of the records to exclude ineligible articles and to remove the duplicates. The remaining records were analyzed for eligibility, and finally, the included articles underwent further review. The steps are shown in the following PRISMA flow chart at figure 1.

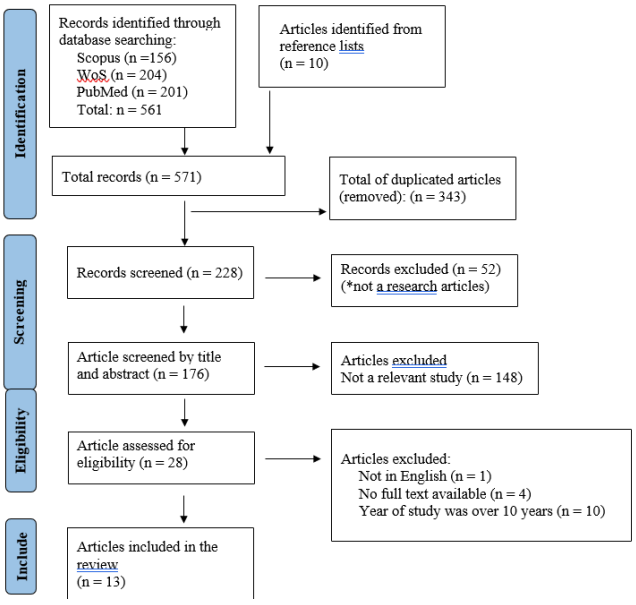

Figure 1: PRISMA checklist for scoping reviews (84)

Charting of the Data

One reviewer aggregated data taken from the research (RR). The variables selected was the author, year of publication, country of origin, sample population and sample size, methodology, substances or chemicals used, and significant findings were all listed in the table.

Collating and Summarizing the Results

Table II shows the research section contains the year of publication, study location, methodology, sample selection, substances or compounds involved, and study outcome. A narrative review was then used to discuss the findings. Year of publications and study locations selected as one of variables because from these variables, we can analyse how many research study had done on paint workers exposure over recent years and from which country having critical exposure to paint workers. Methodology used by all study selected also were important variables to showed various method used to find the significant effect and from here we can determined the best method to identify the significant finding from exposure effect. Then, chemical found by the study also very important to showed any possible carcinogenic chemical involved which also causes the severity of the toxicology effect to the workers. Finally, the study outcomes was the most important variables selected to determined the severity of the paint exposure to workers involved and significant effect occurrence.

RESULTS

Selection of Articles

From the database searches, 561 articles were initially identified, of which 204 obtains from the Web of Science, 201 from PubMed, 156 from Scopus, and 10 more items gleaned from the bibliography. After eliminating 343 duplicates, a total of 228 unique records were found and reviewed. Another 52 articles were eliminated because they were not research articles, leaving a total of 176 articles. Then, another 148 articles were also excluded after a screening of their title and abstract found them not being related specifically to paint workers or the paint industry. The remaining 28 articles then underwent further screening for inclusion and exclusion criteria, including the eligibility criteria. Eleven articles were removed based on the chosen criteria, 10 of which were published more than ten years ago, four of which did not have a complete text accessible and one were written in chinese and we does not find the english version. As a result, 13 articles (2, 8,9,13,18,20,32,34,35,36,37, 38) matched all of the criteria and were thus included for further examination.

