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?-Glutathione S-Transferase, KIM-1, and Surfactant Protein-A as Predictive Biomarkers of Occupational Toxic Gas Exposure

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Abstract

General Background: Occupational exposure to toxic gases in petroleum industries is associated with subclinical damage to hepatic, renal, and pulmonary systems, necessitating sensitive biomarkers for early detection. **Specific Background:** α-glutathione S-transferase (α-GST), kidney injury molecule-1 (KIM-1), and surfactant protein-A (SP-A) are proposed indicators of early organ-specific injury related to toxic exposure. **Knowledge Gap:** Limited studies have evaluated these biomarkers collectively as a predictive panel, particularly in high-risk populations such as petroleum workers in developing regions. **Aims:** This study assessed the prognostic value of α-GST, KIM-1, and SP-A as early biomarkers of occupational toxic gas exposure. **Results:** In a case-control study of 130 exposed workers and 56 controls, serum levels of α-GST, KIM-1, and SP-A were significantly higher in exposed individuals ($p < 0.01$). KIM-1 and SP-A showed increasing trends with longer exposure duration, while α-GST demonstrated site-specific variation. Logistic regression identified all three biomarkers as independent predictors of exposure. **Novelty:** The study provides integrated evidence supporting a multi-biomarker panel reflecting hepatic detoxification, renal tubular injury, and pulmonary epithelial response in occupational settings. **Implications:** These findings support the application of α-GST, KIM-1, and SP-A in early detection and occupational health monitoring, enabling improved risk stratification and surveillance in hazardous industrial environments.

Highlights:
- Elevated biomarker levels distinguish exposed workers from non-exposed controls
- Duration-dependent increases observed in renal and pulmonary indicators
- Combined biomarker panel predicts multi-organ response to workplace hazards

Keywords: Occupational Toxic Gas Exposure, Alpha Glutathione S Transferase, Kidney Injury Molecule 1, Surfactant Protein A, Biomarkers

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Introduction:

Exposure to toxic gases in the workplace has been one of the primary health issues of worldwide concern especially to the employees in petroleum and oil-processing sectors. These employees are regularly exposed to complex blends of hazardous agents, such as volatile organic substances, hydrocarbons, hydrogen sulfide, nitrogen oxides, and particulate matter, and usually in circumstances of chronic exposure and repeated exposure [1]. These exposures have been linked to a vast and diverse variety of negative health effects on various organ systems, particularly, respiratory, renal, and hepatic. Most of these toxic impacts are however subclinical and would go unnoticed until irreversible harm is inflicted, and hence the necessity of sensitive and dependable bio-markers to be used in the early detection and related risks assessment in the workplace [2].

Conventional occupational health surveillance has been based on environmental indicators and clinical examinations, which might not be sufficient to represent personal biological reactions to toxic exposures [3]. More recently, there has been a growing focus on biomarker-based solutions that have the capacity to detect early biochemical and cellular changes before an overt disease has occurred. In this regard, biomarkers of oxidative stress, inflammation, epithelial injury, and organ-specific damage are of particular value, as they can offer insight on the intensity of exposure, as well as, on biological susceptibility. Of these, α-glutathione S-transferase (α-GST), kidney injury molecule-1 (KIM-1), and surfactant protein-A (SP-A) have been able to be identified as promising markers of toxic gas-induced organ system injury in the different organ systems [4],[5].

The α-glutathione S-transferase is a cytosolic enzyme that mainly occurs in the hepatocyte and proximal tubular cells of the kidney, where it performs the main role of conjugation of glutathione to the reactive electrophilic sub-units. The high levels of α -GST of serum are believed to be an early evidence of hepatocellular and renal tubular stress, especially in reaction to chemical and environmental toxins [6]. Because α-GST is rapidly released into the circulation following cellular injury, it has been proposed as a sensitive biomarker for early toxicant-induced tissue damage, even before conventional liver or kidney function tests become abnormal [7].

Kidney injury molecule-1 is a transmembrane glycoprotein that is minimally expressed in healthy kidneys but markedly upregulated in proximal tubular epithelial cells following toxic or ischemic injury [8]. KIM-1 is shed into the bloodstream and urine during early renal damage, making it a highly sensitive and specific biomarker of subclinical nephrotoxicity. Occupational exposure to hydrocarbons and industrial chemicals has been linked to tubular injury through oxidative stress and inflammatory pathways, positioning KIM-1 as a valuable tool for monitoring renal effects of chronic toxic gas exposure in exposed workers [9],[10].

Surfactant protein-A is a key component of the pulmonary surfactant system and is primarily produced by alveolar type II epithelial cells and Clara cells. Some of the biological functions of SP-A include stability of the alveoli, regulating immune responses, and safeguarding the lung against inhaled pathogens and pollutants. There is evidence of increased SP-A in the circulation and pulmonary epithelial injury and inflammatory responses in the lung, especially after exposure to airborne toxins and particulate matter. Therefore, SP-A is a valuable biomarker of epithelial health at the lung and initial occupation exposures of the respiratory system [11],[12].

