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Occupational Exposure to Inhalation Anesthetics in Operating Room and Adverse Health Outcomes: A Systematic Review

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KEYWORDS: Volatile Anesthetics; Operating Room; Exposure; Adverse Health Effects; Systematic Review

SUMMARY: *Volatile anesthetics (VA) are essential agents for inducing and maintaining unconsciousness during specific surgical procedures, but they pose several health risks for exposed workers. The aim of the systematic review was to assess the effects of long-term VA occupational exposure in operating rooms. The review was conducted in accordance with the PRISMA Statement, and the search was conducted in PubMed, Scopus, and Web of Science to identify articles published between January 1, 1994, and December 31, 2024, that reported data from observational, quasi-experimental, and experimental studies. The protocol was registered in PROSPERO (ID: CRD42024500838). The quality of the studies was assessed using the standard Newcastle-Ottawa Scale versions for cohort and case-control studies, and an adapted version for cross-sectional studies. A total of 65 studies were included. Adverse effects were categorized into four groups: reproductive and adverse pregnancy or offspring outcomes, neurotoxic alterations, laboratory parameter changes, and cyto- and genotoxicity. Overall, no significant associations were found between VA exposure and reproductive or pregnancy outcomes. One study reported neurological alterations (prolonged reaction times). Additionally, some studies have documented impairments in immune function and minor alterations in renal and hepatic function parameters. Finally, several studies indicated an increased risk of genotoxicity and oxidative stress. Given this evidence, protective measures and health surveillance for exposed workers remain crucial preventive measures.*

1. INTRODUCTION

About 266 million surgeries are performed each year, many of which require general inhalation anesthesia [1]. This large surgical volume exposes a broad range of healthcare workers (HCW) including anesthesiologists, nurse anesthetists, operation rooms (ORs) nurses, operating room technicians/personnel, recovery room nurses, and surgeons to volatile anesthetics (VA), with a gradient of median exposure based on occupation (anesthesiologist more

than scrub nurses, more than surgeons, more than circulation nurses). It has recently been estimated that 10% of HCW are exposed to VA, and, given 6 million HCW worldwide, the number of potentially exposed individuals could be as high as 600.000 [1].

Before the 1970s, the most commonly used anesthetics, such as ether and chloroform, were found to be neurotoxic and hepatotoxic. In the 1970s, exposure levels to halogenated anesthetics such as halothane were often high, up to several hundred ppm, due to underestimating inhalation risks and

the almost total lack of evacuation systems, the poor efficiency of environmental ventilation systems, and the use of high-flow systems in anesthesia techniques. In Italy, considerable improvements have been made by adapting the ventilation system to the rules of the Ministry of Health indicated in 1989, which provided certain values for nitrous oxide but did not refer to a value for halogenates, recommending that efforts be made to respect the National Institute of Occupational Safety and Health (NIOSH) limit values established in 1977, i.e., for N₂O 25 ppm, for halogenates alone 2 ppm 'C' Ceiling, and for halogenates in combination with N₂O 0.5 ppm [2, 3]. Conversely, the American Conference of Governmental Industrial Hygienists (ACGIH) in 2011 recommended a higher global standard for occupational exposure (TLV-TWA) to halogenated gases for halothane and N₂O (50 ppm) and for enflurane and isoflurane (75 ppm). ACGIH did not set any biological exposure index for VA, even though the concentration of unmetabolized VA or their metabolites in urine has been found to be a reliable tool. Health authorities have also developed technical procedures (e.g., sampling methods, active air treatment systems, maintenance procedures, and leak tests of the machinery used for anesthesia) to minimize VA concentrations and have determined the medical surveillance of exposed workers. Moreover, in clinical practice, there has been a shift toward sevoflurane, desflurane, and isoflurane, displacing the obsolete halothane (peak use in the 1970s) and reducing N₂O to a large extent. Nonetheless, despite improvements in anesthetic techniques and instrumentation, the risk of exposure to VA remains in operating rooms [4, 5] and continues to be a matter of concern, given the long exposure for HCW, which can exceed 20 years. Numerous studies have examined the acute or chronic effects of VA on mutagenic and carcinogenic risk in operating room personnel, using *in vivo* and *in vitro* approaches. The main VA are degraded into potentially toxic products. Enflurane, isoflurane, and desflurane generate carbon monoxide, a potential cause of poisoning [6]. Halothane and sevoflurane generate difluoroethylene, haloalkane, and trifluoromethyl vinyl ether (commonly known as "compound A"). In chronically exposed individuals, compound A may

cause hepatotoxicity, nephrotoxicity, carcinogenesis, immunodeficiency, impairment of fertility, and adverse effects on fetal development [7, 8]. Hoerauf et al. [9] showed that inhaled exposure to traces of VA can affect HCW. Several authors suggested that chronic exposure to VA could change the genome of the target cell [4, 10].

In addition to the effect on HCWs, recent studies have analyzed the effect of VA on the environment and have pointed out that volatile anesthetics such as N₂O, as well as the highly fluorinated gases sevoflurane, desflurane, and isoflurane, are greenhouse gases and ozone-depleting agents, although to a smaller extent (0.1%) than CO₂ [1]. Although limited, there are still workplaces without artificial ventilation and scavenging systems, and hospitals where halothane is still in use. The aim of the present systematic review was to assess the effects of long-term occupational exposure to VA among HCWs working in operating rooms, using a 30-year period from 1994 to 2024.

2. MATERIALS AND METHODS

2.1. Search Strategy

The systematic review was carried out in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [11]. The review protocol was registered in PROSPERO with the reference number CRD42024500838. The review question focuses on adverse outcomes associated with long-term occupational exposure to inhalation anesthetics in healthcare personnel of all genders working in the operating rooms. The studies selection procedure used the "PICOS" methodology (P stands for patient, population or problem; I for intervention; C for control group or comparison; O for outcome; S for study design) to generate the search query, and adherence to the following eligibility criteria was required: the population was made up of adult workers of all genders, occupationally exposed to inhalation anesthetics; the intervention/exposure was the occupational exposure to inhalation anesthetics in the operating rooms; the outcome was the evaluation of adverse outcomes for human health associated to the occupational exposure to

inhalation anesthetics; study design included observational, quasi-experimental, and experimental studies. For the purpose of this review, quasi-experimental studies were defined as non-randomized intervention or before–after designs conducted in occupational settings. We queried three electronic databases to search for articles: PubMed, Scopus, and Web of Science. The search was conducted from February 15th 2025 to February 28th 2025. The full search strategies for each database, including Boolean operators, is: (“Anesthetics Inhalation” OR “Volatile anesthetics” OR “Anaesthetic Gases” OR “Desflurane” OR “Isoflurane” OR “Nitrous oxide” OR “Sevoflurane” OR “Xenon” OR “haloflurane” OR “enflurane”) AND (“Health Personnel” OR “health care worker*” OR “HCW” OR “operating rooms” OR “Operating Theatre”) AND (“Occupational Diseases” OR “occupational health” OR “Occupational surveillance” OR “occupational exposure” OR “risk assessment” OR “occupational risk assessment”).

2.2. Inclusion/Exclusion Criteria

Articles were considered eligible if they included data from observational, quasi-experimental, or experimental studies of adult workers occupationally exposed to VA in operating rooms, regardless of gender or age. We included only items published in English or Italian from 01 January 1994 to 31 December 2024. These criteria were chosen because of changes in experiences, laws, and the use of VAs: since the 1970s, many studies have examined the potential health risks associated with exposure to VAs. For this reason, many countries have introduced regulatory limit values for VA concentrations in operating rooms. Operating rooms have also been upgraded through the introduction of scavenging systems, closed dispensing systems, and strict air-exchange protocols. Most of these improvements became widespread after 1990. For these reasons, we decided to assess the potential risk of exposure over the past 30 years to reflect the current situation and minimize bias in our study.

Studies that included data from the general population or workers exposed to VA but not in operating rooms were excluded. We also excluded

studies of HCWs not occupationally exposed to inhalation anesthetics, in vitro studies, and animal studies. Other types of studies, such as reviews, meta-analyses, case studies, qualitative investigations, book chapters, editorials, and commentaries, were not considered.

The titles and abstracts from the three databases were imported into the reference management software Zotero (version 7.0.6) to conduct the initial relevance assessment. The next phase involved title and abstract screening, during which potentially suitable studies were independently reviewed by five authors (AC, KV, LC, ADG, and SG). Subsequently, the full texts of these studies were independently examined by the same two authors, and a discussion took place regarding their potential inclusion in the review. Any disagreements were resolved through consensus among the authors. All steps were supervised by two other investigators (CP and MV).

The collected data were summarized in tables that presented bibliographic details (including author, year of publication, and country of origin), sample size, participant age and gender. The tables also included information on employment characteristics, inhalation anesthetics, associated effects, confounding and interfering variables considered, and the key findings of the selected studies.

2.3. Study Quality and Evaluation

We conducted the quality assessment using the Newcastle–Ottawa Quality Assessment Scale (NOS) [12]. The standard NOS versions were applied for cohort and case–control studies. For cross-sectional studies, we used an adapted version of the NOS based on previously proposed modifications, maintaining the original three-domain structure (Selection, Comparability, and Outcome/Exposure). The adapted scale for cross-sectional studies included a maximum of 7 points: Selection (maximum 3 points), Comparability (maximum 2 points), and Outcome (maximum 2 points. For case-control and cohort studies: good quality (3 or 4 criteria in selection domain, 1 or 2 criteria in comparability domain, and 2 or 3 criteria in outcome domain); fair quality (2 criteria in selection domain, 1 or 2 criteria in comparability domain, and 2 or 3 criteria

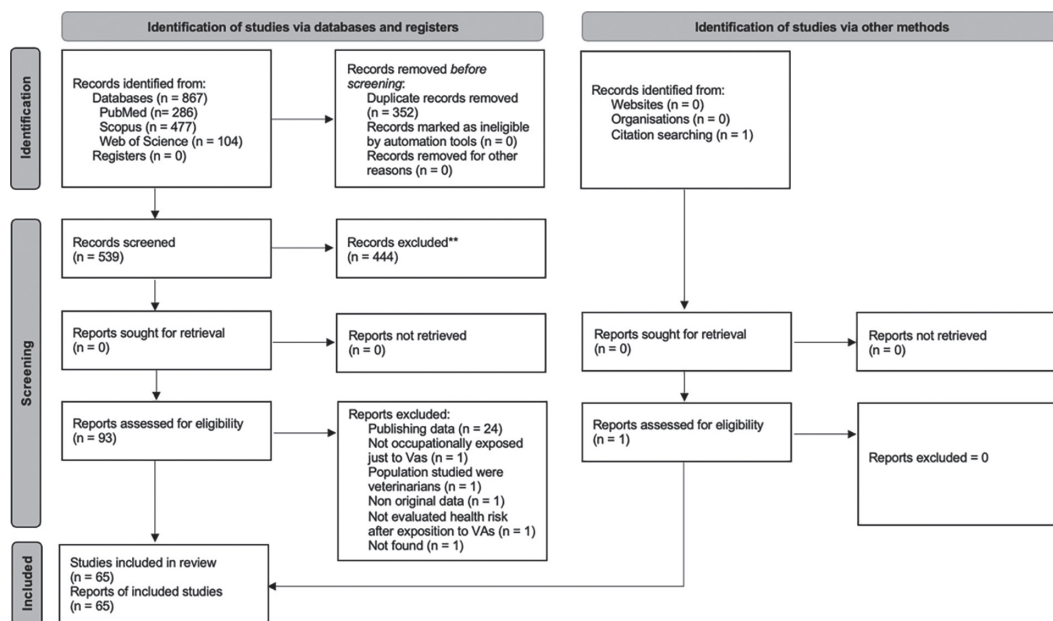


Figure 1. Article selection process used for the systematic review following the PRISMA guidelines.

in outcome domain); poor quality (0 or 1 criterion in selection domain, 0 criteria in comparability domain, or 0 or 1 criteria in outcome domain).

Each study was scored by five authors (AC, KV, LC, ADG and SG), and any discrepancies were resolved through consensus among all the authors.

3. RESULTS

3.1. Article Selection

Figure 1 shows article selection process used for the systematic review following the PRISMA guidelines.

A total of 1,062 articles were found in all searched databases (351 from PubMed, 694 from Scopus, and 97 from Web of Science). After duplicate deletion, 819 records were screened for inclusion and, of the remaining studies, 725 were deleted after analyzing the title and abstract. Then, the full texts of 94 articles were assessed for eligibility and they were evaluated considering the inclusion and exclusion criteria. After the evaluation, 29 articles were excluded because of the exclusion criteria and specifically for the following reasons: 24 articles because they were published before 01 January 1994, 1 article considered exposure not just to VAs but

mixed with other substances, 1 studied exposure of veterinarians, 1 did not use original data, 1 did not evaluate health risk after exposure and 1 because it was not found. Finally, 65 articles met the inclusion criteria, and were included in the analysis.

3.2. Main Characteristics of the Included Studies

Figure 2 shows the global distribution.

The included articles involved almost all continents, with 39 from Europe, 2 from North America, 16 from Asia, 8 from South America. In particular, the studies were performed in the following countries: 12 in Italy [6, 13–23], 11 from Turkey [24–34], 9 from Iran [35–43], 8 from Brazil [44–51], 6 from Poland [10, 52–56] and 3 from Croatia [57–59]. Other countries were less represented: Canada [60, 61], China [62, 63], Germany [64, 65] and Saudi Arabia [66, 67] had two studies each. Only one study was conducted each in Austria [68], Czech Republic [69], France [70], India [4], Ireland [71], Pakistan [72], Slovenia [73] and Taiwan [74].

The studies were grouped based on the main health risk: fertility and pregnancy (Table 1), neurotoxicity (Table 2), laboratory and immunology (Table 3) and cytogenetic effects (Table 4).



Figure 2. Distribution of included articles according to the geographical areas.

Table 1. Characteristics of studies on fertility and pregnancy outcomes associated with exposure to volatile anesthetics.

Author(Y)	Design/ Country	Sample	VA Exposure	Exposure	Main Findings	Quality ecaluation according to NOS Scale
Teschke (2011)	Retrospective cohort, Canada	9433 F	Multiple halogenated agents + N ₂ O	NS	↑congenital anomalies with ↑exposure; OR>2 for halothane, isoflurane, sevoflurane	Poor (3)
Uzun (2014)	Cross-sectional, Turkey	60 F, 31±6 y	Desflurane, isoflurane, sevoflurane, N ₂ O	6.8±7 y	No differences in pregnancy-related lab markers	Poor (3)
Zanetti (2004)	Longitudinal, Italy	61 F	Mainly sevoflurane + N ₂ O (max 7.8 ppm; 590 ppm)	16 y	No infertility or adverse offspring outcomes; abortivity↑ only in doctors (confounders)	Poor (3)

NS = not specified

These groups were chosen based on presenting studies divided on the main clinical parameters they investigated, to let us show the results merged based on the clinical evaluation. Some of these studies (n = 4) have been reported in more than 1 domain due to the outcomes investigating more areas of health risk. All the studies included subjects with

an average age of 34.32 years (minimum average 26, maximum average 45) with a sample size ranging from 23 individuals [44] to 9,433 [23] (average 254.53). Most of the studies involved both males and females, while nine studies including only females [23, 28, 34, 53, 55, 56, 60, 73, 74], four only males [41, 66, 67, 72], and seven did not state the

Table 2. Neurobehavioral and neurological effects of occupational exposure to volatile anesthetics.

Author (Year)	Design / Country	Sample	VA Exposure	Exposure	Main Findings	Quality evaluation according to NOS Scale
Isolani (1998)	Longitudinal, Italy	37 HCW	N ₂ O	NS	No relation between N ₂ O levels and vigilance/mood tests; only daily arousal variation	Poor (3)
Kozanhan (2017)	Cross-sectional, Turkey	60 exp / 51 ctrl	Desflurane, sevoflurane, N ₂ O	≥5 h/day ≥1 y	Altered thiol/disulfide homeostasis after adjusting for anxiety	Poor (3)
Lucchini (1995)	Cross-sectional, Italy	62 exp / 46 ctrl	Ethane, N ₂ O (1.3 / 62.6 ppm)	8.4±5.9 y	Higher SRT in exposed workers after shift	Good (7)
Lucchini (1996)	Cross-sectional, Italy	30 exp / 20 ctrl	N ₂ O (≈5–54 ppm)	4.2±4.3 y	↑ SRT and PRL only with gaseous anesthesia; cortisol unchanged	Good (7)
Lucchini (1997)	Cross-sectional, Italy	112 exp / 135 ctrl	Isoflurane 0.4 ppm, N ₂ O 23.2 ppm	9.7±7.5 y	No correlation between atmospheric and biological indicators	Fair (5)
Proietti (2000)	Cohort, Italy	300 HCW	Isoflurane 1.5–3.2 ppm, N ₂ O 40–88 ppm	10 y	Subjective symptoms (anxiety) but no blood alterations	Poor (3)
Scapellato (2008)	Cross-sectional, Italy	38 exp / 23 ctrl	Isoflurane, N ₂ O	9.3±7.5 y	Non-linear dose–effect trend for N ₂ O and neurobehavioral impairment	Fair (5)
Tran (1994)	Cross-sectional, Canada	99 exp / 182 ctrl	N ₂ O (TWA 43–62 ppm)	NS	Symptoms more frequent in controls due to poor IAQ	Fair (5)
Vouriot (2005)	Cross-sectional, France	53 exp / 53 ctrl	Desflurane, isoflurane, sevoflurane, N ₂ O	>5 y	Worse static/dynamic balance; ↑ reliance on visual input	Fair (5)

NS = not specified

Table 3. Hematologic, immunologic, neuro-renal and reproductive effects associated with occupational exposure to volatile anesthetics.

