

Tremor among Artisanal Small-scale Gold Mining Workers and its Related Factors in Indonesia's West Nusa Tenggara and Banten Provinces

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ABSTRACT

Background. Artisanal and small-scale gold mining (ASGM) workers are at risk of mercury exposure, particularly through inhalation of mercury vapor during gold amalgam smelting. Tremor is one of the earliest and most common neurological manifestations of mercury intoxication; however, its prevalence and associated risk factors among Indonesian ASGM workers remain poorly characterized.

Objective. This study determined the prevalence of tremor among ASGM workers and identified factors associated with its occurrence.

Methods. A cross-sectional study was conducted among ASGM workers in West Nusa Tenggara and Banten Provinces, Indonesia. Eligible participants had worked in ASGM for at least three months. Tremor was assessed using the finger-to-nose test performed by trained physicians. Urinary mercury concentration, measured from first-morning spot urine samples using inductively coupled plasma-mass spectrometry (ICP-MS), was used as a biomarker of mercury exposure. Demographic, occupational, and exposure-related variables were collected using the WHO-UNEP mercury health assessment questionnaire. Associations between tremor and potential risk factors were analyzed using Chi-square or Fisher's exact tests, while urinary mercury levels between groups were compared using the Mann-Whitney test.

Results. A total of 209 ASGM workers were included in the analysis. The prevalence of tremor was 8.6% (18/209), with most cases classified as mild to moderate. Thirty-four point nine percent of workers had urinary mercury concentrations exceeding the Biological Exposure Index ($>20 \mu\text{g/g}$ creatinine), while 7.2% had levels $\geq 100 \mu\text{g/g}$ creatinine. Workers aged >40 years had significantly higher odds of tremor compared with those aged <32 years (OR = 5.09, 95% CI: 1.05–24.48; $p = 0.02$). No significant associations were observed between tremor and smoking status, duration of employment, occupational exposure category, pesticide handling, or urinary mercury concentrations using either 20 or 100 $\mu\text{g/g}$ creatinine thresholds. Median urinary mercury levels were higher among workers with tremor than those without, although the difference was not statistically significant (13.78 vs. 10.75 $\mu\text{g/g}$ creatinine; $p = 0.678$).



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Conclusions. Tremor prevalence was 8.5% higher than the general population. Older age was the only factor significantly associated with tremor, whereas occupational mercury exposure indicators were not significantly associated in this study. Smoking habit, workers' job type, exposure to elemental mercury vapor, and pesticide exposure had no significant association with tremor.

Keywords: mercury poisoning, tremor, occupational exposure, gold mining, urinary mercury

INTRODUCTION

Tremor is one of the most common movement disorders encountered in clinical practice.¹ A meta-analysis by Louis et al. reported an overall prevalence of tremor of 0.4% among adults, increasing to 4.6% among individuals aged 65 years and older.² Tremor is generally progressive and may lead to functional impairment, causing affected individuals to change occupations or retire prematurely.³ In a study among older adults in New York, USA, 85.4% of individuals with tremor reported disability related to their condition.⁴

Several factors contribute to the development of tremor, including occupational exposure to neurotoxic substances.⁵ Workers exposed to pesticides, manganese, and mercury are at increased risk of developing tremor.⁵ Occupational exposure to mercury occurs in a variety of workplace settings, ranging from dental clinics to artisanal mining operations. Anglen et al. reported an increased prevalence of tremor among dentists exposed to mercury from dental amalgam, which was associated with elevated urinary mercury concentrations.⁶

Mercury exposure is also common among workers engaged in artisanal and small-scale gold mining (ASGM), where elemental mercury is used to extract gold from ore. The primary route of exposure is inhalation of mercury vapor released during the burning of gold-mercury amalgam, resulting in neurotoxic effects in which tremor is one of the earliest and most prominent clinical manifestations.⁷ O'Reilly et al. reported that 54% of highly exposed ASGM workers, particularly those involved in smelting gold-mercury amalgam, showed evidence of mercury intoxication accompanied by multiple neurological manifestations and increased body mercury burden.⁸ In Indonesia, approximately 109,000 ASGM workers are estimated to be at risk of occupational mercury exposure.⁹

Determining the prevalence of tremor and identifying factors associated with its occurrence among ASGM workers are essential for developing occupational health interventions and strategies to reduce mercury-related neurological disorders. Therefore, this study aimed to determine the prevalence of tremor among ASGM workers and identify factors associated with its occurrence.