Solvent Involved in Paint

Generally, paint compositions include thousands of chemical components as pigments, extenders, binders, solvents, and additives. However, the chemical makeup of fundamental paint components varies greatly depending on the colour, durability, and other needed

Table II: Findings on effect of chemical in paint among paint manufacturing worker

Author	Study Type	Aim of Study	Sample	Measures & Instrument	Compound Involved	Outcomes
Cassini et al. 2011 (8), Brazil	Cross-sectional	Occupational risk assessment of oxidative stress and genotoxicity in workers exposed to paint during a working week	Total N: 62 CG: 29 EG: 33	**Instrumental used:** Questionnaire, Urine sample, buccal cell sampling, delta aminoleyulinic acid and hippuric acid measurement. **Measures:** This study measures oxidative markers and genotoxicity using comet assay and micronucleus (MN) assay.	Toluene Lead	● Oxidative stress found increases among esposed worker via quantitiy of Hippuric Acid (HA) and Delta-Aminolevulinic (ALA) compared to control group. ● Dna damage also slightly higher in Friday than Monday among exposed worker.
Chang et al. 2011 (34), Taiwan	Cross-sectional	Urinary 8-Hydroxydeoxyguanosine as a biomarker of oxidative DNA damage in workers exposed to ethylbenzene	Total N: 64 CG: 30 EG: 34	**Instrumental used:** Questionnaire, personal air sampling and urine samples **Measures:** This study measures oxidative DNA damage caused by ethylbenzene via mandelic acid (MA), hippuric methyl acid (MHA), creatinine and 8-OHdG determination.	Xylene, Ethylbenzene	● The air sampling showed major solvent used were xylene and ethylbenzene. ● 8-OHdG concentration in urinary found increases during working days among paint workers compared to holiday leave. ● The concentration ofurinary OHdG was higher among spray painters than sandblasting workers and office workers. ● Thus, the concentration also higher during working day compared to holiday leave. ● The 8-OHdG also showed significant correlation between ethylbenzene and xylene. 8-OHdG biomarkers shows level of oxidative DNA damages.
Moro et al. 2012 (36), Brazil	Cross-sectional	Evaluation of genotoxicity and oxidative damage in painters exposed to low levels of toluene	Total N: 61 CG: 24 EG: 37	**Instrumental used:** blood, buccal cell and urine sampling **Measures:** This study measures oxidative DNA damage caused by low level of toluene exposure via quantification of hippuric acid (HA), toluene metabolite, urine ortho-cresol (o-C). This study also determine lipid and protein damage via lipid peroxidation (MDA), IMA, protein carbonyl, and albumin	Toluene	● DNA damage index (DI) in painters were higher than control group via comet assay while the DI were no significant with smoking status and alcohol intake. ● Lipid peroxidation (MDA) level show significant different between painters and control groups. ● Urine hippuric acid was greater in painters compared to control while PCO and IMA levels were similarly higher in painters. MDA, PCO, and IMA levels increased while albumin levels decreased, indicating oxidative stress with genotoxic consequences.
Oliveira et al. 2012 (26), Brazil	Cross-sectional	Occupational risk assessment of paint industry workers	Total N: 88 CG: 30 EG: 58	**Instrumental used:** Face to face interview, blood, buccal cell and urine sampling. **Measures:** This study measures genotoxicity effect via MN test and comet assay on buccal and lymphocyte cell.	Toluene	● Genetic damage among paints industry workers via HA levels were significantly increased in the exposed group relative to the control group. ● The comet assay analysis showed that damage index (DI), and damage frequency (DF) were significantly higher in buccal epithelial cells and blood leukocytes of the exposed group than in the control group.
Awodele et al. 2013 (18), Nigeria	Cross-sectional	Trace elements and oxidative stress levels in the blood of painters in Lagos, Nigeria	Total N: 30 EG: 30	**Instrumental used:** Questionnaire & blood sampling **Measures:** This study measures oxidative stress and trace element via blood parameters.	NA	● Significant increase on lipid peroxidation plasma levels in painters compared to control group. ● The levels of glutathione, superoxide dismutase, and catalase were significantly decreased in painters compared to the control. This show decrease in ability to inhibit the autooxidation.
Kianmehr et al. 2015 (35), Iran	Cross-sectional	DNA damage assessment in construction painters' lymphocytes by comet assay	Total N: 28 CG: 14 EG: 14	**Instrumental used:** Blood sampling **Measures:** This study measures DNA damage effect via comet assay analysation of lymphocytes cell.	NA	● DNA tail length increases 4.3 times of among painters compared to control group. While 13.2 times more elevated in tail moment of painters compared to control group. ● This study found positive and significant correlation between DNA damage and duration of exposure to the paint.