Author (Year)	Design/ Country	Sample (n)	VA (summary)	Exposure (mean)	Key finding (summary)	Quality evaluation according to NOS Scale
Amiri (2018)	Cohort, Iran	52 exp / 52 ctrl; 34.0±6.3 y	Isoflurane, sevoflurane, N ₂ O (2.4;0.2;851 ppm)	10.8±5.6 y	↓Hb, Hct, MCH, MCHC, RBC in exposed vs controls	Good (7)
Bakhshaei (2017)	Cross-sectional, Iran	75 exp / 75 ctrl; NS	Halothane 1.5±1.4 ppm	NS	Urinary Br correlated with exposure; ↑abnormal ALT/AST in exposed women	Fair (5)
Bargellini (2001)	Cross-sectional, Italy	51 exp / 20 ctrl; 34.9±5.6 y	Isoflurane, N ₂ O (not specified)	Exposure score (months)	Altered lymphocyte subpopulations (↓CD3, ↓CD4; ↑NK)	Poor (3)
Casale (2013)	Cross-sectional, Italy	119 exp / 184 ctrl; 41.6±9.0 y	Enflurane, halothane, isoflurane, N ₂ O (ns)	14.0±6.1 y	Altered liver markers; ↓ neutrophils, ↑ lymphocytes	Fair (5)
Chaoul (2015)	Cross-sectional, Brazil	15 exp / 15 ctrl; 28.2±1.5 y	Isoflurane, sevoflurane (>7 ppm); N ₂ O (100 ppm)	3 y	↑IL-8 (pro-inflammatory) in exposed staff	Poor (3)
Emara (2020)	Cross-sectional, Saudi Arabia	120 exp / 60 ctrl; 34.3±5.6 y	Multiple VAs + N ₂ O (ns)	7.3±2.0 y	↑ inorganic F, HFIP, liver toxicity markers; hematologic disturbances	Fair (5)
Goto (2000)	Cross-sectional, Ireland	20 exp / 10 ctrl; 35.6±9.1 y	Isoflurane, sevoflurane, N ₂ O (SI/UI reported)	NS	Reduced neutrophil apoptosis at 24 h in exposed workers	Poor (3)
Gruber (2002)	Cross-sectional, Austria	48 exp / 10 ctrl; 35.5 y	Not specified	NS	Urinary neopterin within normal range; higher in <35 y	Poor (3)
Hua (2021)	Cross-sectional, China	68 exp / 82 ctrl; 30.6±5.8 y	Sevoflurane 1.1±0.7 ppm	8.3±5.2 y	↓ SOD and vital organ parameters; ↑ MDA, bilirubin, creatinine, QT/QTc	Poor (3)

Table 3 continues

Author (Year)	Design/ Country	Sample (n)	VA (summary)	Exposure (mean)	Key finding (summary)	Quality evaluation according to NOS Scale
Jafari (2018)	Cross-sectional, Iran	42 exp / 30 ctrl; 31.3±10.1 y	Isoflurane, sevoflurane (median 1.3 ppm)	Ventilation 15 ACH	Oxidative stress: ↑ transaminases, ↓ antioxidants, ↑ MDA	Good (7)
Ji (2021)	Cohort, China	28 exp / 28 ctrl; 33.1±5.2 y	Sevoflurane 1.0 (0.0–2.2) ppm	2–20 y	No significant effects on lymphocyte apoptosis, cell cycle, subsets or Ig levels	Good (7)
Krajewski (2007)	Cross-sectional, Poland	95 exp / 90 ctrl; 37.6 y	Halothane, isoflurane, sevoflurane, N ₂ O (mg/m ³)	Ventilation varied; scavenging	↓ Vit B12 and ↑ tHcy in exposed, worse above exposure limits	Fair (5)
Nasiri& Hosseinimehr (2006)	Cross-sectional, Iran	70 exp / 70 ctrl; 31±9 y	Halothane (ns)	NS (>1 y)	↑ SGOT in exposed (within normal limits)	Fair (5)
Neghab (2020)	Historical cohort, Iran	52 exp / 52 ctrl; 34.0±6.3 y	Isoflurane, sevoflurane, N ₂ O (ns)	10.8±5.6 y	↑ ALT, AST, ALP, GGT, α-GST; ↑ KIM-1, creatinine; α-GST	Fair (5)
Neghab (2023)	Historical cohort, Iran	30 exp / 30 ctrl; 35.7±6.3 y	Isoflurane, sevoflurane, N ₂ O (ns)	10.9±6.7 y	↑ IL-4, ↑ IFN-γ and ↑ IFN-γ/IL-4 ratio → Th1 shift	Fair (5)
Trevisan (2003)	Cross-sectional, Italy	61 exp / 43 ctrl; 39.5±9.8 y	Sevoflurane 0.3 ppm; N ₂ O 31.3 ppm	NS	Slight ↑ urinary total protein; dose–response for sevoflurane suggested	Good (7)
Uzun (2014)	Cross-sectional, Turkey	60 exp; 31±6 y; 100% F	Desflurane, isoflurane, sevoflurane, N ₂ O Scavenging present	6.8±7.0 y	No differences in homocysteine, folate, B12, anticardiolipin/ antiphospholipid Abs	

NS = not specified

Table 4. Genotoxic, oxidative, immunologic, and other biological effects associated with occupational exposure to volatile anesthetics.

Author (Year)	Design / Country	Sample (n)	VA (summary)	Exposure (mean)	Key finding (summary)	Quality evaluation according to NOS Scale
Al-Rasheedi (2021)	Cross-sectional Saudi Arabia	120 exp / 60 ctrl; 34.3±1.2 y	Desflurane, isoflurane, sevoflurane (ns)	7.3±0.4 y	↑ plasma fluoride, ↑ IFN-γ, ↑ IL-2; IL-4 higher in anesthesiologists; oxidative stress markers altered	Fair (5)
Aun (2018)	Cohort, Brazil	26 exp; 26.8±2.1 y	Desflurane, isoflurane, sevoflurane, N ₂ O	1 y	No early cytotoxicity/genotoxicity in first residency year	Poor (3)
Aun (2023)	Cohort, Brazil	23 exp; 26.1±2.5 y	Desflurane, isoflurane, sevoflurane, N ₂ O	~41.2 h/wk (OR)	↑ lipid peroxidation, DNA damage, altered antioxidant gene expression during residency	Poor (3)
Baysal (2008)	Cross-sectional Turkey	30 exp / 30 ctrl; 32.5±5 y	Multiple VAs + N ₂ O (ns)	7±4 y	↑ leukocyte DNA damage, ↑ TOS/OSI, ↓ TAS in exposed	Good (7)
Bilban (2005)	Cross-sectional Slovenia	153 exp / 350 ctrl; 37 y	Isoflurane, halothane, N ₂ O (range)	15.9±7.5 y	↑ SCE, SCE frequency and MN in anesthesia group vs controls	Good (7)
Bozkurt (2002)	Cross-sectional Turkey	16 exp / 16 ctrl; 32.0±4.1 y	Halothane, isoflurane, sevoflurane, N ₂ O	0.2–16 y	Higher SCE/HFC% in exposed (not statistically significant)	Fair (5)
Braz (2018)	Cross-sectional Brazil	30 exp / 30 ctrl; 28.6±1.7 y	Isoflurane, sevoflurane, N ₂ O (5–155 ppm)	3.1±0.5 y	↑ micronuclei, karyorrhexis, pyknosis in buccal cells	Good (7)
Braz (2020)	Cross-sectional Brazil	32 exp / 31 ctrl; 28.1±1.8 y	Isoflurane, sevoflurane, N ₂ O (5–180 ppm)	3 y; 37 h/wk	↑ basal DNA damage, ↑ IL-17A; slight ↑ MN; oxidative markersNS	Good (7)
Çakmak (2019)	Cross-sectional Turkey	46 exp / 21 ctrl; 33±6.1 y	Sevoflurane (0.3–0.6 ppm)	5 y	↑ MN in PBLs (~2×) and BECs (~3×); urinary sevoflurane high	Good (7)

Table 4 continues

Author (Year)	Design / Country	Sample (n)	VA (summary)	Exposure (mean)	Key finding (summary)	Quality evaluation according to NOS Scale
Cegin (2016)	Cross-sectional Turkey	32 exp / 32 ctrl; 34.9 y	Desflurane, sevoflurane, N ₂ O (ns)	6.9 y	↑ MPO and lipid hydroperoxides; ↓ catalase and sulfhydryl groups	Fair (5)
Cerit (2014)	Cross-sectional Turkey	25 exp; 37 y (100% F)	Isoflurane, sevoflurane (ns)	80 h/ month	↓ ARE and TAS; ↑ TOS and OSI in anesthesia personnel	Fair (5)
Chandrasekhar (2006)	Cross-sectional India	45 exp / 45 ctrl; 38.9±9.0 y	Multiple VAs + N ₂ O (ns)	11.0±4.5 y	↑ DNA damage (comet), ↑ chromosomal aberrations and MN	Good (7)
Chang (1996)	Cross-sectional Taiwan	18 exp / 18 ctrl; 36±1.8 y	N ₂ O (ns)	13.7±1.2 y	In vitro evidence of DNA repair errors; correlation with years of employment	Poor (3)
Costa Paes (2014)	Cross-sectional Brazil	15 exp / 15 ctrl; 27.4±2.1 y	Isoflurane, sevoflurane, N ₂ O (ns)	8–22 months (30 h/wk)	↑DNA damage; changes in plasma thiols and GPx over time	Poor (3)
Eroglu (2006)	Cross-sectional Turkey	25 exp / 25 ctrl; 34.4±7.1 y	Sevoflurane, N ₂ O (8.9;119 ppm)	~6.6 y (78.9±74.3 mo)	↑SCE in anesthesiologists; SCE decreased after 2-month leave	Good (7)
Hoerauf (1999)	Cross-sectional Germany	27 exp / 27 ctrl; 33.3 y	Isoflurane, N ₂ O (0.5;11.8 ppm)	3 months (8 h/day)	↑SCE frequency after exposure	Fair (5)
Hua (2021)	Cross-sectional China	68 exp / 82 ctrl; 30.6±5.8 y	Sevoflurane 1.1±0.7 ppm	8.3±5.2 y	↓SOD; ↑MDA, bilirubin, creatinine, QT/QTc	Poor (3)
Jafari (2018)	Cross-sectional Iran	42 exp / 30 ctrl; 31.3±10.1 y	Isoflurane, sevoflurane (median 1.3 ppm)	Ventilation 15 ACH	↑transaminases, ↑MDA, ↓antioxidants (oxidative stress)	Good (7)
Kargar Shourok (2018)	Cross-sectional Iran	60 exp / 60 ctrl; 35.7±6.9 y	Isoflurane, sevoflurane, N ₂ O (2.4;0.2;851 ppm)	NS	↑MN and chromosomal aberrations; genotype modifies susceptibility	Good (7)
Khisroon (2020)	Cross-sectional Pakistan	50 exp / 49 ctrl; 32.1±8.8 y	Not specified	Mean job 6.5±4.7 y	↑comet assay TCS; exposure duration and GST polymorphisms affect DNA damage	Fair (5)

Author (Year)	Design / Country	Sample (n)	VA (summary)	Exposure (mean)	Key finding (summary)	Quality evaluation according to NOS Scale
Kozanhan (2017)	Cross-sectional Turkey	60 exp / 51 ctrl; 34.7±6.5 y	Desflurane, sevoflurane, N ₂ O	≥5 h/day ≥1 y	Disturbed thiol/disulfide homeostasis after anxiety adjustment	Poor (3)
Lewinska (2005)	Cross-sectional Poland	46 exp / 28 ctrl; 39.0±7.1 y	Isoflurane, sevoflurane, N ₂ O (range)	17.7±10.1 y	↑MN frequency in exposed nurses	Good (7)
Malekirad (2005)	Cross-sectional Iran	66 exp / 66 ctrl; 32 y	Halothane, N ₂ O (ns)	9.3 y	↑lipid peroxidation; ↓thiol groups; TAC unchanged	Fair (5)
Musak (2013)	Cross-sectional Czech Rep	247 exp / 250 ctrl; 37±9.8 y	Isoflurane, sevoflurane (mg/m ³)	12.8±9.6 y	↑chromosomal damage indices (CAT _{tot} , CTA, CSA) vs unexposed	Good (7)
Neghab (2020)	Cross-sectional Iran	60 exp / 60 ctrl; 35.7±6.9 y	Isoflurane, sevoflurane, N ₂ O (2.4;0.2;851 ppm)	≥6 h/day; 11.0±5.6 y	↑MN/CA, ↑MDA, ↓TAC and SOD; antioxidant status inversely correlates with MN/CA	Good (7)
Pasquini (2001)	Cross-sectional Italy	46 exp / 66 ctrl; 39.7±6.9 y	Enflurane, N ₂ O (ns)	12.2±16.3 y	Mixed SCE results; sex and smoking influenced outcomes	Fair (5)
Rozgaj (1999)	Cross-sectional Croatia	129 exp / 41 ctrl; 38.7±7.8 y	Halothane, N ₂ O (350 mg/m ³ ; 350–400 ppm)	11.8±7.8 y	↑ chromosome breaks, acentric fragments, dicentric in exposed	Fair (5)
Rozgaj (2001)	Cross-sectional Croatia	43 exp / 26 ctrl; 35.1±7.4 y	Halothane, N ₂ O (ns)	12.1±7.7 y	↑ chromosomal aberrations and MN; women higher RR for MN	Fair (5)
Rozgaj (2009)	Cross-sectional Croatia	50 exp / 50 ctrl; 38.7±7.6 y	Isoflurane, sevoflurane, N ₂ O (ns)	13.0±9.0 y	↑ comet assay tail length/moment and MN frequency in exposed	Fair (5)
Santovito (2014)	Cross-sectional Italy	21 exp / 21 ctrl; 35.7±5.7 y	Not specified	8.6±4.4 y	↑ SCE in exposed; GSTT1 null associated with higher SCE	Fair (5)
Sardaş (1998)	Cross-sectional Turkey	66 exp / 41 ctrl; NS	Halothane, isoflurane, N ₂ O (ns)	1–17 y	↑ comet assay DNA damage in exposed; smoking also increased damage	Fair (5)

Author (Year)	Design / Country	Sample (n)	VA (summary)	Exposure (mean)	Key finding (summary)	Quality evaluation according to NOS Scale
Sardaş (2006)	Cross-sectional Turkey	17 exp / 19 ctrl; 33.3±3.5 y	Desflurane, isoflurane, sevoflurane, N ₂ O	>8 y	Vitamin C+E supplementation ↓ comet TCS in exposed (12 wks)	Fair (5)
Silva (2023)	Cross-sectional Brazil	100 exp / 93 ctrl; 34.0±12.1 y	Isoflurane, sevoflurane, N ₂ O (TWA 7–165 ppm)	9 (1–30) y	↑ buccal MN and NBUD; oxidative stress and instability with longer exposure; genotype effects	Good (7)
Souza (2016)	Cross-sectional Brazil	30 exp / 27 ctrl; 41.5±15.0 y	Desflurane, isoflurane, sevoflurane, N ₂ O	>2 y, Inadequate scavenging (0–8 ACH)	(Study truncated in file) — genomic instability and oxidative markers assessed	Good (7)

NS = not specified

gender of the participants [10, 19, 32, 35, 43, 61, 70]. All the included studies were observational studies, most of them were cross-sectional studies [4, 6, 10, 13, 15–18, 20–22, 24–30, 32–34, 36–40, 42, 46–59, 61, 62, 65–74], and other articles presents the results of longitudinal studies [14, 19, 23, 35, 41, 43–45, 60, 63]. Even though the methodology of the studies were similar, they have been run in different times, in particular from 1994 to 2004 we included 19 studies [10, 13–19, 22, 23, 25, 31, 57, 59, 61, 64, 68, 71, 74], from 2005 to 2014 we included 23 studies [4, 6, 20, 21, 24, 28, 29, 32–34, 39, 40, 49, 53–56, 58, 60, 65, 69, 70, 73], from 2015 to 2024 23 studies [26, 27, 30, 35–38, 41–43, 45–48, 50–52, 62, 63, 66, 67, 72]. This distribution emphasizes the importance of the theme in the scientific world nowadays.

The main results are reported in the following four main classes: the area “Fertility and pregnancy” (Table 1), the area “Neurotoxicity” (Table 2), the area “Laboratory and immunology” (Table 3), the area “Cytogenetic effects” (Table 4). The full scoring criteria for each study design is shown in each Table.

The area “Fertility and pregnancy” included three articles [23, 34, 60], two of them stated that there was not significant evidence about their main outcome. One of these studies, conducted on 9,433

mothers that were nurses exposed to halothane and this exposure was probably connected with possible congenital anomalies. Concerning the quality assessment of these studies, they all were evaluated as Poor.

The area “Neurotoxicity” included nine articles [14–17, 19, 21, 30, 61, 70]. The main outcomes were poorer neurobehavioral performance, measured by a specific test, and personal feelings of anxiety. An important note is that three studies stated that there was not significant evidence in the field of neurotoxicity. As the quality assessment of these studies, two were marked as Good, four as Fair, and three as Poor.