METHODS

Study Design and Setting

This cross-sectional study was conducted among artisanal and small-scale gold mining (ASGM) workers in West Nusa Tenggara Province and Banten Province, Indonesia.

Study Participants

Eligible participants were ASGM workers who had been employed for at least three months. The variables included in the analysis were sex, age, smoking status, duration of employment, job type, history of pesticide handling, urinary

mercury concentration, and the presence of tremor assessed using the finger-to-nose test.

Occupational activities were categorized into three major job types: (1) miners, who collected ore from mining sites; (2) amalgamation workers, who crushed and milled ore and mixed it with elemental mercury to produce gold-mercury amalgam; and (3) smelters, who burned the gold-mercury amalgam to recover gold. For analysis, participants were further classified into two exposure groups. The high-exposure group included all workers involved in smelting, whether exclusively or in combination with other mining activities, while the low-exposure group consisted of workers who did not participate in smelting.

Data Collection

Anamnestic and physical examination data were collected using the World Health Organization–United Nations Environment Programme (WHO-UNEP) questionnaire, which was designed to assess the health status of populations with suspected mercury exposure. The questionnaire also included information on dietary habits, particularly fish consumption, as a potential source of methylmercury exposure.

Mercury Testing

Mercury body burden was assessed using a pre-shift, first-morning spot urine sample, which is considered a practical and feasible specimen for biological monitoring in occupational field settings.¹⁰ Urinary mercury reflects integrated mercury exposure over the preceding weeks to months, making it suitable for group-level occupational biomonitoring.¹¹ Urine samples were collected by trained physicians after completion of the interview and physical examination. Samples were transported to a local branch of a national laboratory chain accredited under ISO/IEC 17025 and subsequently forwarded to the central laboratory under a maintained cold chain at approximately 4°C. Urinary mercury concentrations were determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and expressed as micrograms of mercury per gram of creatinine ($\mu\text{g/g}$ creatinine). ICP-MS provides high analytical sensitivity, precision, and accuracy for the determination of urinary mercury and is considered the reference method for biomonitoring.¹²

Tremor Assessment

Tremor was assessed using the finger-to-nose test. Participants were instructed to alternately touch their nose and the examiner's fingertip while standing, and the examining physician determined the presence or absence of tremor.¹³ Prior to data collection, all examining physicians underwent standardized training using an instructional video on the neurological manifestations of mercury intoxication developed by O'Reilly et al. The finger-to-nose test was selected because mercury-induced tremor is predominantly

an intention tremor during the early stages of intoxication and is best elicited during goal-directed movements.¹⁴

Urinary mercury concentrations were categorized according to the American Conference of Governmental Industrial Hygienists (ACGIH) Biological Exposure Index (BEI) as ≤ 20 $\mu\text{g/g}$ creatinine and >20 $\mu\text{g/g}$ creatinine.¹⁵ Because previous studies have suggested that tremor becomes clinically apparent at urinary mercury concentrations of approximately 100 $\mu\text{g/g}$ creatinine, an additional analysis was performed using a cutoff value of 100 $\mu\text{g/g}$ creatinine.¹⁶

Data Analysis

Descriptive statistics were generated for all study variables. Associations between tremor and categorical variables were analyzed using the Chi-square test or Fisher's exact test, as appropriate. Odds ratios (ORs), 95% confidence intervals (CIs), and corresponding *p*-values were calculated. Differences in urinary mercury concentrations between participants with and without tremor were assessed using the Mann-Whitney U test because urinary mercury levels were not normally distributed. Multivariable analysis was planned if variables met the criteria for inclusion.

RESULTS

A total of 316 individuals were initially available for the study. After applying the inclusion and exclusion criteria, 209 ASGM workers were included in the final analysis. One hundred seven individuals were excluded because they were not ASGM workers or had been employed for less than three months.

The prevalence of tremor among the study participants was 8.6% (18/209). Of these, 16 participants exhibited mild to moderate tremor, while two had marked tremor. The demographic and occupational characteristics of the study population are summarized in Table 1.