EG- Experimental Group, CG-Control Group

Table II: Findings on effect of chemical in paint among paint manufacturing worker (continued)

Author	Study Type	Aim of Study	Sample	Measures & Instrument	Compound Involved	Outcomes
Villalba et al. 2016 (37), Colombia	Retrospective	Quantifying cell-free DNA for evaluating genotoxic damage from occupational exposure to car paints.	Total N: 66 CG: 33 EG: 33	**Instrumental used:** Peripheral blood sampling and active air sampling. **Measures:** This study measures genotoxic damage via evaluating of cell-free DNA. Comet assay and cfDNA assay analysis used to determine the DNA damage. Benzene, toluene and xylene in the air were determined via active air sampling.	Benzene, toluene, xylene (BTX)	● Comet scores levels of damage according to a percentage of DNA in the tail, level 0 until level 4. ● 66.7% of the exposed group showed type 3 & 4 comets compared to the non-exposed group that showed 82% had type 1 comets. ● Significant changes in cfDNA quantification concentrations were found in the exposed group. Meanwhile, benzene levels and toluene levels in air samples were significantly higher in the workshops.
Londono-Velasca et al. 2016 (2), Columbia	Cross-sectional	Assessment of DNA damage in car spray painters exposed to organic solvents by the high-trough out comet assay	Total N: 104 CG: 52 EG: 52	**Instrumental used:** Questionnaire and blood sampling. **Measures:** This study measures DNA damage via comet assay analysis on lymphocyte cell.	NA	● Significantly increase in %TDNA value in exposed compared to the unexposed group. ● Car painters' alcohol drinkers did not show significant differences in DNA damage related to nonalcohol drinkers. The DNA damage also was not associated with age and time of exposure.
Maksoud et al. 2018 (13), Egypt	Case control	Assessment of hematotoxicity and genotoxicity among paint workers in Assiut Governorate	Total N: 100 CG: 50 EG: 50	**Instrumental used:** Questionnaire and blood sampling **Measures:** This study measures genotoxicity and hematotoxicity via biochemical analysis on the blood sample.	N/A	● Exposed workers had highly significant changes on the mean value of caspase-3 as an apoptotic marker and Human 8-Hydroxy-deoxyguanosine (8-OHdG) levels, which were significantly lower than control, whereas the mean level of the anti-apoptotic marker Human Bcl-2 was significantly lower. ● Exposed worker with arthralgia, pallor, tiredness, and dyspnea increased dramatically. ● Exposed employees also significantly lower total red blood cells (RBC), haemoglobin (HGB), and hematocrit value (HCT) compare to control group. ● White blood cell counts wereconsiderably lower in the exposed group. ● Working time and human 8-OHdG exhibited a substantial favourable relationship. Human Bcl-2, an anti-apoptotic marker, showed a strong relationship with RBC levels.
Dos Reis Filho et al. 2019 (20), Brazil	Cross-sectional	To study the increases of DNA damage, instability and cytokinesis defect among car painters that exposed to the paint.	Total N: 74 CG: 37 EG: 37	**Instrumental used:** Questionnaire, buccal cell sampling. **Measures:** This study measures DNA damage via buccal micronucleus cytome assay (BMCyt) analysis on buccal cell sample.	NA	● Significant different on structural profiling of the buccal cell between exposed compared to control group. ● An extensive DNA damage in cellular changes due to occupational exposure as a car painter.
Varona-Uribe et al. 2020 (38), Colombia	Cross-sectional	To evaluate the genotoxic effects of exposure to organic solvents among car painters.	Total N: 122 CG: 60 EG: 62	**Instrumental used:** Questionnaire and blood sampling **Measures:** This study measures chromosomal damage in lymphocytes via Cytokinesis-block micronucleus assay (CBMN) and polymerase chain reaction (PCR) to determine genetic polymorphisms of CYP2E1 enzyme.	N/A	● Significant chromosome damage on c1c1 genotype with higher micronuclei and micronucleated cells among exposure workers compared to non exposed worker.
Brum et al. 2020 (32), Brazil	Cross-sectional	DNA damage and inflammatory response in workers exposed to fuels and paint	Total N: 61 CG: 16 EC: 45	**Instrumental used:** Interviewed and blood sampling. **Measures:** This study measures DNA damage and inflammatory response via biochemical assay analysis on blood samples and determination of 8-hydroxydeoxyguanosine (8-OHdG) level as oxidative biomarkers.	NA	● Reducing neutrophil (%) and platelet levels in painters. DNA damage index was increased in GSA and painters compared to the control group.
Cavallo et al. 2021 (9), Italy	Cross-sectional	Occupational exposure in industrial painters: sensitive and non-invasive biomarkers to evaluate early cytotoxicity, genotoxicity, and oxidative stress	Total N: 35 CG: 18 EG: 17	**Instrumental used:** Questionnaire, urine sampling, blood sampling and buccal cell sampling **Measures:** This study measures early cytotoxicity, genotoxicity and oxidative stress via BMCyt assay analysis, comet assay on blood samples and analyzed 8-oxoGua, 8-oxoGuo, cytokine and urine creatinine concentrations in urine samples.	Benzene, toluene, xylene (BTX)	● MN levels of roller worker was higher than spray painters and control group. ● Tail DNA percent, tail moment (TM), and tail length (TL) also increased statistically significantly among the exposed worker, indicating direct DNA damage. ● Both exposed groups exhibited greater mean values of oxidative DNA damage (DNA percent) compared to control group. ● Fpg-comets and urine VOC metabolites and cytokine release of both painting groups had the greatest levels compared to control group.