The area “Laboratory and immunology” included 17 articles [6, 13, 22, 34–37, 40, 42, 44, 48, 55, 62, 63, 67, 68, 71], the main outcome was also the oxidative stress, marked by the increasing of pro-inflammatory cytokines or for example the alteration of some blood parameters, such as transaminases and lymphocytes. About the quality assessment of these studies, four were marked as Good, seven as Fair, and six as Poor.

In total, 40 articles were included in the area “Cytogenetic effects” [4, 10, 18, 20, 24–33, 37–39, 42, 44–47, 49–54, 56–59, 62, 64–66, 69, 72–74]. The main outcome was the correlation between exposure and

oxidative stress, and some of them reported different types of reversible DNA damage (sister chromatid exchange, micronuclei frequencies, specific type of cells such as leukocytes, etc). Considering the quality assessment of these studies, 17 were marked as Good, 17 as Fair and six as Poor.

4. DISCUSSION

Waste anesthetic gases (WAGs) are small releases of anesthetic gases that leak from a patient's anesthetic breathing circuit during delivery of or recovery from anesthesia. WAGs include N₂O and halogenated anesthetics such as halothane, enflurane, isoflurane, desflurane and sevoflurane. The halogenated anesthetics are often administered in combination with N₂O and may pose a hazard to hospital workers. The anesthetic breathing circuit includes the mask, endotracheal tube, anesthetic gas machine, ventilator, pumps, scavenging devices that limit WAG releases, plus connecting tubing and other elements, depending on EPHB Report No. 2022-DFSE-822 [75], the delivery system and are typically only used in the operating room (OR) [76].

In the USA, in a survey among USA anesthesiologists [77], 97% of them reported using anesthesia machines with scavenging systems, showing a great adherence to the NIOSH recommendation [78]. However, not only the recommendations from countries may vary, but also access to scavenging and/or exhaustion systems. These factors may therefore reduce adherence and lead to the exposure of healthcare workers to WAGs [79]. Nonetheless, we must highlight that it does not exist a global indication toward the exposure limits. The first regulations [80] were established in the USA, in 1977, when the National Institute for Occupational Safety and Health (NIOSH) determined a threshold of 25 ppm of nitrous oxide (N₂O) measured as a time-weighted average (TWA) during the administration of the drug, and 2 ppm of the other volatile anesthetics. Others have assigned a threshold of 50 ppm for N₂O for an 8-h working day [77, 81].

The European Union (EU) uses its own threshold values and exposure limits, which tend to be higher than the North American. Large discrepancies in

threshold limits remain; for example, isoflurane threshold levels range from a maximum of 5 ppm in Denmark to 50 ppm in Spain. In the United Kingdom (UK), the maximum permitted levels per anesthetic under an 8-h TWA are 100 ppm for N₂O, 50 ppm for isoflurane, and 10 ppm for halothane; however, there are no defined values for sevoflurane or desflurane. In general, because absolute safe levels have not been scientifically established, most guidelines and policies regarding inhaled anesthetics are advisory rather than mandatory.

4.1. Reproductive and Pregnancy Outcomes

The evidence regarding reproductive and pregnancy outcomes among healthcare workers occupationally exposed to volatile anesthetics appears overall inconsistent and does not support a clear association under contemporary operating room conditions. In a meta-analysis [82], a 50% increase in risk of spontaneous abortion was calculated with exposure to anesthetic gases. Across the studies included in this review, reproductive outcomes were investigated mainly through retrospective cohort and cross-sectional designs, often relying on registry data [60] or self-reported reproductive histories. Sample sizes were generally moderate to large; however, exposure assessment was frequently qualitative or indirect, and information on scavenging systems and ventilation was often incomplete. Most studies conducted after the widespread introduction of scavenging systems and improved ventilation standards did not report a statistically significant increase in infertility, spontaneous abortions, or congenital anomalies among exposed workers compared with controls. When associations were observed, they were often limited to specific subgroups or historical periods characterized by higher exposure levels, particularly involving halothane and nitrous oxide. Importantly, several studies suggested that non-chemical occupational factors—such as night shifts, workload, stress, and work-life imbalance—may have contributed to adverse reproductive outcomes, potentially confounding the relationship with anesthetic exposure.

Taken together, these findings suggest that, under current exposure scenarios and with modern

anesthetic agents, occupational exposure to volatile anesthetics is unlikely to represent a major determinant of adverse reproductive or pregnancy outcomes. Nevertheless, the heterogeneity in study design, exposure metrics, and outcome definitions limits the ability to draw definitive conclusions, and residual confounding cannot be excluded.

4.2. Neurotoxicity and Neurobehavioral Effects

In the 1970s, many studies focused on neurotoxicity from VA. With new anesthetics and the lowering of exposure, neurotoxicity seemed to be set aside. In fact, studies investigating neurotoxic and neurobehavioral outcomes were relatively few and heterogeneous in terms of design, outcome measures, and exposure characterization. Most evidence derives from cross-sectional studies assessing cognitive performance, reaction times, mood, or subjective symptoms using standardized neurobehavioral tests. Overall, most studies conducted at exposure levels below or near occupational limits did not identify clinically relevant neurobehavioral impairment. Some investigations reported subtle alterations [16], such as prolonged reaction times, changes in vigilance, or increased subjective symptoms (e.g., fatigue, headache, reduced concentration), particularly at the end of work shifts or workweeks. These effects were generally mild, reversible, and not consistently correlated with biological or environmental exposure indicators.

Notably, studies that identified neurobehavioral changes often involved exposure to N₂O, either alone or in combination with halogenated anesthetics, and were conducted in settings with suboptimal ventilation or incomplete scavenging. Conversely, studies performed in operating rooms equipped with modern air-exchange systems and scavenging devices tended to report null or weak associations.

Overall, the available evidence does not support a strong or consistent neurotoxic effect of long-term occupational exposure to volatile anesthetics at current exposure levels. However, the limited number of high-quality longitudinal studies and the reliance on cross-sectional assessments preclude firm conclusions, particularly regarding subtle or cumulative effects.

4.3. Laboratory and Immunological Alterations

A larger body of evidence addressed laboratory and immunological parameters, including hematological indices, liver and kidney function markers, oxidative stress biomarkers, and immune cell profiles. These studies were predominantly cross-sectional, with some cohort designs, and generally involved small to moderate sample sizes. Several studies reported statistically significant differences between exposed workers and controls in liver enzymes, renal markers, inflammatory cytokines, and oxidative stress indicators. However, in most cases, these alterations remained within clinical reference ranges and were interpreted as subclinical or early biological effects rather than overt disease. Immune-related findings, such as changes in lymphocyte subpopulations or cytokine profiles, suggested a possible modulation of immune function, although results were not uniform across studies. Exposure levels varied widely, and positive findings were more frequently reported in studies conducted in environments lacking adequate scavenging systems or involving higher concentrations of anesthetic gases, particularly nitrous oxide. However, studies with documented low-level exposure and effective ventilation often failed to detect significant laboratory abnormalities.

These findings suggest that chronic occupational exposure to volatile anesthetics may be associated with mild and potentially reversible biological alterations, particularly related to oxidative stress and immune modulation. Nonetheless, the cross-sectional nature of most studies and the limited control for confounding factors—such as smoking, alcohol consumption, concurrent chemical exposures, and work-related stress—limit causal inference.

4.4. Cyto- and Genotoxicity and Oxidative Stress

Some studies, especially *in vitro*, found increased DNA damage, higher frequency of chromosomal aberrations, sister chromatid exchange or micronuclei in lymphocytes, while others, especially *in vivo*, did not [18]. A substantial number of studies, including several of good methodological quality, documented increased frequencies of micronuclei,

sister chromatid exchanges, chromosomal aberrations, and markers of oxidative DNA damage in exposed workers compared with controls. These effects were observed across different countries and study populations and were often accompanied by evidence of oxidative stress imbalance, characterized by increased lipid peroxidation and reduced antioxidant defenses. Importantly, some studies reported dose–response relationships and correlations with duration of exposure, supporting a potential causal link. Genetic susceptibility, such as polymorphisms in detoxification enzymes (e.g., GST genes), also appeared to modulate individual vulnerability to genotoxic effects. Many studies deepen the role of VA on oxidative stress, especially in its chronic form, which may lead to several irreversible effects, such as fibrosis, necrosis, atrophy, vascular damage and DNA breakage. Malekirad et al. [39] investigated oxidative stress induced by chronic exposure to VA and Sardas et al. [32] studied the effect of antioxidant supplementation in HCW, obtaining that supplementation of the diet with vitamin C and vitamin E results in significant decrease in the DNA damage. From a clinical point of view, there is currently much discussion on the proinflammatory, proangiogenic, and antiapoptotic cellular effect of VA [83]; based on this, VA should be detrimental in patients with cancer, although this is unproved [84].

Although many of these studies involved relatively young and otherwise healthy workers, and the observed alterations were subclinical, the consistency of findings across different settings raises concern regarding long-term health implications. Even in studies conducted under modern operating room conditions, low-level exposure to volatile anesthetics was sometimes associated with measurable genotoxic biomarkers, suggesting that current exposure limits may not fully prevent early biological effects.

4.5. Overall Interpretation and Relevance to Current Operating Room Settings

Taken together, the evidence reviewed over the last three decades indicates a gradient of effects associated with occupational exposure to volatile anesthetics. While reproductive outcomes and neurotoxicity appear weakly or inconsistently

associated with exposure under contemporary conditions, laboratory alterations and, more notably, genotoxic and oxidative stress markers show more consistent associations. It is important to emphasize that many of the included studies are subject to methodological limitations, including cross-sectional designs, limited exposure assessment, and incomplete adjustment for confounders. Nevertheless, the convergence of findings on genotoxic endpoints across multiple independent studies suggests that even low-level, chronic exposure to waste anesthetic gases may induce early biological effects that warrant attention. Differences in exposure levels, laboratory methods, possible insufficient statistical power and lack of control for confounding aspects may explain these conflicting results. Future research should prioritize longitudinal designs, standardized exposure metrics, and harmonized outcome definitions, with particular attention to modern anesthetic agents and current operating room technologies. Such approaches are essential for clarifying the long-term health implications of observed subclinical alterations and informing evidence-based occupational health policies. Nowadays another technique to induce anesthesia is the Total Intravenous Anesthesia (TIVA). With this technique, the risk of exposure does not exist; however, the VAs technique cannot yet be substituted for TIVA.

4.5. Limitations of the Systematic Review

The present systematic review has some limitations. First, the results cannot be considered definitive because the included studies employed different exposure assessment methods, used different analytical methods, had insufficient statistical power, and lacked control for confounding variables. Secondly, grey literature was excluded because we considered only peer-reviewed studies. Moreover, we included articles published in Italian or English; consequently, some studies published in other languages may have been excluded. However, limiting systematic reviews to English-language publications has little impact on effect estimates or conclusions. Finally, we did not conduct a meta-analysis due to heterogeneity in the assessment methods and results across the included studies.

5. CONCLUSION

The reviewed articles highlight that occupational exposure to VA remains a subject of debate. Further studies are needed to evaluate the risk of chronic VA exposure in controlled operating rooms, considering factors such as ventilation systems and VA limits.

Most studies report a statistically significant increase in early-effect biomarkers, particularly cytogenetic ones, among workers exposed to VA compared with control groups, underscoring the importance of these biomarkers in biomonitoring studies. Minimizing VA exposure in work environments is crucial through the use of appropriate ventilation systems and continuous monitoring of VA levels in ppm. Moreover, it is essential to establish an international consensus on uniform, adequate global limits to protect all workers, as the adverse effects of chronic exposure beyond European and American limits are real and irreversible.

Overall, evidence over the last three decades most consistently supports an association between occupational exposure to waste anesthetic gases and early biomarkers of genetic/oxidative damage, while findings on reproductive outcomes and neurotoxicity are less consistent. Future studies should prioritize standardized exposure assessment, control for major confounders, and harmonized outcome definitions to improve comparability across settings.

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Prevalence and Multivariate Impact of Musculoskeletal Disorders on General Health, Occupational Fatigue, and Productivity in an Industrial Workforce

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ABSTRACT

Background: Musculoskeletal disorders represent a leading occupational health challenge in heavy-industry settings, yet their combined impact on workers' general health, fatigue, and productivity remains underexplored. This study aims to quantify the relationship between multisite musculoskeletal symptom burden and key health and performance outcomes among copper-industry employees. **Methods:** A cross-sectional survey of 585 workers used the Standardized Nordic Musculoskeletal Questionnaire, the 28-item General Health Questionnaire, the SOFI-20 fatigue inventory, and the HPQ-26 productivity survey. Spearman's rank correlation was used to examine bivariate relationships, and multivariable linear regression models, generally adjusting for demographic, work-related, and psychosocial factors, were employed to estimate the independent effect of the number of painful sites on health, fatigue, and productivity outcomes. **Results:** Fifty-seven percent of workers reported pain in at least one region during the preceding 12 months, with an average of 2.6 painful sites per person (standard deviation 2.4). The number of painful sites showed a moderate positive correlation with poorer general health scores ($\rho = 0.43$, $p < 0.001$) and higher fatigue scores ($\rho = 0.53$, $p < 0.001$), and a moderate negative correlation with productivity ratings ($\rho = -0.30$, $p < 0.001$). In adjusted regression analyses, each additional painful site was associated with a 1.9-point worsening in general health score (95% CI 1.5 to 2.2), an 8.4-point increase in fatigue score (95% CI 7.3 to 9.6), and a 1.6-point decrease in productivity score (95% CI -2.0 to -1.2), all with p -values < 0.001 . **Conclusions:** There is a clear dose-response relationship between the number of painful anatomical sites and declines in health, increases in fatigue, and reductions in productivity among copper-industry workers. To address this multifaceted impact, interventions should integrate ergonomic workstation design, task rotation, optimized break schedules, and comprehensive health-promotion services targeting both physical and psychosocial risk factors.

1. INTRODUCTION

Musculoskeletal disorders (MSDs) are widely recognized as one of the foremost occupational health concerns of the twenty-first century, exacting profound costs on employees, employers, and national economies alike. Annual global estimates attribute approximately 25% of all work-related illnesses to MSDs, with affected workers incurring higher rates of sickness absence, reduced functional capacity, and long-term disability [1-3]. In heavy-industry environments where manual handling of ores, protracted static postures at assembly lines, and exposure to whole-body vibration are commonplace, 12-month prevalence rates frequently exceed 50% [4-6]. Economically, direct medical expenditures and compensation payments for work-related MSDs absorb up to 2% of gross domestic product in many high-income nations. At the same time, indirect costs, such as lost productivity, recruitment, and training of replacement staff, can double that figure [7, 8]. Despite the availability of ergonomic guidelines and assistive technologies, implementation remains uneven, particularly in resource-constrained processing facilities and subcontracted operations, perpetuating a cycle of injury risk and unmet prevention needs.

Beyond the overt musculoskeletal impairments, chronic low-back pain, rotator cuff tendinopathy, and degenerative knee pathology, MSDs precipitate a constellation of adverse psychosocial outcomes that erode workers' mental health and social functioning. Population-based surveys spanning manufacturing, mining, and construction sectors report that employees with pain at multiple anatomical sites are two to three times more likely to exhibit clinically relevant depressive symptoms, anxiety, and sleep disturbances than those with isolated complaints [9-11]. According to the biopsychosocial model, this interplay is bidirectional: heightened stress and poor sleep quality exacerbate pain sensitivity through central sensitization, while persistent nociceptive input fuels mood dysregulation and cognitive fatigue [12]. Moreover, interpersonal tensions with supervisors and colleagues often escalate as productivity falters, fostering presenteeism and social withdrawal [13]. Coping strategies vary

widely from adaptive problem-solving and social support to maladaptive withdrawal or substance use, highlighting the need for integrated interventions that address both ergonomic risk factors and mental health promotion in high-strain work environments.

Converging evidence suggests that the presence and severity of MSDs substantially exacerbate both peripheral and central dimensions of occupational fatigue, creating a self-reinforcing cycle of pain and tiredness that undermines worker resilience [14, 15]. Chronic nociceptive input from injured tissues induces prolonged muscle co-contraction and altered movement strategies, increasing metabolic demand and accelerating the onset of peripheral fatigue during even routine manual tasks [16, 17]. Simultaneously, persistent pain activates central stress pathways, elevating levels of proinflammatory cytokines such as interleukin-6 and tumor necrosis factor- α , which cross the blood-brain barrier to impair neurotransmitter balance and cortical excitability, thereby magnifying cognitive fatigue and slowing psychomotor responses [18, 19]. Moreover, sleep fragmentation is common among workers with MSD-related discomfort, further diminishing restorative processes, lowering pain thresholds, and heightening subjective fatigue the following day [20]. Despite these mechanistic insights, few studies have simultaneously quantified the relative contributions of pain intensity, anatomical distribution of disorders, and sleep quality to distinct fatigue domains within heavy-industry cohorts.