Although there has been accumulating evidence to support the individual applicability of α-GST, KIM-1, and SP-A, few studies have specifically examined the biomarkers as a concerted predictive panel of occupational exposure to toxic gases, especially in the high-risk environment such as in the oil industry. Further, information about the developing countries, such as Iraq is limited, even though the petroleum cuts are extensive, and the number of employees who may be susceptible to dangerous gases due to changeable safety circumstances is considerable [13].

Thus, the joint predictability of α-GST, KIM-1, and SP-A could be used in the study that will be an overall measure of the systemic, renal, and respiratory reactions to exposure to toxic gases at work. This approach will be able to contribute to the early identification of subclinical organ injury, help to risk stratify and inform occupation-specific health interventions. The current research will fill this gap by assessing these biomarkers in petroleum workers in Basrah, Iraq, with a view in enhancing evidence-based surveillance measures and enhance the safety of workers in hazardous industrial settings [14].

Methodology:

The study conducted between December 2024 and July 2025 was a case-control study of male oil industry workers in Basrah, Iraq, where n = 52, n = 38, and n = 40 represent the number of 130 occupationally exposed workers of Al-Shuaiba Refinery, Al-Barjesia Oil Field, and Al-Tuba Oil Field respectively and 56 apparently healthy non-exposed controls. The criteria required were members aged between 28 and 59 years of age with over five years of continuous exposure to occupational exposure and that they be free of cancer and people who have chronic systemic diseases. Venous blood was taken under a set of conditions, and the serum concentrations of α-glutathione S-transferase (α-GST), kidney injury molecule-1 (KIM-1), and surfactant protein -A (SP-A) were analyzed with the help of the commercially available enzyme-linked immunosorbent assay (ELISA) kits as per the instructions of the manufacturers. Other biochemical parameters were serum creatinine, urea, alanine amino-transferase, aspartate amino-transferase, lactate dehydrogenase, and C reactive protein by automated Cobas assays.

Statistical analysis:

The statistical tests were conducted with the help of the IBM SPSS Statistics software version 26.0, and the continuous variables were presented in the form of the mean with the standard deviation. To compare groups based on independent

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incidences, independent-sample t-tests or one-way ANOVA was used where applicable, and binary logistic regression was used to assess the predictive value of 3 enzymes, α-GST, KIM-1, and SP-A, to occupational toxic gas exposure, with odds ratio and confidence interval reported. A p-value of below 0.05 was regarded as significant.

Ethical approval:

The research protocol was considered and endorsed by a local ethics committee that is suitable according to the national research rules. The study objectives and procedures were communicated to all participants and they signed informed consent written before being allowed to participate in the study. Confidentiality was kept to the highest level and all personal information were anonymous and were only utilized during research.

Results

Comparison of Key Predictive Biomarkers Between Exposed Workers and Controls

Serum levels of α- glutathione S-transferase (α-GST), kidney injury molecule-1 (KIM-1) and surfactant protein-A (SP-A) were significantly elevated in exposed workers than in the control group ($p < 0.01$). These levels demonstrate changes in hepatic activity of detoxification, early-stage renal tubular damage, and pulmonary epithelial reaction in relation to professional exposure to harmful gases, which suggests the predictive power of these biomarkers to demonstrate exposure-associated biological outcomes.

Table 1: Serum Levels of α-Glutathione S-Transferase, KIM-1, and Surfactant Protein-A

Variable	Exposed workers (n=130) Mean ± SD	Controls (n=56) Mean ± SD	P value
α-GST (ng/mL)	248.566 ± 197.327	147.560 ± 89.065	0.001
KIM-1 (ng/mL)	75.842 ± 17.747	57.966 ± 18.388	0.0001
SP-A (ng/mL)	171.015 ± 71.604	133.260 ± 45.161	0.001

Site-Specific Variations in Predictive Biomarkers Among Petroleum Workers

Exposure analysis site Specific analysis demonstrated that all exposed workers had greater α-glutathione S-transferase (α -GST), kidney injury molecule-1 (KIM-1), and surfactant protein-A (SP-A) levels than controls, and was varied at all worksites. SP-A was highly elevated in all work sites, especially in Al-Barjesia as an indication of improved epithelial reaction of the lungs to work place exposure in the area.