EG- Experimental Group, CG-Control Group

features of the paint [IARC 2012]. Before early 1990s, several hazardous chemicals including (asbestos, benzene, phthalates (plasticizers), chromium and lead oxides) were used in paint in some country, however all the chemical had been banned due to many studies found serious health effect related to those chemical exposure, but somewhere else still use illegally in paint IARC (39).

Some of the solvent in paint were organic solvents, including aromatic hydrocarbons (such as benzene (9,37), toluene (8,9,26,36&37), ethylbenzene (34), and xylene (9,34,37), aliphatic hydrocarbons, ketones, alcohols, esters, and metals (such as aluminum, titanium, cobalt, chromium, and lead (8,20). Kianmehr (35) found two solvents adopted as thinners, which are toluene ($C_6H_5CH_3$) and acetone (CH_3COCH_3), that comprise almost 25% of paint production. Some of the researcher found presence of BTX solvent (benzene, toluene and xylene) exposed to painter (9&37). Toluene is primarily found in paints (18) because of its fast-drying ability that is desirable in thinning paints, varnishes, and other commercial products (40). Besides, other than solvent as the major portion made up the paint, pigments, extenders, binders, and additives also consist in a paint to play role on special features.

Pigment also one of chemical used in paint, it may be organic or inorganic chemical (62). Pigment play role to give colour, opacity, and shine pigments also impact the coating's viscosity, flow, hardness, durability, and other physical and chemical properties. The white pigment titanium dioxide (TiO_2) is now the most widely used pigment in paint (35). Binders were act as vehicle component in paint, in modern paint films, binder are made out of polymer components such resins and drying oils, which are used to give film hardness, gloss, and surface adherence, as well as resistance to weather, air pollutants that cause corrosion in the atmosphere, acids, alkalis, and other agents (25). Paint additives was the lowest component generally (1%-5% by weight) in paint. Different type of additives has different specific function or provide paints or coating unique property (5). Some of additives comprising titanium dioxide and silver nanoparticles are also use (19).