Work in mineral-processing environments exposes employees to a confluence of physical, chemical, and psychosocial hazards that synergistically undermine physiological homeostasis and psychological resilience. Extreme ambient temperatures, airborne particulates, and high noise levels induce thermal strain, respiratory irritation, and auditory damage. At the same time, chronic exposure to heavy metals and chemical solvents disrupts endocrine function and cellular metabolism [21, 22]. Prolonged shifts and rotating schedules further compromise circadian regulation and sleep architecture, exacerbating cognitive fatigue and mood disturbances [23, 24]. Simultaneously, elevated production targets, stringent supervision, and perceived job insecurity

fuel chronic psychosocial stress, marked by sustained cortisol elevations and maladaptive coping behaviors [25]. The relative isolation of remote processing sites also diminishes social support networks, heightening susceptibility to anxiety and depressive symptoms [26]. Collectively, these intertwined stressors potentiate MSD progression and deepen fatigue by altering pain perception, impairing immune responses, and eroding motivation, thereby compromising overall well-being and resilience among copper-industry workers.

Accordingly, this cross-sectional investigation focuses on employees of the copper industry to examine the independent relationship between multisite musculoskeletal symptom count and key health and performance metrics. By quantifying how symptom burden correlates with general psychological and somatic health, multidimensional occupational fatigue, and self-reported work productivity while accounting for demographic, psychosocial, and ergonomic covariates, this study will generate robust evidence tailored to the mineral-processing milieu. The resulting insights are expected to inform the development of targeted ergonomic modifications, fatigue-mitigation strategies, and organizational policies to reduce musculoskeletal burden, safeguard worker health, and optimize operational efficiency in copper-processing facilities.

2. METHODS

2.1. Study Design and Participants

This cross-sectional study was conducted at a copper-processing facility. A stratified random sampling approach was employed to ensure representativeness across work units and shift schedules. The sampling frame was constructed using the company's human resources roster, stratified by department (e.g., smelting, casting, maintenance) and shift type (day vs. rotating).

The operational departments included smelting, casting, crushing and milling, concentrate handling, maintenance, laboratory and quality control, and logistics. Core activities across these units included material handling, equipment operation, thermal processing, inspection, and mechanical servicing,

each with varying biomechanical and environmental demands. Within each stratum, employees were selected by simple random sampling to reach a target of 585 participants. The number of participants selected from each department and shift group was proportional to the size of that stratum in the workforce roster; therefore, sample sizes were not equal across groups.

Eligible individuals were full-time staff with at least one year of continuous employment; those with a prior clinical diagnosis of musculoskeletal pathology or a clinically documented psychiatric disorder (as recorded in occupational health files) were excluded. It should be noted that the operational workforce in this facility is composed exclusively of male employees; therefore, all study participants were male. Written informed consent was obtained from all participants, and the study protocol was approved by the institutional ethics committee under approval code IR.SUMS.SCHEANUT.REC.1404.064. All questionnaires were self-administered, with researchers present to provide procedural guidance if needed without influencing responses.

2.2 Data Gathering Tools

2.2.1. Demographic and Occupational Questionnaire

A self-administered form was used to collect sociodemographic data (age, sex, marital status, number of children, educational attainment) and occupational parameters (years of work experience, daily and weekly working hours, employment status, shift type, job title, and department). This instrument was pilot-tested with 20 workers to ensure the clarity and appropriateness of the response options.

2.2.2. Nordic Musculoskeletal Questionnaire (NMQ)

The Standardized Nordic Musculoskeletal Questionnaire (NMQ) was employed to ascertain the 12-month and point-prevalence of musculoskeletal pain or discomfort across nine body regions (neck; shoulders; upper back; lower back; elbows; wrists/hands; hips/thighs; knees; ankles/feet). For each

region, respondents indicated whether they had experienced ache, pain, or discomfort at any time over the past 12 months and right now. The NMQ has demonstrated high content validity and test–retest reliability (κ coefficients ≥ 0.70) in industrial populations [27]. An overall MSD_Count score (0–9) was calculated by summing the number of regions with positive 12-month responses.

2.2.3. General Health Questionnaire (GHQ-28)

Psychological well-being and somatic symptoms were measured using the GHQ-28, a widely used screening tool comprising 28 items across four subscales: somatic symptoms, anxiety/insomnia, social dysfunction, and severe depression. Each item employs a 4-point Likert scale (0 = “not at all” to 3 = “much more than usual”), yielding total scores from 0 to 84. In line with validated cut-points for industrial populations, a threshold of 24 was used to differentiate “Healthy” (< 24) from “Possible disorder” (≥ 24). The Persian version demonstrated excellent internal consistency (Cronbach’s $\alpha = 0.90$) [28].

2.2.4. Swedish Occupational Fatigue Inventory (SOFI-20)

Occupational fatigue was assessed via the SOFI-20, which captures five dimensions of fatigue (lack of energy, physical exertion, physical discomfort, lack of motivation, and sleepiness) through twenty 11-point items (0 = “not at all” to 10 = “to a very high degree”). The total score, therefore, ranges from 0 to 200. The SOFI-20 has established construct validity and internal consistency ($\alpha > 0.85$) in ergonomic research [29]. Scores were categorized into three levels: Low fatigue (< 42.5), Moderate fatigue (42.5–117.5), and High fatigue (> 117.5).

2.2.5. Human Resource Productivity Questionnaire (HRP-26)

Worker productivity was assessed using the 26-item Human Resource Productivity Questionnaire (HRP-26), which evaluates seven domains of performance (Ability, Clarity, Help, Incentive, Evaluation, Validity, Environment). Each item is rated on

a 5-point Likert scale (1 = “very poor” to 5 = “excellent”), yielding a total score range of 26–130 [30]. Total scores were then converted to a percentage of the maximum possible score and classified as Poor ($< 50\%$), Moderate (50–70%), or Strong ($> 70\%$).

2.3. Statistical Analysis

All statistical analyses were conducted in R version 4.3.0. Continuous variables were examined for central tendency and dispersion (mean \pm SD, median, interquartile range, minimum–maximum), and categorical variables were summarized as frequencies and proportions. Normality of the key continuous outcomes MSD_Count, GHQ_Total, SOFI_Total, and HRP-26 percentage scores was assessed using the Shapiro–Wilk test and complemented by skewness and kurtosis indices. The 12-month prevalence of musculoskeletal symptoms in each anatomical region was estimated with binomial 95% confidence intervals.

Given significant deviations from normality (all Shapiro–Wilk $p < 0.001$), associations between MSD_Count and each outcome were quantified using Spearman’s rank correlation (ρ), with Pearson’s r computed in parallel to verify that $|\rho - r| < 0.03$. Unadjusted linear regression models then estimated the crude effect of MSD_Count on GHQ_Total, SOFI_Total, and HRP-26 scores (β coefficients, R^2 , and p -values). To determine the independent contribution of MSD_Count, multivariable linear regression models were fitted, controlling for age, work experience, number of children, daily and weekly working hours, education level, marital status, shift type, and employment status. Multicollinearity was evaluated via variance inflation factors (all VIF < 5), and heteroskedasticity of residuals was assessed with the Breusch–Pagan test; where indicated (GHQ and SOFI models), heteroskedasticity-consistent (HC3) standard errors were applied. Model adequacy was judged by adjusted R^2 and diagnostic plots of standardized residuals versus fitted values and Cook’s distance. Statistical significance was defined as $\alpha = 0.05$ (two-tailed).

3. RESULTS

3.1. Demographic and Occupational Characteristics

The study sample consisted of 585 copper-industry employees whose demographic and work-related profiles are detailed in Table 1. Participants were predominantly mid-career adults (mean age 39.2 ± 6.6 years) with substantial tenure (mean work experience 9.1 ± 6.4 years). On average, workers reported a 7.5-hour workday and a 42.1-hour workweek. Educational attainment varied: approximately 38% held a high school diploma or less, 20% had completed an associate degree, and 42% had a bachelor's degree or higher. The majority were married (88%) and under permanent contracts (76%). Shift distribution was balanced, with 41.5% on day shifts and 58.5% rotating through afternoon and night schedules. Collectively, these data (Table 1) describe

Table 1. Demographic and Occupational Characteristics of the participant (n = 585).

Quantitative variable	Category	Mean \pm SD
Age (years)		39.2 (6.62)
Work experience (years)		9.05 (6.36)
Daily work hours		7.48 (1.41)
Weekly work hours		42.11 (8.99)
Qualitative variable		No. (%)
Education Level	\leq Diploma	223 (38.1)
	Associate	115 (19.7)
	\geq Bachelor	247 (42.2)
Marital Status	Married	515 (88)
	Single	70 (12)
Employment Status	Permanent	446 (76.2)
	Contractual/ Temporary	139 (23.8)
Shift Type	Day	243 (41.5)
	Afternoon/ Night	342 (58.5)

Table 2. General Health Status, Occupational Fatigue Levels, and Productivity among Copper-Industry Employees.

Questionnaire		No. 585 (%)
GHQ-28	Healthy	454 (77.6)
	Possible disorder	131 (22.4)
SOFI-20	Low fatigue	282 (48.2)
	Moderate fatigue	252 (43.1)
	High fatigue	51 (8.7)
HRP-26	Poor	98 (16.8)
	Moderate	381 (65.1)
	Good	106 (18.1)

a stable, well-qualified workforce operating under standard industrial work patterns.

Table 2 presents the distribution of general health status, occupational fatigue levels, and productivity among employees of the copper industry. Most employees (77.6%) were classified as “Healthy” on the GHQ-28, while roughly one in five exhibited scores indicative of potential disorder. Fatigue levels were predominantly low to moderate, with only 8.7% of workers reporting high fatigue on the SOFI-20. On the HRP-26 scale, most participants rated their productivity as “Moderate” (65.1%). In contrast, smaller proportions fell into the “Good” and “Poor” categories. A notable subset still experiences elevated distress or fatigue and reduced productivity.

3.2. Prevalence of Musculoskeletal Symptoms

Table 3 illustrates that musculoskeletal symptoms were highly prevalent among the 585 copper-industry workers: 57.1% reported pain in at least one anatomical region over the past year (mean MSD_Count = 2.63 ± 2.35), and nearly 30% experienced discomfort in three or more sites. The lower back (43.3%), knees (41.2%), and neck (32.7%) were the most frequently affected regions, whereas elbow pain was the least common (11.9%). These findings highlight a substantial MSD burden in this workforce and underscore the importance of ergonomic interventions targeting spinal and lower-limb stressors.

Table 3. Point and 12-month Prevalence of Musculoskeletal Symptoms by Body Region (n = 585).

Region	Point prev No. (%)	12-mo prev No. (%)
Lower back	173 (29.6%)	254 (43.4%)
Knees	166 (28.4%)	242 (41.4%)
Neck	126 (21.5%)	188 (32.1%)
Shoulders	113 (19.3%)	168 (28.7%)
Wrists	121 (20.7%)	176 (30.1%)
Hands	116 (19.9%)	174 (29.8%)
Ankles	110 (18.9%)	160 (27.3%)
Upper back	98 (16.8%)	149 (25.4%)
Feet	101 (17.2%)	144 (24.6%)
Hips/thighs	89 (15.2%)	134 (22.9%)
Chest	70 (12.0%)	106 (18.2%)
Elbows	62 (10.6%)	92 (15.7%)
Overall MSD burden		
Mean number of affected regions		2.63 ± 2.35
Any MSD (MSD_Count ≥ 1)		334 (57.1)
Multiple MSDs (MSD_Count ≥ 3)		173 (29.6)

Table 4. Spearman correlations between MSD_Count and outcome scores (n = 585).

Outcome Variable	Spearman ρ	<i>p</i> -value
GHQ_Total	0.43	< 0.001
SOFI_Total	0.53	< 0.001
HRP_Total	-0.30	< 0.001

3.3. Correlation Between MSD Burden and Outcome Scores

Because MSD_Count and the outcome variables deviated from normality (Shapiro–Wilk $p < 0.001$ for all), we employed Spearman's rank correlation (ρ) to quantify their associations. Pearson's coefficients were also examined and differed by less than |0.03| from the values reported below, confirming that the substantive interpretation is insensitive to the correlation metric. Table 4 summarizes the results.

As illustrated in Table 4, each additional painful body region was moderately associated with higher distress and fatigue: MSD_Count correlated with GHQ_Total ($\rho = 0.43$) and SOFI_Total ($\rho = 0.53$),

Table 5. Unadjusted Linear Regression of Outcomes on MSD_Count (n = 585).

Outcome	β	R ²	<i>p</i> (β)
GHQ_Total	1.84	0.164	< 0.001
SOFI_Total	8.68	0.296	< 0.001
HRP_Total	-1.59	0.106	< 0.001

both highly significant ($p < 0.001$). Conversely, a greater MSD burden corresponded to lower productivity, as reflected in a negative correlation ($\rho = -0.30$) with HRP_Total ($p < 0.001$).

3.4. Simple Linear Regression (Unadjusted Models)

Unadjusted linear regression models were fitted to quantify the direct relationship between musculoskeletal symptom burden (MSD_Count) and each outcome—general health distress (GHQ_Total), occupational fatigue (SOFI_Total), and productivity (HRP_Total). As displayed in Table 5, MSD_Count emerged as a significant predictor in all three models ($p < 0.001$).

A one-unit increase in MSD_Count was associated with a 1.84-point rise in GHQ_Total, accounting for 16% of its variance, and an 8.68-point increase in SOFI_Total, explaining nearly 30% of the variability in fatigue. In contrast, each additional symptomatic region was associated with a 1.59-point decrease in HRP_Total ($R^2 = 0.11$), indicating that greater musculoskeletal burden is linked to lower productivity. These findings, before any covariate adjustment, underscore the substantive impact of MSD_Count on general health, occupational fatigue, and worker productivity.

3.5 Multiple Linear Regression (Adjusted Models)

Multivariable linear regression analyses were conducted to assess the unique contribution of MSD_Count to each outcome after controlling for age, work experience, number of children, daily and weekly working hours, education level, marital status, shift type, and employment status. As

Table 6. Adjusted Linear Regression Models Predicting Outcomes from MSD_Count (n = 585).

Outcome	β	95% CI	Adj. R ²	p (β)
GHQ_Total	+1.85	[1.50, 2.20]	0.174	< 0.001
SOFI_Total	+8.44	[7.33, 9.55]	0.321	< 0.001
HRP_Total	-1.63	[-2.02, -1.24]	0.117	< 0.001

shown in Table 6, MSD_Count remained a significant predictor across all models (all $p < 0.001$). Specifically, each additional painful region was associated with a 1.85-unit increase in GHQ_Total ($\beta = 1.85$, 95% CI [1.44, 2.26], Adj. R² = 0.17), indicating that MSD burden independently contributes to poorer general health status. For occupational fatigue, the adjusted effect of MSD_Count was 8.44 units (95% CI [7.20, 9.68]), underscoring its substantial role in explaining fatigue variance. Finally, MSD_Count inversely predicted HRP_Total, with each additional site linked to a 1.63-unit decrease ($\beta = -1.63$, 95% CI [-2.04, -1.22], Adj. R² = 0.12), highlighting the detrimental impact of musculoskeletal complaints on productivity.

4. DISCUSSION

This cross-sectional investigation examined the independent relationship between multisite musculoskeletal symptom burden and three critical outcomes: general health status, occupational fatigue, and self-reported productivity among copper-industry workers. Consistent with our hypotheses, we found that an increasing number of painful body regions was significantly associated with poorer psychological and somatic health, elevated multidimensional fatigue, and reduced work productivity, even after adjustment for demographic, psychosocial, and ergonomic covariates. These findings underscore the pervasive impact of musculoskeletal disorders beyond localized pain, extending to broader health and performance domains in heavy-industry settings.

4.1. Impact on General Health Status

Our results demonstrate that as the number of painful anatomical regions increases, so too does the burden of psychological and somatic symptoms.

While earlier studies showed that workers reporting pain in multiple sites experienced greater anxiety and body complaints than those with single-site pain [31, 32], they stopped short of estimating how each additional pain site contributes to overall distress. In contrast, our data reveal a consistent incremental effect. Each new pain region was associated with a 1.85-point increase in the total general health score, accounting for approximately 18% of the variance in general health distress. This pattern underscores that musculoskeletal complaints should not be viewed in isolation; relatively, pain across the body exerts a cumulative toll on mental and physical well-being [33]. Importantly, copper-industry workers perform strenuous manual tasks, including lifting and repetitive motions, exposure to vibration, and environmental challenges such as heat and airborne irritants. These factors likely exacerbate the psychological impact of multisite pain [4, 34]. Our findings therefore reinforce the need for comprehensive health surveillance that captures the breadth of musculoskeletal symptoms alongside traditional mental-health assessments in industrial workforces.

4.2. Effects on Occupational Fatigue

The present study extends the understanding of how widespread musculoskeletal discomfort drains workers' energy reserves. Previous field research in automotive and light manufacturing contexts reported that pain at two or more sites moderately predicted self-reported exhaustion [35, 36]. Here, we find that each additional painful site was associated with an 8.44-point increase in the SOFI-20 total fatigue score, accounting for 32% of the overall variability in fatigue levels. Under the unique conditions of copper processing, long shifts, rotating schedules, high ambient temperatures, and fine particulate exposures, workers enduring multisite pain not only perceive their tasks as more physically demanding but also report greater difficulty recovering between bouts of work [37]. In practical terms, this manifests as heightened sensations of heaviness, reduced willingness to initiate or sustain activity, and frequent reliance on brief pauses or task modifications [38]. These fatigue experiences can accumulate over

days, leading to a persistent low-energy state that undermines safety, increases error risk, and erodes overall quality of life [39]. Our findings suggest that fatigue-management strategies in heavy-industry settings must account for the pervasive influence of multisite pain by integrating ergonomic adjustments with targeted rest-break scheduling and education rather than focusing solely on single-region injuries.