Table 2: Comparison of α-Glutathione S-Transferase, KIM-1, and Surfactant Protein-A Across Worksites and Controls

Biomarker	Al-Masfa (n=52) Mean ± SD	Al-Barjesia (n=38) Mean ± SD	Al-Tuba (n=40) Mean ± SD	Controls (n=56) Mean ± SD	P value (site vs control)
α-GST (ng/mL)	191.869 ± 154.142	277.792 ± 181.961	294.508 ± 242.960	147.560 ± 89.065	Masfa: 0.080 / Barjesia: 0.0001 / Tuba: 0.0001
KIM-1 (ng/mL)	78.467 ± 19.183	76.037 ± 16.633	72.245 ± 16.601	57.966 ± 18.388	Masfa: 0.0001 / Barjesia: 0.0001 / Tuba: 0.000
SP-A (ng/mL)	163.923 ± 73.784	186.447 ± 73.464	165.575 ± 66.260	133.260 ± 45.161	Masfa: 0.013 / Barjesia: 0.000 / Tuba: 0.007

Predictive Biomarkers According to Duration of Occupational Exposure

Duration-based analysis reflected a strong rising pattern in kidney injury molecule-1 (KIM-1) and surfactant protein-A (SP-A) concentration with increased occupational exposure ($p = 0.001$ and $p = 0.047$, respectively), showing that there are cumulative toxic gas exposure effects on the renal and pulmonary system. By comparison, α-glutathione S-transferase (α-GST) did not exhibit any significant differences between different exposure duration groups ($p = 0.350$), indicating that the dose-response relationship relating to hepatic detoxification activity was less predictable.

Table 3: Changes in α-Glutathione S-Transferase, KIM-1, and Surfactant Protein-A Across Exposure Duration Categories

Variable	1–10 y (n=40) Mean ± SD	11–20 y (n=64) Mean ± SD	21–30 y (n=21) Mean ± SD	31–40 y (n=5) Mean ± SD	P value
α-GST (ng/mL)	202.827 ± 171.382	223.230 ± 177.617	277.248 ± 211.691	265.660 ± 209.683	0.350
KIM-1 (ng/mL)	64.059 ± 20.723	75.816 ± 16.083	80.390 ± 14.706	90.420 ± 9.211	0.001
SP-A (ng/mL)	146.560 ± 63.208	175.060 ± 69.744	170.470 ± 68.837	184.000 ± 70.937	0.047

Predictive Value of Key Biomarkers for Occupational Toxic Gas Exposure

Binary logistic regression analysis indicated that α-glutathione S-transferase (α-GST), kidney injury molecule-1 (KIM-1) and surfactant protein-A (SP-A) were the significant independent predictors of occupational toxic gas exposure. An increase in alpha-GST, KIM-1, and SP-A with a unit increase was followed by the odds of exposure, which means that these 3 phenomena are highly predictive of the exposure-related hepatic, renal, and pulmonary biological responses in petroleum workers.

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Table 4: Binary Logistic Regression Analysis of α-Glutathione S-Transferase, KIM-1, and Surfactant Protein-A

Predictor	OR	95% CI	P value
α-GST	1.009	1.002–1.016	0.012
KIM-1	1.044	1.006–1.082	0.022
SP-A	1.014	1.004–1.024	0.008

Worksite-Based Differences in Predictive Biomarkers Among Exposed Petroleum Workers

Comparison of exposure sites indicated that the level of α-glutathione S-transferase (α-GST) varies significantly between the worksites with higher levels observed in Al-Masfa, Al-Barjesia, and Al-Tuba ($p = 0.025$) indicating that there is site specificity in the site response to the detoxification. Kidney injury molecule-1 (KIM-1), and surfactant protein-A (SP-A), conversely, showed no significant differences between sites ($p > 0.05$), suggesting a type of relative homogeneity in the renal and pulmonary response to the exposure sites.

Table 5: Comparison of α-Glutathione S-Transferase, KIM-1, and Surfactant Protein-A Across Exposure Locations

Variable	Al-Tuba (n=40) Mean ± SD	Al-Barjesia (n=38) Mean ± SD	Al-Masfa (n=52) Mean ± SD	P value
α-GST (ng/mL)	294.508 ± 242.960	277.792 ± 181.961	191.869 ± 154.142	0.025
KIM-1 (ng/mL)	72.245 ± 16.601	76.037 ± 16.633	78.467 ± 19.183	0.250
SP-A (ng/mL)	165.575 ± 66.260	186.447 ± 73.464	163.923 ± 73.784	0.288

Discussion:

The current work compared the predictive capacity of 103 alpha-glutathione S-transferase (103) -glutathione S-transferase, kidney injury molecule-1 (KIM-1) and surfactant protein-A (SP-A) as biomarkers of occupational exposure to toxic gases among petroleum workers. The results showed that all three biomarkers are present in high levels in exposed workers but not in controls, which confirms their applicability as sensitive biomarkers of subclinical organ injuries associated with chronic inhalational and systemic exposure.