Occupational Exposure in Paint Industry

Occupational toxicology studies the toxic effect on humans caused by occupational exposure to many chemicals. Occupational exposure happens when there is an exposure route for an agent to enter the human body. According to IARC (43), inhaling fumes and gases, skin absorption, and/or ingesting are the main routes of exposure. Indeed, paint workers deal with various chemical compounds via inhalation and dermal exposures, which typically occur when they are involved in paint production and as painters. Cassini (8) found significant different in genotoxicity between Monday samples and Friday samples, the researcher suggest that genotoxicity on Monday sample lower than Friday sample show that the exposure increases can cause increases in genotoxicity. Exposure occurs mostly during processes involving human handling during the manufacture of the paint, such as weighing components (pigments, extenders, resins, additives), placing them into mixer equipment, pouring solvents to milling machine, and washing equipment (mixers, mills, reactors, kettles, tanks, filters. Additional solvent exposure occurs during thinning, tinting, and shading, as well as filling and varnish filtering activities (44).

Paint solvents release gases into the atmosphere. The paint mist may create direct contact to the employees' respiratory system and can deposit or rebound onto their attire or body, causing dermal absorption. Maksoud (34) found oxidative DNA damage higher among spray painter than sandblasting employee. This study also supported by Lodono (2) which found increases in % tail of DNA that showed the DNA damage among the spray painter compared to control. Furthermore, employees' unclean skin is sometimes washed with chemicals that might cause dermal absorption. Industrial hygienists have traditionally given greater attention to inhalation dangers because they believed that inhalation was the primary way of exposure; nevertheless, other studies have shown that in certain work situations, the cutaneous route is the primary contributor body exposure (6).

In biological monitoring, concluded skin absorption is a source of exposure. According to Chang (34), occupational exposure via inhalation can be reduced by using masks as protective equipment that significantly reduces exposure to xylene and ethylbenzene, but the occupational exposure still occurs via dermal absorption. Cavallo (9) found slightly significant in BMCyt and significant increases in tail DNA percent among rolled painters compared to spray painters. Daniell et al. (45) stated that, hand exposed to liquid xylene for 15 minutes resulted in an absorption dosage that was higher than the inhalation dose acquired during the course of an 8-hour workday. Moreover, studies by Brooke (5) revealed that xylene vapours can be absorbed through the skin, with an estimated 1-2% occurring from the dermal exposure route among subjects exposed to m-xylene in their study. Several previous studies found that donning respirators reduced workers' inhaling of solvent vapours, but cutaneous exposure became the predominant part of total body burden of solvents. This showed that occupational exposure to paint workers comes from two major routes, which are inhalation and dermal exposure, though some minor cases come from the ingestion route.

According to IARC 2010 (43), aromatic hydrocarbons used as solvents and paint removers (BTX - benzene, toluene, xylene) have been added to the list of compounds to which paint industry employees are exposed. Majority of this solvents metabolic products, such as S-phenyl

mercapturic and transtranstrans- muconic acids derived from benzene and hippuric acid derived from toluene, are excreted in the urine, some intermediate metabolites can interact with DNA and alter its structure, causing benzene to cause haematological disorders and cancers, and toluene's toxic properties are primarily found in neuronal, urinary (7, 46).

All of the studies that were considered were based on the effects of occupational exposure to paint workers (2,8,9,13,18,20,32,33,34,35,36,37,38) rather than the route of exposure, according to our evaluation. Painters are exposed to a variety of paint chemicals, some of which were classified as carcinogens while others have not. Nevertheless, mixtures of them or some individual metals can induce a cancer risk (29,35), neurologic issues, hepatic and respiratory diseases. A previous study reported several diverse health effects that included eye irritations, respiratory tract irritation (6), declining motor abilities, and hepatic and renal disorders (9,30&47). Several studies reported severe effects on workers' health, even with low exposures to the solvents (9,49&48). As many prior research have shown, these elements have a variety of negative impacts on neurobehavioral, blood, kidney, liver, cardiac, respiratory, spleen, and other physiological systems (49,50). Commercial painting was categorised as a high-risk category for lung and bladder cancer development by the IARC in 2012 (46). Moreover, the articles selected in this review reported that occupational exposures could induce genotoxicity and DNA damages.