4.3. Consequences for Work Productivity

Beyond health and fatigue, multisite musculoskeletal pain appears to influence how workers engage with their tasks and the work environment. Our analysis indicates that each additional painful region corresponded to a 1.63-point reduction in total productivity score, explaining about 12% of the variance in self-reported work performance. Prior investigations into presenteeism have highlighted that chronic discomfort can distract from task goals and diminish workers' sense of control and satisfaction [40, 41]. By quantifying the effect of each new pain site on the overall productivity metric, we show that as pain spreads to additional body regions, employees increasingly struggle to maintain focus, adapt to changing work demands, and interact positively with colleagues and supervisors. This is not simply a matter of taking longer to complete a job; instead, pain across multiple sites alters cognitive and emotional engagement, leading to more frequent errors, hesitancy in decision-making, and reduced willingness to volunteer for extra tasks or collaborate on complex operations [42]. In heavy-industry environments where precision and coordination are critical, these declines in engagement can cascade into slower production lines, higher rework rates, and greater reliance on supervisory oversight [43]. Addressing multisite pain, therefore, is not only a matter of individual health but also a strategic priority for maintaining workforce motivation, adaptability, and sustained productivity in demanding operational contexts.

4.4. Implications for Practice

Our findings highlight the urgent need for comprehensive ergonomic and psychosocial interventions

in copper-processing facilities. Engineering controls such as adjustable workstations, mechanical material-handling aids, and task rotation can mitigate spinal loading and lower-limb strain, directly reducing MSD prevalence. Concurrently, organizational policies promoting regular rest breaks, fatigue management training, and access to on-site physiotherapy or exercise programs may attenuate the pain-fatigue feedback loop. Moreover, integrating mental health support, including stress-reduction workshops and peer-support networks, can address the psychosocial dimensions of MSDs, thereby enhancing overall well-being and sustained productivity.

4.5. Strengths and Limitations

Despite the strengths of this study, including a large stratified sample, validated measurement tools, and multivariable modeling controlling for key confounders, several limitations should be acknowledged. The cross-sectional design precludes causal inference, and reliance on self-reported instruments may introduce recall or perception biases. Furthermore, although sampling was stratified by department, no department-specific biomechanical or environmental exposure data (such as workload, heat, noise, or chemical agents) were collected, preventing examination of inter-departmental differences and leaving the possibility of residual confounding. The GHQ-28 assesses general psychological distress without distinguishing between work-related and non-work-related origins, limiting the interpretation of its association with occupational factors. Finally, as the study population consisted exclusively of male workers, the findings may not extend to female populations. Future longitudinal studies incorporating objective ergonomic assessments, physiological markers, and wearable fatigue-monitoring technologies are recommended to clarify causal pathways and better characterize exposure-response relationships.

4.6. Future Directions

Building on our results, randomized controlled trials of multifaceted intervention packages combining ergonomic redesign, fatigue-mitigation

strategies, and mental health support are warranted to determine the most effective approaches for reducing MSD burden and enhancing productivity. Additionally, cost-effectiveness analyses could guide resource allocation by comparing the economic benefits of reduced absenteeism and improved performance against intervention costs. Finally, examining the role of organizational culture, safety climate, and worker engagement may reveal further levers for optimizing health and performance in high-risk industrial settings.

5. CONCLUSION

In conclusion, our study demonstrates a clear dose-response relationship between the number of painful musculoskeletal sites and overall health outcomes among copper-industry workers: as the count of affected regions increases, employees report significantly elevated psychological distress, greater occupational fatigue, and pronounced declines in work productivity. These findings highlight multisite symptom burden as a pervasive, rather than isolated, occupational health risk that undermines both well-being and performance. Practically, this means that interventions must move beyond targeting single anatomical areas to adopt system-wide strategies such as redesigning workstations for flexibility, implementing proactive task rotation and rest schedules, and offering integrated health-promotion services including physiotherapy and fatigue-management training. By addressing the cumulative impact of musculoskeletal pain through multidisciplinary ergonomic and organizational measures, industry stakeholders can more effectively mitigate distress and fatigue, safeguard worker health, and sustain productivity in demanding industrial environments.

INSTITUTIONAL REVIEW BOARD STATEMENT: The study was reviewed and approved by the Ethics Committee of Shiraz University of Medical Sciences under the approval code IR.SUMS.SCHEANUT.REC.1404.064. All procedures were conducted in accordance with the relevant ethical standards, and written informed consent was obtained from all participants prior to data collection.

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The Silent Strain: Grip Strength, and Wrist/Hand Musculoskeletal Disorders Among Meat Cutters

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KEYWORDS: Grip Strength; Meat Cutters; Musculoskeletal Symptoms

ABSTRACT

Background: Meat cutters are a working group that engages in awkward postures, repetitive motion, and forceful wrist/hand exertion. This study was conducted a) to examine the prevalence of musculoskeletal symptoms among Iranian meat cutters, b) to assess the wrist musculoskeletal disorders risk assessment and hand grip strength. **Methods:** Ninety-five male meat cutters in Iran (≥ 1 year tenure) completed a demographic/occupational questionnaire, the Nordic Musculoskeletal Questionnaire (NMQ), and the Boston Carpal Tunnel Syndrome Questionnaire (BCTQ). Ergonomic risk was assessed via the ACGIH-TLV[®] hand activity method, and maximum hand-grip force was measured. **Results:** With 69.5% reporting point prevalence and 70.5% reporting period prevalence of wrist/hand musculoskeletal symptoms, the study indicated that meat cutters had a significant prevalence of these symptoms. Most participants demonstrated mild to moderate severity in self-reported wrist symptoms while retaining asymptomatic functional status. The ACGIH-HAL assessment indicated most participants operated at or above the action level (AL), suggesting potential ergonomic risks. Moreover, The ACGIH-HAL ratio had a weak negative association with hand grip strength ($\beta = -0.0071$, $p = 0.12$). **Conclusions:** These findings highlight the ergonomic challenges associated with meat-cutting tasks.

1. INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) encompass a spectrum of arthritic and degenerative conditions that cause pain and functional impairment. These disorders are primarily caused or exacerbated by occupational activities or by conditions in the work environment [1-3]. Several epidemiological studies have shown a relationship between ergonomic risk factors in manual work, especially repetitive

and forceful exertions, and musculoskeletal disorders (MSDs) [3-5].

Occupational exposure to high physical workloads, a prominent factor in MSD development, correlates significantly with higher prevalence of musculoskeletal disorders in affected populations [2, 6]. Meat-processing operations are linked to recognized ergonomic risk factors, including high work pace, strenuous knife use, and excessive grip force demands [7-11]. Meat-processing workers perform

diverse, physically demanding tasks, such as lifting heavy carcasses and performing repetitive, forceful, and technically precise movements. These activities often involve awkward postures, limited recovery time, intensive tool use, and exposure to cold environments, all of which contribute to biomechanical strain [12]. Such factors significantly contribute to occupational health issues, notably MSDs [2, 13–15]. Kaka et al. [2] reported that low back pain was the most common WMSD among butchers. Numerous studies have shown that MSDs related to the workplace are complex and have a wide range of contributing factors, including those observed among meat cutters [5, 16–18].

Multiple occupations require excessive and/or sustained muscular exertion, which, when coupled with repetitive tasks, may lead to a high incidence of work-related wrist disorders [19, 20]. Meat cutters are more likely than other industrial workers to develop carpal tunnel syndrome (CTS) and trigger finger, which are believed to be induced by the use of handheld tools such as knives [21]. Musculoskeletal disorders (MSDs) affecting other upper-limb joints, such as tendinitis, neck and lower back pain, as well as epicondylitis and tenosynovitis, are problematic among meat-processing workers [22–26]. Hansson et al. identified rapid wrist kinematics and forceful exertions as critical contributors to the onset of musculoskeletal disorders (MSDs) in meat-cutting tasks. These risks are prevalent in both assembly line work and individual cutting stations [27, 28]. Accidents and disorders can be caused by the knife, which is the primary and frequently the only tool used by meat cutters [26, 29, 30]. The prevalence of CTS, a common hand disorder, ranges from 5.8% in females to 0.6% in males [31].

In recent years, research has advanced understanding of ergonomic risks and interventions in the meat-processing industry. Recent findings indicate that repetitive knife tasks, high physical workload, and insufficient recovery time remain major predictors of upper-limb musculoskeletal disorders in slaughterhouse environments, even after ergonomic training and awareness programs [32]. Organizational factors such as work rotation, task distribution, and production pace have also been shown to significantly influence the occurrence of

these disorders [33]. Intervention studies in meat-processing plants have shown that applying ergonomic checkpoint tools, redesigning workstations, and adjusting knife-handling tasks can effectively reduce physical strain and improve postural alignment [32, 34]. Moreover, environmental factors—particularly cold exposure—have been found to exacerbate discomfort and muscle fatigue, highlighting the importance of proper thermal conditions and personal protective equipment [35]. Collectively, recent studies emphasize that modern ergonomic approaches combining workstation redesign, participatory ergonomics, and environmental control are essential for reducing biomechanical strain and mitigating long-term musculoskeletal risks in meat-processing occupations.

Most studies in the manual meat-cutting sector have focused primarily on tool and workstation design. These investigations have examined the impact of knife sharpness on the cutting force required to process animal carcasses, ergonomic modifications to hand tools and workspaces to minimize musculoskeletal strain, and the advantages of mechanization for butchers [10, 26]. Although mechanization and automation have significantly increased production in the poultry industry, knives remain essential for tasks such as cutting, trimming, skin or fat removal, and processing. Despite efforts to improve knife design, these tools still require forceful exertions and repetitive motions, which contribute to the development of MSDs [36]. In developing countries like Iran, occupational health and safety hazards, including MSDs, receive relatively little attention. Currently, no statistical data are available on injury rates, occupational health issues, or other ergonomic concerns specific to Iranian butchers.

Only a few studies have investigated the occupational health and safety of butchers [37]. However, no prior research has specifically examined the prevalence of WMSDs or evaluated hand force exertion among Iranian meat cutters. Hence, the current study was undertaken in this sector with the following objectives: a) To evaluate the occurrence of musculoskeletal disorders (MSDs) in Iranian meat-processing industry workers, and b) To assess the risk of wrist musculoskeletal disorders and hand grip strength. The results of this study provide

a foundational framework for reducing the risk of biomechanical overload and for developing and deploying targeted ergonomic interventions in workplace settings. These actions are aimed at improving workers' well-being and the quality of professional life.

2. METHODS

2.1. Participants

This study included 95 right-handed male meat cutters with at least one year of experience. The mean duration of job experience among participants was 15.03 ± 2.78 years. Individuals with pre-existing musculoskeletal conditions or prior illnesses affecting the musculoskeletal system were excluded from participation. Participants were selected from a slaughterhouse in Shiraz using simple random sampling from a random number table. All workers participated voluntarily after receiving full disclosure of the study's aims and procedures. Written informed consent was obtained from all participants prior to the study's initiation. The study was conducted in accordance with the Helsinki Declaration of 1964, as revised in 2008 [38].

2.2. Data Gathering

In this research, the required data were collected using standard methods/tools as detailed below.

2.2.1. Demographic/Occupational Questionnaire

This questionnaire included questions on age, weight, height, job experience, daily working hours, marital status, and level of education. Table 1 shows the personal profiles of the participants.

2.2.2. Nordic Musculoskeletal Questionnaire (NMQ)

NMQ evaluates the self-reported prevalence of musculoskeletal symptoms across various anatomical regions within the studied demographic [39]. In this study, period prevalence (during the 12 months preceding the study) and point prevalence of musculoskeletal symptoms across various bodily regions

Table 1. Personal Profile of the Participants (n = 95.)

Quantitative variable	Mean \pm SD [†]
Age (years)	36.62 \pm 11.59
BMI* (kg.m ⁻²)	25.65 \pm 3.59
Job experience (years)	15.03 \pm 2.78
Working time per day (hours)	11.14 \pm 2.10
Qualitative variable	No. (%)
Marital status	38 (40)
• Single	57 (60)
• Married	
Education level	86 (90.5)
• Diploma and lower	9 (9.5)
• Associate Diploma and higher	

*Body Mass Index.

[†]Standard Deviation.

among participants were reported. Participants completed the questionnaire in their respective work environments. The validity and reliability of the Persian version of NMQ were assessed by Choobineh et al. (Cronbach's alpha = 0.691) [40].

2.2.3. Boston Carpal Tunnel Syndrome Questionnaire (BCTQ)

The BCTQ is a measurement tool specifically designed to assess self-reported symptom severity and functional status associated with the disease. Symptom severity is scored on a scale of 11 (no symptoms) to 55 (most severe symptoms), and functional status is measured on a scale of 8 (normal function) to 40 (total functional impairment) [41]. The Persian version of the BCTQ has demonstrated good reliability and validity in the study by Reza zadeh et al. (Cronbach's alpha = 0.90) [42].

2.2.4. American Conference of Governmental Industrial Hygienists Threshold Limit Value (ACGIH-TLV) for Hand Activity Level (HAL)

The ACGIH TLV for hand activity was used to assess job risk factors for MSDs of the hand and wrist. Hand activity was rated on a scale from 0 to 10, and the level of effort was measured as

normalized peak force (NPF) on a similar scale. NPF was assessed using three methods: quantified as a percentage of maximal voluntary contraction (MVC), self-assessed ratings of perceived exertion (RPE), and observational assessments derived from the Moore-Garg Strain Index protocol. The combination of HAL and NPF was then plotted on a TLV graph to determine the risk level, with a TLV of 0.78 and an action limit (AL) of 0.56 [43].

2.2.5. Jamar Hand Dynamometer

The Jamar hand dynamometer (Sammons Preston Model: 563213) was used to measure peak grip strength. This dynamometer uses precision load cell technology, enhancing measurement sensitivity and accuracy, even for very low grip strengths. By adhering to the industry-standard Jamar design, researchers can easily compare their findings with existing standardized normative data.

2.3. Implementation of the Study

In this study, individuals completed demographic/occupational, NMQ, and BCTQ questionnaires at their workplace. Peak hand grip strength was assessed using the Jamar Hand Dynamometer. Participants were seated in a standardized posture with adducted, neutrally rotated shoulders, 90° elbow flexion, and neutral anatomical alignment of the forearms and wrists. They held the dynamometer in their hand, with a wrist safety strap securing it and gentle support at the base to prevent accidental dropping. Grip force was applied smoothly, avoiding rapid or jerking motions. A 0–30° wrist extension was permitted to achieve maximal grip. Any wrist position other than extension or exceeding 30° of extension was noted.

Hand activity levels were assessed using the ACGIH-HAL method while workers performed their regular job tasks at the workstations. The force component (Normalized Peak Force) was determined using self-assessed ratings of perceived exertion embedded in the ACGIH-HAL method. Workers rated the effort required to perform their cutting tasks on a 0–10 scale, with 0 indicating ‘no

exertion’ and 10 indicating ‘extremely strong exertion’. This perceived exertion score was then used to derive the NPF value for placement on the ACGIH TLV graph.

2.4. Statistical Analysis

Data were analyzed using the Statistical Package for Social Sciences 16 (SPSS Inc, Chicago, IL, USA). Descriptive statistics (mean, standard deviation, number, and percent) and the Spearman correlation coefficient were used to analyze the collected data. A p-value less than 0.05 was considered statistically significant. To test the normality of the data, the Kolmogorov-Smirnov, Shapiro-Wilk, and Skewness & Kurtosis tests were used. A multivariable linear regression model was used to assess the association between the ACGIH-HAL ratio and maximum hand grip strength (measured using a Jamar hand dynamometer), while controlling for potential confounders including age, body mass index (BMI), and daily work hours.

3. RESULTS

3.1. Prevalence of Musculoskeletal Symptoms

Table 2 presents the point and 12-month period prevalence of musculoskeletal symptoms across different anatomical regions among the participants. The highest point and period prevalence of musculoskeletal symptoms among the participants were related to the wrists/hands, reported by 66 workers (69.5%) and 67 workers (70.5%), respectively.

3.2. Self-Reported Wrist Symptom and Functional Status Derived from the P-BCTQ

Table 3 demonstrates self-reported wrist symptom severity and functional status of the meat cutters derived from the P-BCTQ. As shown in Table 3, the majority of participants fell within the mild and moderate severity levels concerning disease severity. However, regarding functional status, most participants were asymptomatic.

Table 2. Point and period prevalence of musculoskeletal symptoms in different body regions of the participants (n = 95).

Body region	Point prevalence	Period prevalence
	No. (%)	No. (%)
Neck	34 (35.8)	36 (37.9)
Shoulders	46 (48.4)	46 (48.4)
Elbows	16 (16.8)	18 (18.9)
Wrists/ hands	66 (69.5)	67 (70.5)
Upper Back	31 (32.6)	32 (33.7)
Lower Back	54 (56.8)	54 (56.8)
Thighs	8 (8.4)	8 (8.4)
Knees	56 (58.9)	56 (58.9)
Ankles/feet	60 (63.2)	61 (64.2)

Table 3. Self-reported wrist symptom and functional status of the meat cutters (n = 95).