Most participants were male (97.6%), with one-third aged over 40 years. The median duration of employment in ASGM was six months (range: 3–27 months). Approximately four-fifths (78.0%) of the participants belonged to the high-exposure group, while 22.0% were classified in the low-exposure group. Nearly one-quarter (22.0%) reported a history of pesticide handling.

The median urinary mercury concentration was 11.14 $\mu\text{g/g}$ creatinine (range: 0.14–348.71 $\mu\text{g/g}$ creatinine). Seventy-three participants (34.9%) had urinary mercury concentrations exceeding the Biological Exposure Index (BEI) of 20 $\mu\text{g/g}$ creatinine, while 15 participants (7.2%) had concentrations of at least 100 $\mu\text{g/g}$ creatinine.

The associations between participant characteristics and the presence of tremor are presented in Table 2. Age greater than 40 years was the only variable significantly associated with tremor (OR = 5.09; 95% CI, 1.05–24.48; *p* = 0.02). Participants aged 32–40 years also showed higher odds of tremor than those younger than 32 years, although the

Table 1. Frequency Distribution for Variables of Interest

Variable	n	%
Tremor		
Present	18	8.6
Absent	191	91.4
Sex		
Male	204	97.6
Female	5	2.4
Age in years (Me; Min, Max: 36; 13,75)		
>40	70	33.49
32–40	68	32.54
<32	71	33.97
Smoking habit		
Smokers	176	84.2
0–10 cigarettes per day	31	14.8
10–20 cigarettes per day	111	53.1
>20 cigarettes per day	34	16.3
Non-smokers	33	15.8
Working duration [Median (Min- Max) = 6 (3–27)]		
≥ 6 months	120	57.4
<6 months	89	42.6
Job type		
High exposure	163	78.0
Smelting only	2	1.0
Mining and smelting	4	1.9
Amalgamation and smelting	117	56.0
Mining, amalgamation and smelting	40	19.1
Low exposure	46	22.0
Mining only	5	2.4
Amalgamation	25	12.0
Mining and amalgamation	16	7.7
Handling pesticide		
Yes	46	22.0
No	163	78.0
Urinary mercury level in mcg/gram creatinine [Median (Min- Max) = 11.14 (0.14 – 348.71)]		
>20 mcg/gram creatinine	73	34.9
≤ 20 mcg/gram creatinine	136	65.1
≥ 100 mcg/gram	15	7.2
<100 mcg/gram	194	92.8

association did not reach statistical significance (OR = 3.96; 95% CI, 0.79–19.78; *p* = 0.07).

No statistically significant associations were observed between tremor and smoking status, duration of employment, occupational exposure category, history of pesticide handling, or urinary mercury concentration using either the 20 $\mu\text{g/g}$ creatinine or 100 $\mu\text{g/g}$ creatinine cutoff values.

The median urinary mercury concentration was higher among participants with tremor than among those without tremor (13.78 [range: 0.43–143.81] vs. 10.75 [range: 0.14–348.71] $\mu\text{g/g}$ creatinine); however, the difference was not statistically significant (Mann-Whitney U test, *p* = 0.678).

Table 2. Relationship of Various Variables with Tremor

Variable	Tremor		OR	95% CI	p value
	(+)	(-)			
Sex					
Male	18 (8.8%)	186 (91.2%)	–	–	–
Female	0 (0%)	5 (100%)			
Age (years)					
>40	9 (12.9%)	61 (87.1%)	5.09	1.05 – 24.48	0.02
32–40	7 (10.3%)	61 (89.7%)	3.96	0.79 – 19.78	0.07
<32	2 (2.8%)	69 (97.2%)	Ref		
Smoking habit					
Smokers	16 (9.1%)	160 (90.9%)	1.55	0.34 – 7.08	0.74*
Non-smokers	2 (6.1%)	31 (93.9%)	Ref		
Working duration					
≥6 months	11 (9.2%)	109 (90.8%)	1.18	0.43 – 3.18	0.74
<6 months	7 (7.9%)	82 (92.1%)	Ref		
Job type					
High exposure	14 (8.6%)	149 (91.4%)	0.99	0.31 – 3.16	0.59*
Low exposure	4 (8.7%)	42 (91.3%)	Ref		
Pesticide handling					
Yes	5 (10.9%)	41 (89.1%)	1.41	0.47 – 4.18	0.56*
No	13 (8.0%)	150 (92.0%)	Ref		
Urinary mercury levels					
>20 mcg/g creatinine	7 (9.6%)	66 (90.4%)	1.21	0.45 – 3.26	0.71
≤20 mcg/g creatinine	11 (8.1%)	125 (91.9%)	Ref		
Urinary mercury level					
≥100 mcg/g creatinine	2 (13.3%)	13 (86.7%)	1.71	0.36 – 8.26	0.62*
<100 mcg/g creatinine	16 (8.2%)	178 (91.8%)	Ref		
Difference of urinary mercury level [Median (Min – Max)]	13.78 (0.43 – 143.81)	10.75 (0.14 – 348.71)	–	–	0.678 ^a