Paint Workers and DNA Damage Effects

Paint solvent toxicity is shown by the production of reactive oxygen species (ROS), which cause cell damage by increasing lipid peroxidation, lowering antioxidant enzyme activity, and producing free radicals (51). Breaking single and double strands of DNA, as well as base changes, may be caused by oxygen-free radicals (52). A number of biomonitoring tests were carried out to measure the extent of DNA damage. Because it is vulnerable to oxygen free radical damage to DNA (7,32), 8-OHdG biomarkers have been used to quantify DNA damage in individuals exposed to cancer-causing chemicals such as heavy metals and polycyclic aromatic hydrocarbons (48). The organic solvent in paints can induce apoptosis by activating mitochondrial apoptotic proteins (53), producing apoptotic signals to trigger cell death (54).

From this review, Maksoud's (13) research found that DNA damage in employees exposed to paints, as measured by 8-OHdG indicators, was significantly higher than in the control group. This finding agrees with Liu (31), and Chang (34) reported the detected when compared to the control group, employees exposed to paint had significantly higher amounts of 8-OHdG in their urine samples. In another study, DNA damage showed a positive correlation in workers exposed to paint daily, as shown by comet assay (2). Maksoud (13) also reported significant increases in 8-OHdG levels. The comet assay, or single-cell gel electrophoresis, has been shown to be a sensitive tool for detecting possible genotoxic effects and DNA damage. In single cells or lymphocytes, comet assay may identify strand breaks, alkali labile spots, DNA cross-linking, and partial excision repair of DNA or RNA. The studies included in this review reported that, they found in buccal cells and blood leukocytes of employees exposed to paint, the damage index (DI) and damage frequency (DF) from comet tests were considerably greater than in the control group (33,55).

Based on Hoyos-Giraldo (39) painter who exposed minimum 5 years to same commercial used of chemical containing complex mixture of toluene, isobutane, xylene, hexane, ethyl-benzene and octane chromosomal aberrations frequency detected significantly higher among exposed worker compared to non exposed worker. While, Villalba (37) reported that from biomonitoring of cfDNA quantification revealed that DNA damage in exposed people was substantially greater than in non-exposed individuals. He found that intermediary metabolites might produce reactive oxygen species (ROS), which would then damage the DNA. Additionally, these metabolites may form DNA adducts, resulting in DNA alterations such as alkali-labile sites, single-stranded breaks (SSB), and double-strand breaks (DSB) (37).

Dos Reis (20) in his recent study, found that basal cells, differentiated cells, condensed chromatin cells, pyknotic cells, karyorrhectic cells, karyolitic cells, binucleated cells, micronucleated cells, and cells with nuclear buds were all shown to have statistically significant differences in a recent research which represented the DNA damage occurrence (20). Thus, the findings of studies included in this review suggest the occurrence of extensive DNA damage and cellular changes due to occupational exposure to paint was persistent.

DISCUSSION

The current scoping review showed that paints, which contain various chemical compounds, including aromatics hydrocarbons such as toluene (8,9,26,36,37), xylene (9,34,37), ethylbenzene (34) and some other metals mixed together, have high possibilities of inducing DNA damage by their chemical interactions. By the 1900s, the use of lead-based paint in the paint industry became controversial due to many studies reporting the carcinogenic and adverse health effects to paint workers. In other previous studies by Chen (59), Painters have been exposed to considerable levels of polycyclic aromatic hydrocarbons (PAHs) in prior studies, which have been linked to an increased risk of lung cancer mortality (14). PAH is known to be mutagenic and carcinogenic, and lead-containing pigments have been linked to an