BCTQ* Subscale	No. (%)
Severity level	19 (20)
• Asymptotic	40 (42.1)
• Mild	26 (27.4)
• Moderate	10 (10.5)
• Severe	-
• Very severe	-
Functional status level	65 (68.4)
• Asymptotic	28 (29.5)
• Mild	1 (1.1)
• Moderate	1 (1.1)
• Severe	-
• Very severe	-

**Boston Carpal Tunnel Syndrome Questionnaire.*

3.3. Assessment of Hand Activity Level by ACGIH-HAL Technique

As described in the methods section, participants' hand activity was assessed using the ACGIH-HAL technique. The final result, the "NPF / (10-HAL)" ratio, was then calculated. The mean \pm SD of the subjects' ratios was 0.61 ± 0.29 .

Finally, this ratio was evaluated based on the action levels of "< AL (0.56)", "AL to TLV (0.78)", and "> TLV". Table 4 shows the frequency of subjects in

Table 4. Frequency of the subjects in the different action levels of the ACGIH-HAL (n = 95).

ACGIH-HAL* action level	No. (%)
1. (<AL [†] (0.56))	46 (48.4)
2. (AL to TLV (0.78))	28 (29.5)
3. (>TLV)	21 (22.1)

* *American Conference of Governmental Industrial Hygienists Threshold Limit Value.*

[†] *Action Level.*

the different action levels. As indicated, most subjects were in Action Level (AL) 1, followed by AL 2.

3.4. Assessment of the Maximum Hand Grip Strength

Mean \pm SD of the "maximum hand grip strength" of the subjects derived from the Jamar hand dynamometer was 423.16 ± 83.51 N.

3.5. Correlation Between the ACGIH-HAL Ratio and Maximum Hand Grip Strength derived from the Jamar Hand Dynamometer

The multivariable linear regression analysis, adjusted for age, BMI, and daily work hours, showed an inverse association between the ACGIH-HAL ratio and maximum hand grip strength (measured with a Jamar Hand Dynamometer) in the study population ($\beta = -0.0071$, $p = 0.12$). The negative beta coefficient indicates an inverse relationship. This means that for every one-unit increase in hand grip strength (measured in newtons), the ACGIH-HAL ratio tends to decrease by 0.0071 units.

4. DISCUSSION

The present study was conducted among male meat cutters in a slaughterhouse. The results showed that the participants had an average age of approximately 37 years and an average of 15 years of work experience. Their average BMI was 25.65 kg/m^2 , and they worked an average of 13 hours daily. Most participants reported MSD symptoms in the hand/wrist region, followed by the lower limbs, lower back, and shoulders. An evaluation of hand activity using

the ACGIH-HAL showed an average hand activity level of approximately 0.6, falling within the range between the AL and the TLV. Although all participants worked in the same slaughterhouse, notable differences were observed in the ACGIH-HAL action levels: 46 workers were below the Action Limit (AL), 28 workers operated between AL and TLV, and 21 workers exceeded the TLV. The variation in HAL action levels among workers is primarily explained by differences in workstation tasks (e.g., carcass breakdown vs. trimming), required cutting force, tool handling technique, and individual anthropometric characteristics. Maximum grip strength was approximately 423 Newtons. However, participants reported applying a moderate amount of force during their work.

Butchers and meat cutters frequently experience pain and discomfort in various body parts due to WMSDs. Among meat-processing professionals, lower back pain is a frequent site of work-related musculoskeletal complaints, with prevalence rates ranging from 42% to 66.7%. Shoulder, wrist, and hand pain are also prevalent, often linked to repetitive and overhead manual tasks [2, 44]. Butchering involves repetitive motions, leading to conditions such as lateral epicondylitis. Moreover, butchers working over 9 hours daily have shown a higher prevalence of musculoskeletal issues [45]. The results obtained in this study are consistent with prior research findings. According to the results of the BCTQ questionnaire, while most of the butchers participating in this study reported experiencing mild to moderate symptoms related to wrist issues, 68 percent remained functionally asymptomatic. A number of studies have demonstrated a relationship between wrist symptoms and hand function. Wrist conditions can adversely affect hand performance. In CTS patients, symptoms such as pain, numbness, and tingling significantly impair hand function, affecting daily activities like grasping, writing, and carrying objects. The severity of symptoms correlates with functional limitations in patients' hand performance [46]. However, a previous study showed that pain interference is the strongest predictor of self-reported disability in individuals with wrist and hand pain. Pain interference is defined as the degree to which pain compromises an individual's capacity

to perform daily tasks and diminishes their overall quality of life [47]. Addressing pain interference is crucial in improving outcomes for individuals experiencing chronic pain.

The trend toward a weak, negative association between the ACGIH-HAL ratio and maximum handgrip strength ($\beta = -0.0071$, $p = 0.12$) indicates that workers with higher grip strength may be slightly less likely to exceed the ACGIH-HAL threshold; however, this association was not statistically significant, suggesting that handgrip strength alone may not be a reliable predictor of compliance with ACGIH-HAL guidelines.

The ACGIH-HAL TLV is designed to assess the risk of upper extremity MSDs by evaluating hand activity and force during occupational tasks. Studies have shown that the HAL TLV can be a useful tool for identifying jobs with higher risks of disorders such as CTS. For instance, according to a study, the HAL was an independent predictor of CTS, with higher HAL scores associated with increased risk [48]. While hand grip strength reflects an individual's maximum voluntary contraction and overall hand function, it does not directly measure the repetitive hand activities and force exertions that contribute to musculoskeletal strain in occupational settings. Physiologically, fatigue can reduce the capacity to sustain force over time without necessarily affecting maximal grip, measured at a single point. This means that individuals with high maximal strength may still experience strain when performing repetitive tasks [49]. Therefore, relying solely on hand grip strength to assess the risk of exceeding ACGIH-HAL thresholds may overlook critical factors related to task-specific hand activities.

To create a safer, more comfortable work environment for butchers, it's important to focus on their ergonomic needs and minimize the risk of injuries, particularly to the wrists and hands. Here are thoughtful strategies to consider:

- Designing an appropriate workstation: Workstations should be adjusted to each user's height to minimize wrist strain. This adjustment reduces excessive wrist flexion or extension, lowering biomechanical load and the risk of cumulative strain injuries.

- Ergonomic tools: Ensure that knife and hand-tool design is optimized for the individual user: handles sized to the operator's hand, non-slip coatings, angled grips to maintain neutral wrist posture, and minimal force required. Implement a systematic tool maintenance and sharpening program to preserve cutting efficiency and prevent increases in required hand force. Regular knife sharpening and timely replacement of worn-out items are essential to maintain optimal performance and minimize physical strain on workers [32, 50, 51].
- The workplace temperature must not fall below 12 degrees Celsius. Meat cutters who perform tasks in cold environments and feel cold are more likely to experience bodily discomfort [52, 35].
- Training in techniques: Offering training sessions on how to use tools correctly can empower butchers with the skills they need to work safely. Learning the right techniques can significantly lower the risk of developing MSDs.
- Regular breaks: Although ergonomic design can partially correct awkward postures, implementing proper work–rest schedules is essential to further mitigate the effects of repetitive motions and sustained exertion. Short breaks of 5–10 minutes after every 30 minutes of continuous work allow soft tissues adequate time to recover from micro-trauma and fatigue. Moreover, each work period should not exceed 1.5 hours between breaks, and tasks involving knife use should be limited to a maximum of 6 hours per day to prevent cumulative musculoskeletal strain [50, 52].
- Strengthening exercises: Providing simple exercises for the hands and wrists can be beneficial. Strengthening these muscles not only helps prevent injuries but also improves grip and overall performance.
- Assistive devices: Using handy tools or devices that lighten the load can greatly reduce strain on the wrists and hands. These could be anything from holders to specialized cutting

aids that make tasks easier. Where feasible, integrate powered aids or mechanized material handling to reduce repetitive, forceful exertions and cycle times [10].

- Ongoing support: It's essential to regularly check the ergonomic setup of the workplace and the well-being of the butchers. By assessing their needs and any potential issues, we can find effective solutions together.

4.1. Limitations

Most assessments of hand activity and symptoms in individuals were conducted using subjective methods, which are not error-free. This study was conducted among right-handed male meat cutters, so the findings might not apply to female or left-hand-dominant individuals. Data were also collected from a single slaughterhouse, which might not represent other settings or meat-processing methods. In this study, information on participants' sports or strength training activities and psychosocial factors was not collected. These factors may influence perceived exertion ratings and could therefore affect the estimation of force within the ACGIH-HAL assessment. Future studies should include such variables to better account for individual differences in physical capacity and subjective effort perception. In addition, the study's design limits causal inferences about the relationship between risk factors and outcomes.

4.2. Recommendations for Future Studies

Future studies should include female and left-handed participants to enhance the generalizability of findings. Longitudinal research is recommended to establish causal relationships between risk factors and MSDs. Future research should also assess workers' physical conditioning (e.g., participation in sports or strength training) and psychosocial factors, as these may influence perceived exertion ratings and ergonomic risk assessment outcomes. Incorporating objective tools, such as motion analysis and wearable sensors, can provide validation for self-reported data. Additionally, interventional studies should assess the effectiveness of ergonomic

modifications, such as adjustable workstations, improved tool designs, and task rotations, in reducing musculoskeletal risks. Finally, conducting multisite analyses across various slaughterhouses will account for variability in practices and tools, offering a more comprehensive understanding of occupational hazards in the meat-cutting industry.

5. CONCLUSION

This study highlighted the high prevalence of MSDs, particularly in the wrist and hand, among meat cutters, emphasizing the physically demanding nature of their tasks. The findings demonstrated a strong association between hand activity levels and perceived exertion, underscoring the ergonomic risks inherent in repetitive and forceful hand tasks. Although hand grip strength showed a weak correlation with risk levels, the overall results indicated the need for targeted ergonomic interventions. Implementing workplace redesigns, improving tool ergonomics, and adopting preventive strategies can help mitigate these risks. Addressing these occupational challenges is essential for enhancing employee productivity and well-being in the meat processing sector.

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General and Toxicologic Aspects of Occupational Fatalities in the Metropolitan Area of Lyon From 2000 to 2020, a Retrospective Study

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ABSTRACT

Background: *This retrospective study aimed to investigate the general characteristics and the toxicological profile of work-related deaths that occurred in the Lyon metropolitan area (2 million active workers) over a period from 2000 to 2020. Methods:* A total of 476 cases of work-related deaths were identified from the 18,000 autopsies carried out during the study period. 91% of the victims were men. The median age was 48 years, 44% of the deaths were due to natural causes of cardiac origin, 34% to mechanical accidents and 18% to suicide. 16 homicides were also recorded. **Results:** *The cause of death differed significantly between socio-professional categories: suicide was the main cause of death among managers & intellectual occupations (50%), cardiovascular death among non-manual elementary workers (53%), manual elementary workers (49%) and craftsmen, shop keepers & business owners (33%), and physical accidents among farmers (50%) and manual elementary workers (48%). The main cause of death varied by sector: physical accidents in construction (61%), cardiovascular events in transportation and storage (67%) and manufacturing (51%). 27% (n = 130) tested positive for at least one psychoactive substance, including 75 for alcohol, 43 for sedative anxiolytics and 33 for cannabis. Conclusion:* *These results may help occupational health professionals to design policies and campaigns to prevent deaths among the workers concerned. Specific studies to assess the proportion of fatal accidents attributable to the use of alcohol, cannabis or benzodiazepines could contribute to the broader goal of reducing work-related deaths.*

1. INTRODUCTION

Over the past two decades, fatal workplace accidents have accounted for between 300,000 and 400,000 deaths a year worldwide [1-3]. Eurostat reported a decline in the European Union, the incidence being 1.74/100,000 workers in 2019, compared with 2.31 in 2010 [2].

In France, the incidence rate of accidents at work has remained stable over the last ten years, fluctuating between 2.36 and 3.53 per 100,000 workers. In 2019, the French national health services recorded around 46 million working days lost due to occupational accidents [3]. Of the 700,000 occupational accidents that led to medical leave, 733 were fatal, a figure to which we can add 283 people who died

on their way to or from work [4]. These figures are relatively high in comparison with similar western economies, but may be due to the definition of occupational accidents used by the French health system, which includes any accident that occurs at the time and place of work, whatever the cause, including suicides and cardiovascular deaths [5].

Psychoactive substances such as alcohol and cannabis are known to have a negative influence on the incidence and severity of occupational accidents [6-10]. A study of 280 cases of fatal work accidents in Iowa from 2005 to 2008 reported 61 cases of positive toxicological tests (22%) [11]. Another study carried out from 2001 to 2006 in the Australian state of Victoria showed 20% of positive toxicological tests out of 217 cases of occupational deaths. In this study, the coroner's report attributed at least part of the cause of the accident to alcohol in 15% of positive cases and to cannabis in 50% of positive cases [12].

The French population is a heavy consumer of psychoactive substances, 24% of the population exceeding the recommended maximum weekly consumption of alcohol, both in the general and the working population [13]. Weekly cannabis use among workers is estimated at 8% for men and 4% for women [14]. The French population is one of the largest users of anxiolytics, with 5% of women and 3% of men misusing this type of medication [6]. Despite these facts, there is still a lack of scientific knowledge on the impact of the use of these substances on occupational fatalities. This study aimed to describe the characteristics of work-related deaths in the Lyon metropolitan area. The secondary endpoint was the analysis of the prevalence of psychoactive substances by cause of death and occupation.

2. MATERIAL AND METHODS

2.1. Study Design

A descriptive retrospective study was carried out on occupational deaths in the Lyon metropolitan area (2 million active workers) from the autopsy reports of the University Institute of Legal Medicine, where the public prosecutor systematically orders all the autopsies for occupational deaths.

The inclusion criterion was to have died as a direct or indirect result of an accident according to the French definition of an accident at work (any accident occurring at the place and/or time of work, including on the way between home and work, whatever the cause of death). Cases for which the information available was imprecise as to whether the accident occurred at work or during working hours were excluded.

The collected data included the victims' personal characteristics: age, sex, BMI, pre-existing medical conditions, socio-professional categories, and industrial activity. Characteristics of the event were also recorded: date of death, cause of death (cardiovascular, suicide, physical accident, homicide), and toxicological results of biological samples: alcohol (presence and concentration in g/L), cannabis (presence and concentration of THC and THC-TCOOH to distinguish between acute intoxication and previous intoxication), presence of other toxins, and medication. Missing data in autopsy files did not lead to case exclusion; they were included in the analysis as missing values and reported in the tables.

Toxicological analyses are performed systematically using immunochromatographic assays for urine samples. Blood toxicology screening was performed using ultra-high performance liquid chromatography (UHPLC) coupled to tandem mass spectrometry (MS/MS), gas chromatography (GC) coupled to mass spectrometry (MS) with an acetylation step, and liquid chromatography with diode array detector coupled to mass detection. Ethanol was analysed by headspace gas chromatography (HS-GC).

Statistical analyses were performed using either chi-squared or Fisher's exact tests for qualitative data and the Kruskal-Wallis test for quantitative data. A five percent threshold was chosen to consider tests significant.

The software used for all analyses was SAS, version 9.4. Multivariable regressions were performed to study the association between alcohol consumption, recent cannabis use, or anxiolytics, taking missing data into account to avoid bias. To compare characteristics and analyse temporal trends according to cause of death, we applied Hochberg-adjusted p-values to account for multiple testing.

The study was conducted in accordance with French research legislation. Given the impossibility of informing the patients of the use of their data, an authorization request was submitted to the National Commission on Information Technology and Civil Liberties (CNIL) and received a favourable decision, DR-2021-360, issued on 29.12.2021. As the data was collected on behalf of the Public Prosecutor's Office, the Attorney General also issued an authorisation.

3. RESULTS

During the 21 years studied, approximately 18,000 autopsies were performed and examined at the University Institute of Forensic Medicine in Lyon, including 2.7% (n=476) fatal occupational accidents, detailed in Table 1. The cause of death was cardiovascular in 44%, accidental in 34%, suicide in 18% and homicide in 3%. In three cases, the cause of death could not be determined from the autopsy report, because both a cardiovascular event and a physical accident were involved, and it was impossible to decide on which caused the other. In 2 cases, the cause of death was undefined.

There were no significant trends over time in the causes of death (Figure 1), except for homicide with a decrease from the 2000-2002 period to the 2018-2020 period ($p=0.04$).

Most of the victims were men (91.4%), age at death ranged from 17 to 85 years. The median age was 48 years (Table 2). Women were more likely to die from cardiovascular causes, suicide and homicide, men from physical accidents ($p<0.0001$). Most cardiovascular deaths were due to cardiac ischaemia (48%), followed by dilated and hypertrophic cardiomyopathies.

Hanging was the first method of suicide (63%), followed by the use of firearms (21%). Of the 159 physical accidents, the first cause of death was falls (31%), followed by mechanical accidents with machinery (20%) and being crushed by machinery (11%). Accidents involving vehicles accounted for 10% of all cases of mechanical injury. Only 8 cases of poisoning by dangerous chemicals were reported. Homicides were committed with firearms or knives. Most of them seemed to be caused by factors outside

the professional activity of the victims (13/16; personal feuds or drug trafficking), but 2 of the victims were psychiatric ward nurses killed by psychotic patients and one was a security guard for a money transport company attacked by criminals.

Suicide was more common among managers & intellectual occupations, being the cause of death in 50% of cases, compared to 8% among manual workers (Table 2). Cardiovascular death was the first cause of death in three categories: "non-manual"

Table 1. Detailed causes of death.