The increase in α-GST of the exposed workers is an effect of the increased hepatic and renal detoxification activity due to prolonged exposure to hydrocarbons and volatile organic compounds [15]. α-GST is a sensitive early measure of toxic damage by quickly dissociating itself upon cellular stress coupled with chemicals [16]. The same high levels of α-GST have been found in workers of refineries and petrochemical plants in contact with organic solvents and industrial pollutants [17]. Certain studies have not however found great differences in the level of α-GST, especially in cohorts that have a short exposure duration or have good protection strategies [18]. Such differences can be explained by variations in exposure level and length, and safety measures at the workplace, and genetic differences in the detoxification mechanisms.

Exposed workers had a significantly higher level of KIM-1, which was significantly related to longer exposure time, which signifies a cumulative renal tubular damage. KIM-1 has been identified as a very sensitive biomarker of early nephrotoxicity which may occur before any alteration in conventional renal functional tests e.g. serum creatinine [19]. We are in line with several occupational studies that showed high levels of KIM-1 in individuals who have been exposed to heavy metals, hydrocarbons and industrial chemicals [20]. Contrastingly, there have been only minimal results of changes in KIM-1 levels in low exposure/environmentally-controlled studies [21], indicating that renal effects are heavily exposure-dependent and can be underestimated in cross-sectional studies that have limited exposure contrast.

Exposed workers and all worksite locations showed a great enhancement of the SP-A levels, which reveals a direct impact on pulmonary epithelia as a major target of toxic gas exposure. The main source of SP-A is the alveolar type II cells and it has a key role in the homeostasis and immunity in the lungs. It has been linked to epithelial damage and augmented alveolar permeability in the event of exposure to air pollutants and particulate matter because of elevated circulating SP-A [22]. The results are consistent with reports that show high levels of SP-A in the petroleum fumes exposed workers, the combustion products, and the fine particulate matter [23]. In contrast, other studies have found no significant differences in SP-A, especially among younger cohorts or those exposed over a shorter period [24], possibly because of adopting countermeasures in the body to respond to the pulmonary alteration or as a result of inadequate cumulative exposure.

Site-based analysis indicated that the α-GST of the site was higher at Al-Tuba and Al-Barjesia than the Al-Masfa indicating non-homogeneity in the exposure profile of the worksites. Differences in operational activities, ventilation systems, as well as, emission control measures can be contributive towards differences in the toxicant burdens [25]. By comparison, there was no significant difference in KIM-1 and SP-A concentration between sites and this suggests a relatively standardized renal and pulmonary reaction following some exposure threshold. This helps in the idea that systemic and organ-specific biomarkers can be discrepant to variations in exposure locally [26].

The cumulative effect of toxic gas exposure was further confirmed in terms of duration-based analysis where KIM-1 and SP-A showed that they increased significantly over the years of engagement. Such dose response association enhances the biological credibility of these biomarkers to provide evidence on chronic occupational injury [27]. The lack of any substantial change in exposure of α-GST with changes in exposure duration can be due to compensatory detoxification processes or inter-subject differences in the expression of the enzyme [28].

Notably, logistic regression showed that α-GST, KIM-1, and SP-A were important independent predictors of occupational toxic gas exposure. This observation highlights the importance of the multi-biomarker method in order to obtain integrated

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hepatic, renal, and pulmonary reactions instead of focusing on individual organ markers. Similar predictive models have been suggested in studies of occupational and environmental health aiming to enhance better risk stratification and early detecting of effects of exposure [29].

Conclusion:

This new evidence indicates that α-glutathione S-transferase (α-GST) kidney injury molecule-1 (KIM-1) and surfactant protein-A (SP-A) are sensitive and independent predictive biomarkers for occupational toxic gas exposure in petroleum workers. Among the most notable findings is the elevation of all three biomarkers among exposed workers compared with non-exposed controls, indicating elevated hepatic detoxification stress, proximal renal tubular injury, and pulmonary epithelial dysfunction before overt clinical disease. The dose–response trend noted where in multiple instances, increasing levels of KIM-1 and SP-A were seen with increasing exposure duration, makes comprehensive sense biologically with chronic occupational exposure likely resulting in cumulative renal and pulmonary damage. Moreover, logistic regression analysis indicated that these biomarkers represented an independent predictive value, supporting the use of a multi-organ biomarker panel compared to single-organ or single-clinical indicators. These findings have important implications for occupational health practice, with the possibility of α-GST, KIM-1 and SP-A being integrated into routine surveillance programs, which would allow opportunities for earlier detection and risk stratification and enable timely preventive interventions in high-risk industrial settings. Longitudinal cohort designs are needed to discern temporal change and cause and effect, as well as threshold levels, whereas the future combined use of these biomarkers in conjunction with environmental monitoring data will serve not only to make occupational03 22 and environmental21 policy decisions towards the establishment of standardised screening guidelines for petroleum and other hazardous industries.

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