*Fisher exact test ^aMann-Whitney test

DISCUSSION

The prevalence of tremor among ASGM workers in this study was 8.6%, which is considerably higher than the reported prevalence in the general adult population (0.4%) and among adults aged 65 years and older (4.6%).² The observed prevalence was slightly lower than that reported among workers occupationally exposed to mercury in fluorescent lamp manufacturing (9.4%).¹⁷ It was also lower than the 13.2% prevalence reported by O'Reilly et al. among ASGM workers involved in panning and smelting activities.⁸

The lower prevalence of tremor observed in this study may be related to the shorter duration of occupational exposure. The median duration of employment among participants was six months, compared with 2.5 to 5 years in the study by O'Reilly et al., suggesting that prolonged exposure to mercury vapor may increase the risk of developing neurological manifestations.⁸ Nevertheless, more than one-third (34.9%) of the workers had urinary mercury concentrations exceeding the Biological Exposure Index (BEI) of 20 µg/g creatinine despite the relatively short duration of employment. These findings suggest that substantial mercury exposure occurs

early in employment and may pose an increased risk of adverse neurological effects if appropriate preventive measures are not implemented.

Age greater than 40 years was the only factor significantly associated with tremor (OR = 5.09; 95% CI, 1.05–24.48). This finding is consistent with the study by Sur et al., which demonstrated an increasing prevalence of essential tremor with advancing age.¹⁸ The association raises the possibility that some tremor cases among older workers may represent age-related essential tremor rather than tremor attributable solely to occupational mercury exposure. Conversely, the occurrence of tremor among workers younger than 40 years suggests that other contributing factors may also be involved, including caffeine consumption, manganese exposure, or lead exposure, none of which were evaluated in the present study.^{5,19}

No significant association was observed between occupational exposure category (high versus low exposure) and the presence of tremor. One possible explanation is that gold amalgam smelting in the study sites was generally performed outdoors, allowing mercury vapor to disperse and thereby reducing inhalational exposure. This explanation is supported

by studies demonstrating substantially higher mercury concentrations in indoor environments where amalgam smelting is performed. Gyamfi et al. reported greater airborne mercury levels in households where smelting occurred, while Basri et al. found that indoor smelting contributed to increased human mercury burden.^{20,21}

Similarly, urinary mercury concentration was not significantly associated with the presence of tremor, regardless of whether the BEI cutoff of 20 µg/g creatinine or the higher threshold of 100 µg/g creatinine was applied. Although participants with tremor had a higher median urinary mercury concentration than those without tremor, the difference was not statistically significant. This finding may reflect the relatively short duration of occupational exposure among the study population or the multifactorial nature of tremor development.

The primary limitation of this study was the use of secondary data, which limited the availability of potentially important exposure variables. Information on other factors associated with tremor, including caffeine intake and exposure to additional neurotoxic substances such as manganese and lead, was not available. Consequently, residual confounding cannot be excluded. Furthermore, the cross-sectional design precludes establishing a temporal relationship between mercury exposure and the development of tremor.

CONCLUSION

The prevalence of tremor among artisanal and small-scale gold mining workers was 8.6%, which is higher than that reported in the general population and is comparable to findings from other studies involving ASGM workers in developing countries. Age greater than 40 years was the only factor significantly associated with tremor, with workers in this age group having a five-fold higher likelihood of developing tremor than younger workers. No significant associations were found between tremor and smoking status, duration of employment, occupational exposure category, urinary mercury concentration, or history of pesticide handling.

Statement of Authorship

All authors certified fulfillment of ICMJE authorship criteria.

Author Declaration

All authors declared no conflicts of interest.

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