	N	%
Suicide, including	87	18.3
Hanging	55	11.6
Firearms	18	1.5
Defenestration/Fall	7	1.3
Voluntary intoxication	6	3.8
Other/unprecise	1	0.2
Cardiovascular death, including	209	43.9
Cardiac ischaemia	101	21.2
Dilated cardiomyopathies	23	4.8
Hypertrophic cardiomyopathies	21	4.4
Valvular cardiomyopathies	4	0.8
Vascular	17	3.6
Vasculocerebral	5	1.1
Congenital	7	1.5
Other/unprecise	31	6.5
Physical accident, including	159	33.4
Falls	49	10.3
Machine-related accident	31	6.5
Embedding/Crushing	17	3.6
Vehicle	16	3.4
Intoxication	8	1.7
Electrocution	7	1.5
Burns	5	1.1
Other/unprecise	26	5.5
Homicide, including	16	3.4
Firearms	7	1.5
knives	6	1.3
Others	3	0.6
Multi factorial / undetermined	5	1.0

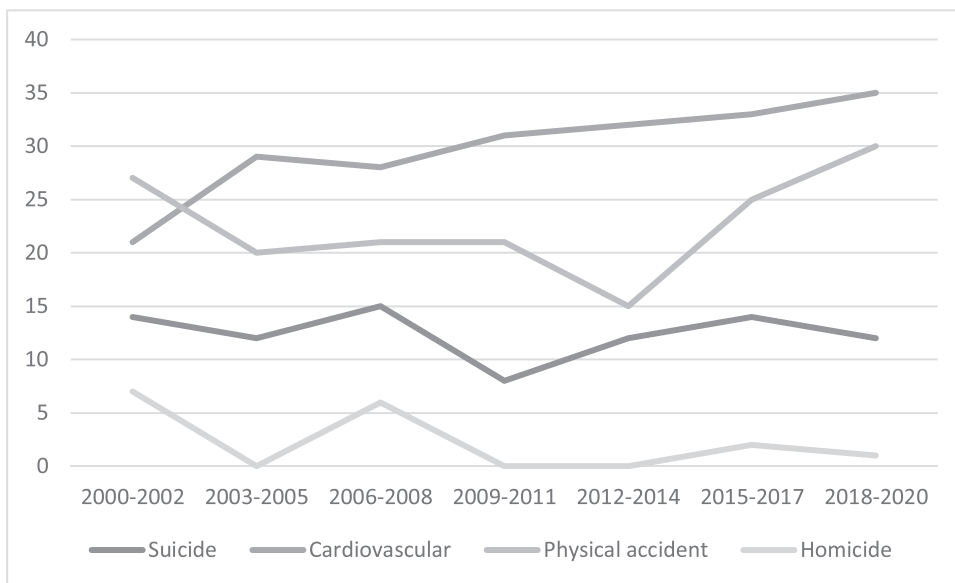


Figure 1. Trend of cause of death (3-years intervals).

elementary workers (53%), “manual” elementary workers (49%) and craftsmen, shop keepers & business owners (33%). Physical accidents accounted for 50% of deaths among farmers and 42% among “manual” elementary workers; “non-manual” elementary workers were the least affected (11%).

There were some differences between the most common industries. Physical accidents were the first cause of death in the construction sector (61%), whereas in transport and storage (67%) and manufacturing (51%) it was cardiovascular events (Table 2). Considering missing data, there is still a significant difference between cause of death (excluding suicide) and PCS ($p < 0.0001$) and NAF ($p < 0.0001$).

The exact details of the chain of events leading to the physical accidents were not always available. However, in about a third of fatal falls (15/50), safety equipment was reported to be completely absent, and in several other cases, it was reported to be inappropriate or defective. In 10 out of 50 cases involving machinery, maintenance work was reported to have been carried out in irregular conditions (e.g., without switching off the power).

Toxicological results were positive for at least one substance in 130 cases, including 75 positive blood tests for alcohol, 43 positive tests for sedative anxiolytics, and 33 cannabis intoxications (and 21 recent

cannabis use) (Table 3). Of these 16% of total cases, men were more likely to be positive for alcohol than women (17% vs 5%, $p < 0.05$). Age-group positivity ranged from 3% among victims aged under 30 years to 20% among victims aged 50 to 60 years. 33 had a blood concentration above 1g/l. The comparison between causes of death showed significant differences, with more positive results for alcohol in suicide cases (32%, $p < 0.0001$), 68% of which had a blood alcohol level of ≥ 0.5 g/L. Managers & intellectual occupations were the most affected, with 41% positivity. The sector with the highest alcohol positivity was agriculture (24%), followed by transport and storage (21%).

Cannabis positivity accounted for 7% of all cases, including 12 cases in which only THC metabolites were detected, compared with 21 cases with THC positivity.

Users tended to be younger ($p < 0.0001$) and primarily men: 9 cases of physical accidents, 5 of homicides, 5 of suicides, and 2 of cardiovascular deaths were under the influence of THC at the time of death.

Manual workers were the most likely to be positive for cannabis. Among the three main sectors of activity, construction had the highest positivity rate (14%), followed by manufacturing (8%) and transport and storage (7%).

Table 2. General, professional and toxicological characteristics according to cause of death.

	All		Suicide		Cardiovascular		Physical accident		Homicide	
	N	%	N	%	N	%	N	%	N	%
Sex - p=0.04^a										
Men	435	91.4%	77	88.5	189	90.4	154	96.9	10	71.4
Women	41	9.6	10	11.5	20	9.6	5	3.1	6	28.6
Age p=0.0004^a										
≤ 30 y. o	43	9.2	9	10.6	5	2.4	28	18.1	1	4.8
31 to 40	80	17.1	17	20.0	20	9.7	35	22.6	8	38.1
41 to 50	138	29.5	28	32.9	63	30.6	42	27.1	5	23.8
51 to 60	152	32.6	26	30.6	88	42.7	31	20.0	7	33.3
> 60	54	11.6	5	5.9	30	14.6	19	12.3	0	0
<i>Missing data</i>	9		2		3		4		0	
BMI - p=0.0004^a										
< 25 kg/m ²	233	51.1	63	73.3	74	37.0	83	55.7	13	61.9
25 to 30 kg/m ²	130	28.5	17	19.8	65	32.5	41	27.5	7	33.3
> 30 kg/m ²	93	20.4	6	7.0	61	30.5	25	16.8	1	4.8
<i>Missing data</i>	20		1		9		10		0	
Socio-professional categories (PCS-ESE classification, first order) - p=0.0004^a										
1. Farmers/Operators	26	5.8	9	10.8	4	2.1	13	8.4	0	0
2. Craftsmen, shop keepers & business owners	39	8.7	13	15.7	13	6.8	10	6.5	3	15.0
3. Managers & intellectual occupations	28	6.2	14	16.9	5	2.6	7	4.5	2	10.0
4. Intermediary occupations	27	6.0	9	10.8	7	3.6	7	4.5	4	20.0
5. «Non-manual» elementary workers	66	14.7	18	21.7	35	18.2	9	5.8	4	20.0
6. «Manual» elementary workers	264	58.7	20	24.1	128	66.7	109	70.3	7	35.0
<i>Missing data</i>	26		4		17		4		1	

(Continued)

	All		Suicide		Cardiovascular		Physical accident		Homicide	
	N	%	N	%	N	%	N	%	N	%
Type of activities (NAF classification, first order) - p=0.0004^a										
A Agriculture, forestry & fishing	39	8.8	10	12.1	9	4.8	20	12.9	0	0
C Manufacturing	52	11.7	4	4.8	26	13.8	20	12.9	2	10.5
F Construction	103	23.1	6	7.2	34	18.1	62	40.0	1	5.3
G Wholesale and retail trade; repair of motor vehicles	34	7.6	10	12.1	21	11.2	2	1.3	1	5.3
H Transportation and storage	88	19.8	5	6.0	58	30.9	20	12.9	5	26.3
Q Human health and social work activities	24	5.4	9	10.8	11	5.8	1	0.7	3	15.8
Others (under 5% of total)	105	23.6	39	47.0	29	15.4	30	19.3	7	36.8
<i>Missing data</i>	31		4		21		4		2	
Alcohol - p=0.0012^a										
Negative	387	83.8	59	67.8	174	86.1	134	88.2	20	95.2
Alcohol <0.5 g/l	29	6.3	9	10.3	13	6.4	7	4.6	0	0
Alcohol >=0.5 g/l	46	9.9	19	21.8	15	7.4	11	7.2	1	4.8
<i>Missing data</i>	14									
Cannabis p=0.4^a										
Negative	429	92.9	82	94.3	192	95.0	139	91.5	16	76.2
Past use	12	2.6	3	3.4	5	2.5	4	2.6	0	0
Recent use	21	4.5	2	2.3	5	2.5	9	5.9	5	23.8
<i>Missing data</i>	14									
Anxiolytic p=0.0004^a										
No	419	90.7	61	70.1	192	95.0	145	95.4	21	100
Yes	43	9.3	26	29.9	10	5.0	7	4.6	0	0
<i>Missing data</i>	14									

Comparisons exclude Homicide.

^a p-value with the Hochberg stepwise test.

Table 3. Positivity of toxicological testing (% line) and multivariable analyses.

	Alcohol ¹		Recent cannabis		Anxiolytics ²		n=43 (9.3%)	
	N	%	N	%	N	%	N	%
Sex								
Men	73	17.3	20	4.7	37	8.8		p=0.2
Women	2	4.9	1	2.4	6	13.9		ref
Age								
≤ 30 y.o	2	5.0	4	10.0		5.0		p=0.8
31 to 40	13	16.5	11	13.9		8.9		Ref
41 to 50	20	15.3	4	3.0		10.7		2.6 [0.5 - 22.7]
51 to 60	31	20.7	1	0.7		8.7		2.9 [0.6 - 23.1]
> 60	7	13.2	0	0		9.4		2.8 [0.6 - 23]
<i>Missing data</i>	2	22.2	1	11.1		22.2		3.1 [0.5 - 29.4]
BMI								5.8 [0.4 - 79.3]
< 25 kg/m ²	40	17.9	11	4.9		12.0		p=0.9
25 to 30 kg/m ²	49	15.0	8	6.3		6.3		Ref
> 30 kg/m ²	15	16.5	1	1.1		7.7		0.8 [0.3 - 2]
<i>Missing data</i>	1	5.0	1	5.0		5.0		1.3 [0.4 - 3.6]
Cause of death								1 [0 - 5.8]
Suicide	28	32.2	2	2.3		29.9		p=0.0002
Cardiovascular	28	13.9	5	2.5		4.9		Ref
Physical accident	18	11.8	9	5.9		4.6		0.1 [0 - 0.4]
Homicide	1	4.8	5	23.8		0		0.1 [0 - 0.4]
Socio-professional categories (PCS-ESE classification, first order)								-
1. Farmers/Operators	5	19.2	0	0		15.4		p=0.2
2. Craftsmen, shop keepers & business owners	39	25.6	1	2.6		15.4		ref
								1.2 [0 - 17]

(Continued)

	Alcohol ¹		n=75 (16.2%)		Recent cannabis		n=21 (4.5%)		Anxiolytics ²		n=43 (9.3%)	
	N	%	OR	[95% CI]	N	%	OR	[95% CI]	N	%	OR	[95% CI]
3. Managers & intellectual occupations	11	40.7	16.2	[2.2 - 122.1]	1	3.7	1.2	[0 - 49.9]	8	29.6	1.7	[0.1 - 23]
4. Intermediary occupations	3	11.1	3.3	[0.3 - 29]	1	3.7	0.4	[0 - 15.9]	3	11.1	0.6	[0 - 9.4]
5. « Non-manual » elementary workers	7	10.8	2.9	[0.4 - 20.5]	2	3.1	0.4	[0 - 12.5]	3	4.6	0.3	[0 - 3.9]
6. « Manual » elementary workers	35	13.9	4.6	[0.8 - 26.7]	16	6.3	2.6	[0.3 - 59.6]	16	6.3	1	[0 - 10.7]
<i>Missing data</i>	4	15.4	4.6	[0.4 - 46.8]	0	0	-		3	11.5	3.1	[0.1 - 64.7]
Type of activities (NAF classification, first order)												
A Agriculture, forestry and fishing	9	23.7	ref		0	0	-		5	13.2	Ref	
C Manufacturing	4	7.8	0.1	[0 - 0.6]	3	5.9	Ref		3	5.9	0.7	[0.1 - 15.8]
F Construction	10	10.1	0.1	[0 - 0.6]	10	10.1	2.4	[0.5 - 17.1]	5	5.0	0.6	[0.1 - 14.2]
G Wholesale and retail trade; repair of motor vehicles and motorcycles	6	17.6	0.2	[0 - 1]	1	2.9	3	[0.1 - 60.8]	5	14.7	0.8	[0.1 - 19.3]
H Transportation and storage	18	21.4	0.3	[0.1 - 1.5]	3	3.6	1	[0.1 - 8.4]	4	4.8	0.6	[0.1 - 12.7]
Q Human health and social work activities	4	16.7	0.2	[0 - 1.3]	1	4.2	1.7	[0 - 50.2]	4	16.7	1	[0.1 - 26.3]
Others (under 5% of total)	19	18.6	0.2	[0 - 0.9]	3	2.9	0.8	[0.1 - 8.1]	16	15.7	1.3	[0.2 - 29.7]
<i>Missing data</i>	5	16.7	0.2	[0 - 1.5]	0	0	-		1	3.3	0.1	[0 - 5.4]

¹Adjusted to anxiolytic consumption.

²Adjusted to alcohol consumption.

Several categories of psychoactive drugs were found in 9% of positive cases (43 cases). Most of these were benzodiazepines, but hypnotics, sedative neuroleptics and anti-5HT were also identified. The prevalence did not differ significantly between men and women, and positivity was pretty stable with age (between 11% and 6%). Anxiolytic positivity was most frequent in suicides (30%, $p=0.0002$). Positivity was also more common in managerial/intellectual occupations (30%), and least common among 'non-manual' elementary workers (5%).

Only two victims were positive for benzoylecgonine (a cocaine metabolite), two were positive for opioids (excluding those who received opioid medication after the accident). Amphetamines were tested but no positive results were found.

It is interesting to note that in 12 suicide cases, screening was positive for both alcohol and anxiolytics. Only one case was positive for cannabis and alcohol and 7 for cannabis and analgesics.

4. DISCUSSION

With 476 cases studied, covering a population of more than 2 million workers over 21 years, our study is one of the most extensive autopsy-based studies to date.

The socio-professional distribution of the population was very different from that of the source population, with an overrepresentation of "manual" elementary workers (59% vs. 19%) and farmers (6% vs. 0.7%), a constant in the international literature [15-19]. In comparison, Managers & intellectual occupations, plus Intermediary occupations, accounted for only a quarter of their population weight (12% vs. 48%).

The most affected industries vary from country to country, but construction, mining, manufacturing, transport and logistics, and agriculture tend to have the highest rates of occupational fatalities. Unsurprisingly, 'manual' elementary workers are more likely to die at work than 'non-manual' elementary workers. The main risks are those associated with physical accidents, such as falls, objects falling on workers, accidents involving vehicles, whether as drivers or pedestrians [15-17, 20, 21].

Construction was the first sector affected, as shown in several studies [17, 21, 22]. Transport and storage accounted for 20% of occupational fatalities

in our study, which is higher than in most studies, but this may be explained by the sector's importance in the study area, a hub for commercial and industrial shipping in France. The high rate of fatal accidents in the manufacturing sector is also well known [21]. It's 16% and third place in our study is in line with what might be expected.

The decision not to exclude cardiovascular diseases, whose direct link with occupational factors is often debated, is in line with the French definition of workplace accidents. Indeed, both physical and organisational, are known risk factors for cardiovascular diseases [such as the effects of heavy physical work, exposure to heat or cold, night shifts, sedentary lifestyles or simply stress on hypertension, diabetes, etc.] [23, 24]. With 44% of all deaths occurring in the workplace, cardiovascular health is becoming a major issue for public health campaigns in the workplace, especially as they accounted for only 12.4% of premature deaths (i.e. < 65 years) in the general population in 2017 [25].

Excluding cardiovascular deaths, physical accidents accounted for 61% of cases, suicides for 33% and homicides for 6%, which are fewer accidents and more suicides than found by McGwin in 2000 or Cohen in 2002 (72% and 91% of physical accidents, respectively) [16,18]. Among the causes of accidents, falls were the most common, as shown in both recent and earlier studies [26]. Of the 10% of cases associated with vehicles, half involved farm tractors, a common source of occupational accidents for agricultural workers [27, 28]. As our study was ill-equipped to detect occupational road accidents due to the lack of data on the occupational nature of these accidents in autopsy reports (and the fact that the Public Prosecutor does not systematically orders autopsies for traffic accidents), we found fewer road deaths than in other studies where they represented around 30% of accidents [20, 31].

With 33% of cases after excluding cardiovascular deaths, the proportion of suicides was higher than international data would suggest: 5% and 3% respectively in the McGwin and Cohen studies [16,18]. This could mainly be explained by differences in the definition of occupational accidents, as suicides are often excluded in Anglo-Saxon systems, to which we can add the generally higher suicide rate in France, with an incidence estimated at

25/100,000 workers in 2010 [30]. In a Korean study in 2020, high socio-professional categories were most at risk of committing suicide at work. The results are consistent and highlight the need for more research on the psychosocial risks and psychological factors of suicide among managers & intellectual occupations. Among the various sectors of activity, agriculture was particularly affected, with 25% of deaths by suicide, in line with previous international studies [31–33].