increased risk of bladder, kidney, and urothelial tumour cancers, as well as multiple myeloma (39). Because of the metals and organic solvents in paint pigments, the IARC categorised painting as a definite (Class 1) cause of cancer (39). Subsequently, the paint industry introduced a new strategy by reducing the amount of solvents used in paint production, but only in a few countries. Ten years of further research showed that painters were still significantly exposed to PAH (58). Previous studies also found that some other aromatics compounds possibly add to the genotoxicity. Xiao et al. (60) discovered that, benzene, toluene, and xylene in paints were the causes to of an abnormal pregnancies in the spouses of exposed employees. The dose-response relationships between the period of exposure and intensity of exposure were also attributable to the severity of the health effects. Long-term exposure and decreasing occupational exposure to organic solvents have also shown a dose-response and symptoms in a population (15). Apart from that, paint workers were reported to show increasing cytogenic damage and DNA damage (9,58,62,35).

In this review, published studies in the past 10 years were chosen to summarise the effect of paint exposure among paint workers and DNA damage. This review aims to explore more on paint exposure and DNA damage after changes had been done in the paint industry to reduce the occupational risk. However, all of the studies included in this review found significant DNA damage among painters, but we also noticed that workers in paint factories are poorly studied. According to the review, significant DNA damage was observed using comet tests on blood and buccal cells (56,17,25,35&37). The comet assay is a cytogenic approach for detecting DNA lesions that has been extensively used. It is a sensitive and quantitative instrument for screening for DNA damage at the single-cell level (42). It is also used for early detection of DNA damage. DNA damage index (DI) & damage frequency (DF) calculations based on the tail moment and tail length detection have been used to present DNA damage. In other findings, Moro et al. (63) reported significantly different DNA damage among workers exposed to paint via lipid and proteic damage evaluation. The occurrence of oxidative stress also shows DNA damage with genotoxic effects. Some chemical compounds or interactions between chemicals may create reactive oxygen species (ROS), which increases lipid peroxidation in cell membranes and damages cell and intracellular membranes, potentially leading to cell death (51). Furthermore, Maksoud (13) also found significant changes in several biochemical parameters that showed DNA damage. Hence, this review finds that there is still a high risk of DNA damage among paint workers. Although several studies found the presence of some aromatic hydrocarbons, including toluene (59,25), benzene, xylene (44) and lead (59), can cause DNA damage, the evidence is still inconclusive. Therefore, further studies are needed to explore the main agents attributed to this effect.

This review also found that organic solvents play a prominent role in producing various unknown chemical compounds toxic to human health. The characteristic of organic solvents being quickly evaporated at room temperature and spreading in the environment can enhance the harmful effects in occupational fields. The toxicity impact is affected by the kind of chemical compounds used and the degree of exposure, which is determined by the working environment, working duration, job rotation, and the employees' specific protection measures. Moreover, lifestyle factors may cause additive or synergistic genotoxic effects in their DNA damage. Another big difficulty is that most employees have little awareness of the dangerous substances involved, thus they take personal and collective protective equipment for granted, despite the fact that doing so may raise the risk of future illnesses. Therefore, more studies on paint workers in paint factories are needed to identify the root causative agents that enhance human DNA damage. These will help improve the workers' health status and productivity during working. However, limitations of this literature review was unable to get more access on the research article. We unable to get more information about the study of selected articles.

CONCLUSION

Studies published in the last ten years on paint workers have demonstrated that industrial paint induces DNA damage and cellular changes, DNA strand breaks, incomplete excision repair of DNA or RNA in single cells or lymphocytes, and several other parameters that indicate damage to the DNA. However, mixtures of the various chemicals or individual compounds with several factors may facilitate an adverse health effect on the paint workers. Moreover, the lack of data on occupational risk and related future diseases could worsen workers' health in the long term. In conclusion, numerous studies found extensive DNA damage among paint workers. However, the actual exposure of paint workers during their working hours is still poorly understood.

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