Positivity for at least one psychoactive substance was higher in our study than in previous papers of similar design. We found 144 positive cases, 30%, whereas studies of occupational fatalities based on autopsy reports by Mc Neilly, Ramirez and Mc Gwin found a prevalence of 22%, 22% and 21% respectively. This higher rate may be explained by the inclusion of benzodiazepines, which were not investigated in these previous studies [11, 12, 16].

Regarding alcohol, 16% of all cases were positive, a rate very similar to the 19% described in the American study by Ramirez & al in 2013. The gender-specific incidence, twice as high in men as in women, was expected and is in line with the prevalence of alcohol use disorders in the general French population [34]. The strong presence of alcohol in suicide cases (28/87, 32%) can be explained by the well-established knowledge of the relationship between the substance and suicidal behaviour, due to the disinhibition effect of acute intoxication. On a more somatic level, alcohol is also a well-known cardiovascular risk factor, both for the development of chronic diseases and for the decompensation of existing ones, and was positive in 14% of the cardiovascular deaths in our results. There were 12% of positive cases among victims of physical accidents. Coroners do not judge the causal relationship between alcohol positivity and the fatal event in autopsy reports. However, the known psychoactive effects of alcohol, together with the results of the meta-analysis by Alpert & al in 2022, which estimated that 8% of non-traffic work and machinery accidents were due to excessive alcohol consumption, make it difficult not to think that a proportion of the accidents in our study would not have happened without alcohol consumption. Craftsmen, shopkeepers & business owners were the most likely to be both positive for alcohol and to have died by suicide, and this relationship was

further explored. Two industries were found to have significantly higher rates of alcohol positivity ($p < 0.0001$). The first was accommodation and food services, where serving alcohol is often part of the job and is readily available during working hours. The second was finance and insurance, where psychological stress is particularly high.

While we expected a high positivity rate for cannabinoids, the incidence of 7% for men is actually lower than the average weekly consumption rate in the French population, 8% for active men in 2019 [6]. However, while in the general population “non-manual” workers have the highest rate of use, in our study, “manual” elementary workers were the most likely to be positive. This could be explained by their large proportion among our cases, by possible differences in the availability of cannabis, as construction sites are excluded from the French ban on smoking at work, making it easier to light up a joint during a shift [6], and, of course, by the fact that cannabis is a known risk factor for fatal accidents.

Results on benzodiazepines were also expected, as they were present in the toxicological results of 30% of suicides, as these drugs are prescribed for suicide-prone conditions such as depression and anxiety disorders. Of note, we cannot determine whether the presence of anxiolytics is due to misuse or treatment. Access to medical records would be helpful to assess the psychiatric and therapeutic follow-up of victims. Even if the association with the onset of accidents is not very clear [35], prolonged treatment duration and high doses could increase the risk of workplace accidents [36].

By comparing the annual cases with data from the French health system, we estimated that our study covered about 80% of all cases of occupational deaths for the area and time period studied. Limitations in the accuracy and completeness of autopsy reports are common. It is known that there are variations in the reporting of occupational deaths [37, 38]. Still, thanks to digitisation and the University Institute of Forensic Medicine in Lyon’s genuine interest in occupational health, the files of recent years contained less data. These results show that fatal workplace accidents remain a cause for concern and highlight the need to improve workers’ health monitoring. This can focus on the specific characteristics of each category: better screening for cardiovascular

disease in patients over 50 and those with obesity, and increased prevention of psychosocial risks among managers and intellectual professions. Additionally, better communication about the dangers of toxic substances would be helpful for all professionals, but especially for younger men regarding cannabis and for older men regarding alcohol.

5. CONCLUSION

Our findings provide new information to help occupational health actors design more specific and effective regulations and prevention campaigns. These should be aimed at managers with regard to suicide at work, and at “manual” elementary workers with regard to cardiovascular prevention, for whom the link between public and occupational health should be deepened. Our results are consistent with previous literature, confirming existing knowledge and opening the way for more extensive further studies to demonstrate causality. Data on the impact of psychoactive substance use in the workplace will be essential in the context of planned regulatory changes regarding the medical and recreational use of cannabis in France. Further research is needed, including studies to establish the causal link between substance use and work-related deaths.

DECLARATION OF INTEREST: The authors have nothing to declare.

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Work-Related Accidents and Their Predictors Among Delivery Drivers in Egypt: A Cross-Sectional Study

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KEYWORDS: Delivery; Driver; Work-Related Accident; Injuries; Predictors

ABSTRACT

Background: *The rapid growth of the delivery sector, driven by online shopping and the COVID-19 pandemic, has raised safety concerns for delivery drivers, particularly work-related accidents and injuries. This study aimed to estimate the frequency of work-related accidents and injuries among delivery drivers and to identify potential predictors associated with these accidents in Egypt.* **Methods:** *A descriptive cross-sectional study with an analytical component was conducted among 172 delivery drivers recruited from gathering areas in Mansoura, Egypt. Participants were interviewed using a semi-structured questionnaire.* **Results:** *Among participants, 57.0% reported at least one work-related road accident during their career, with most accidents (91.8%) resulting from collisions with other vehicles. All injured drivers sustained at least one post-accident injury, most commonly contusions (93.9%). The lower limbs were the most frequently affected body parts (80.6%). After adjusting for confounders, the multivariable logistic regression analysis revealed that the following workplace exposure factors were significantly independent predictors of work-related accidents: being a university student or graduate (AOR = 2.86, 95% CI: 1.35-6.08), having more than five years of driving experience (AOR = 4.62, 95% CI: 2.15-9.94), and using mobile phones while driving (AOR = 3.22, 95% CI: 1.56-6.64).* **Conclusions:** *This study showed a high frequency of work-related road accidents among delivery drivers in Egypt. Key predictors included higher education, extensive driving experience, and mobile phone use while driving. These findings underscore the need for targeted interventions, including safety training, regulation of mobile phone use, and awareness campaigns, to mitigate accident risk among delivery drivers.*

1. INTRODUCTION

The delivery business has grown rapidly over the past few years, aided by the rise in online shopping, especially for food and beverages [1]. Additionally, with the onset of the coronavirus disease 2019 (COVID-19) pandemic, delivery drivers suddenly found themselves in the spotlight. As more and more people adhere to the stay-at-home order, delivery drivers continue to fulfill customer orders [2, 3].

Home delivery is not limited to online shopping. Deliveries were conducted long before the

Internet appeared, including mail, bulk goods, furniture, electrical appliances, televisions, and washing machines delivered to homes. Today, even traditional retailers have become part of the online shopping market by developing their online sales channels [4].

The Egyptian e-commerce and delivery sector has grown significantly over the last decade, covering retail, groceries, meals, and pharmaceuticals [5, 6, 7]. This expansion has increased reliance on mostly informal delivery drivers, with about 6 million young men and women working in the field,

according to the Minister of Social Solidarity [8]. In response, the government launched the “Your Road is Safe” program to provide social and health insurance, financial assistance, and promote safer riding [8]. However, without clear regulations, delivery drivers face economic risks from workplace injuries and lack social benefits like paid leave [9]. The new Labor Law No. 14 of 2025 formally recognizes and regulates platform-based work, offering protections such as minimum wage, legal contracts, and access to specialized labor courts, though enforcement remains a challenge [10].

Based on fieldwork observations, delivery drivers fall into two main employment types: salaried employees and independent/self-employed drivers. Salaried employees work for online marketplaces or delivery companies like Amazon and Talabat, or for individual shops, restaurants, or pharmacies. Their tasks are similar but vary in workflow; those employed by individual establishments typically have fixed shifts aligned with business hours and deliver items specific to their workplace, such as meals or groceries. Orders are often received via direct phone calls, with the business dispatching the driver. In contrast, drivers for delivery companies usually operate through app-based platforms with more flexible schedules. They may deliver multiple shipments from a central warehouse within a designated area or make individual, on-demand pickups from various stores or restaurants. Independent drivers serve individuals and small businesses or act as subcontractors, earning payment per job.

In Egypt, two- and three-wheelers are increasingly popular for commercial transport because they are fuel-efficient, affordable, suitable for poor road conditions, and easily maneuverable through traffic, making delivery faster, more convenient, and cost-effective [11, 12]. However, accidents involving these vehicles are more common in developing countries like Egypt, due to factors such as weak traffic laws and enforcement, poor road infrastructure, lack of regular maintenance, crowded traffic, and business use of motorcycles. The issue is worsened by dangerous driving, high speeds, inadequate licensing, substance abuse, and riders neglecting protective helmets [11, 13].

Research has consistently shown that delivery drivers rank among the highest in occupational injury risk. Aside from road accidents, delivery drivers are susceptible to various other occupational injuries. While nonfatal injuries were typically caused by continuous workplace exposures (e.g., repetitive strain, contact with objects/equipment), fatalities were almost exclusively caused by transportation incidents [14].

Various studies worldwide suggest that multiple factors contribute to road traffic accidents (RTAs) and fatalities among two- and three-wheeler riders. These include rider-related, environmental, and vehicle-related factors [15-18]. Additionally, Zheng et al. [19] examined whether demographic and work-related traits of delivery riders influence their perceived time pressure and if this, in turn, affects riding behaviors. Fatigue levels of delivery riders were also presumed to be impacted by time pressure. Moreover, unsafe behaviors, fatigue, and work-related and demographic characteristics were suggested to influence riders' crash involvement.

The most common work-related risk factor for accidents and injuries among delivery drivers was time pressure due to constant roadwork and the demand to deliver items quickly. While the primary benefit of delivery work is earning income proportional to effort, this also endangers safety, as drivers may prioritize speed over safety [20]. These conditions often lead to risky riding behaviors and route violations, increasing the risk of fatal accidents [21, 22]. To meet customer expectations for rapid deliveries, earn more by completing more orders, and avoid company fines for delays, drivers often speed, use mobile phones while driving, run red lights, skip breaks, and work non-stop [23].

Besides RTAs, package delivery poses many hazards that can cause slip-and-fall accidents. Aside from road irregularities, delivery drivers encounter a never-ending list of premise hazards, including stairs, stairwells, fences, pets, and garbage cans [24].

To our knowledge, few studies have examined work-related hazards impacting the health and safety of delivery drivers, especially within the Egyptian context. This gap in the literature motivated this study. Its aim is to estimate the frequency

of work-related accidents and injuries among delivery drivers and identify potential predictors. Specifically, the study asks: What is the frequency of such incidents among Egyptian delivery drivers, and what factors are associated with their occurrence?

2. METHODS

2.1. Study Design and Study Period

This descriptive cross-sectional study was conducted from July 2023 to March 2024 among delivery drivers in Mansoura City, Dakahlia Governorate, Egypt. The study followed the STROBE guidelines for reporting observational studies [25].

2.2. Study Population

Data were collected from delivery drivers at gathering and waiting areas outside restaurants, pharmacies, and delivery company offices in Mansoura City, the capital of Dakahlia Governorate. This city serves as a hub for medical, commercial, and administrative services for residents and surrounding suburban regions and villages. Inclusion criteria were delivery drivers aged 18 to less than 60 years, with at least six months of experience, either working independently or under temporary or permanent contracts. Exclusion criteria included individuals with chronic diseases such as epilepsy, uncontrolled diabetes, or severe visual impairment to reduce confounding from health-related limitations that could independently affect accident risk and influence associations with work-related exposures.

2.3. Sampling Strategy

Due to practical constraints, convenience sampling was used, as reaching all delivery drivers for simple random sampling was unfeasible. Supervisors and officers explained the study and helped identify willing drivers. Volunteer supervisors arranged small group interviews of 8–10 drivers. Recruitment was based on availability and willingness, considering different work systems, economic activities, and shifts. A total of 172 drivers meeting the criteria provided informed written consent.

2.4. Study Tools

After reviewing the literature, a semi-structured, interview-based questionnaire was developed to meet the study requirements. Before the main survey, it was translated into Arabic and validated for content and clarity to ensure suitability for the study population. Content validity was assessed by a panel of three experts—two in occupational health and one in public health research—who evaluated relevance, comprehensiveness, and clarity. Feedback resulted in minor wording adjustments to ensure the items were easily understood by delivery drivers with diverse educational backgrounds.

An external pilot study with 20 delivery drivers aimed to test reliability, assess completion time, and identify data collection obstacles. It found that data collection took approximately 15–20 minutes per participant. However, limited driver availability during work hours—about 5 minutes of free time—necessitated involving delivery supervisors to facilitate interviews during rest breaks. The study also highlighted challenges interviewing drivers using cars and tricycles due to their schedules and smaller populations; consequently, the final study focused mainly on motorcycle and bicycle riders. The questionnaire was adjusted for clarity and to streamline data collection before the main study, with pilot data excluded from final analysis.

The questionnaire had three sections with 44 items, mainly closed-ended questions, plus a few open-ended ones for details like durations, past jobs, and causes of accidents. The first section gathered socio-demographic data, including age, sex, residence, education, marital status, family income (monthly per capita from all sources) [26], and smoking history. The second covered occupational history, such as work duration, workdays/week, hours/day, shift times, types of products delivered, vehicle used, other part-time/past jobs (if any), and perceived time pressure and effort-reward imbalance. The third assessed driving experience, safety measures adoption, risky behaviors, daily riding hours [12], and work-related accidents and injuries, including causes, injury type, and affected body regions. Most responses were binary (yes/no) or

categorical (multiple-choice), with few numerical or open-text answers. The complete questionnaire is in Supplementary Material. All interviews were conducted by the first author, who had prior practical experience in data collection during her academic training, to ensure consistency.

2.5. Statistical Analysis

Data were analyzed using IBM SPSS for Windows, Version 25.0 (IBM Corp., 2017). Categorical data were tested for significance with Chi-square, Fisher's exact test (FET), or Monte Carlo Exact Probability (MEP) as appropriate. Normality of numerical data was assessed with the Kolmogorov-Smirnov test and visualized with histograms and Q-Q plots. Data were presented as mean \pm SD for parametric or median (min-max) for non-parametric. A binary logistic regression with forward stepwise (Wald) method identified independent predictors of work-related accidents. Variables significant in bivariate analysis were included to develop a parsimonious model of key predictors. The stepwise approach adjusts for confounding by evaluating each variable's contribution while controlling for others, resulting in a model adjusted for covariates affecting the exposure-outcome relationship. Adjusted odds ratios (AOR) and 95% confidence intervals were calculated. P-values \leq 0.05 were considered statistically significant.

3. RESULTS

A total of 172 delivery drivers from Mansoura City consented to participate in the study.

3.1. Participants' Demographics

Regarding the socio-demographic characteristics of the delivery drivers, all were male, with a mean age of 26.9 ± 7.6 years. About 50% of them were secondary school graduates, either general or technical, and 40.7% were university students or graduates. A large proportion (66.9%) were from urban areas; 65.1% were single, and about half (54.7%) had a family income per month that just met routine expenses. About half (52.9%) of the delivery

drivers were either current (38.4%) or former (14.5%) cigarette smokers, while the remaining 47.1% were non-smokers (Table 1).

3.2. Employment Arrangements of the Studied Sample

The majority (93.6%) of study participants were salaried employees on temporary contracts (renewed annually), with 58.7% employed by delivery companies or online marketplaces and 34.9% working directly for individual shops, restaurants, or pharmacies. Only 6.4% were self-employed or worked independently.

3.3. Work-Related Accident Frequency and Distribution

Concerning the frequency and distribution of work-related accidents among the delivery drivers, more than half (57.0%, $n=98$) reported experiencing at least one work-related road accident during their time working as delivery drivers. Among those, nearly half (43.9%) had more than 3 accidents during their careers. With a mean number of reported accidents by each driver of 2.7 ± 1.93 accidents. They all reported having at least one post-accident injury. The majority (93.9%) of injuries were contusions, primarily lower limb(s) injuries (80.6%), with 52% requiring hospital assistance. These accidents were more frequently caused by collisions with other vehicles (91.84%) (Table 2).

3.4. Work-Related Accidents and Participants' Demographics

Drivers who were university students or graduates had a statistically significantly higher frequency of reported accidents (68.6%) than those with lower educational levels. Similarly, current smokers had a statistically significantly higher frequency of reported accidents (71.2%) compared to ex-smokers and non-smokers. However, no statistically significant associations were found between work-related accidents and other socio-demographic variables such as age, residence, marital status, or monthly family income (Table 3).

Table 1. Socio-demographic characteristics of the delivery drivers (n = 172).

Variable	Mean ± SD
Age, years	26.9 ± 7.6
Gender	N (%)
Male	172 (100.0%)
<i>Education level</i>	
Basic education and less ^a	16 (9.3%)
Secondary school (general/technical)	86 (50.0%)
University student or graduate	70 (40.7%)
<i>Residence</i>	
Rural	57 (33.1%)
Urban	115 (66.9%)
<i>Marital status</i>	
Single	112 (65.1%)
Married	52 (30.2%)
Divorced	8 (4.7%)
<i>Family income per month</i>	
In debt	26 (15.1%)
Just meets routine expenses	94 (54.7%)
Meets routine expenses and emergencies	39 (22.7%)
Able to save/invest money	13 (7.6%)
<i>Smoking status</i>	
Non-smoker	81 (47.1%)
Ex-smoker	25 (14.5%)
Current smoker	66 (38.4%)

^aThis category includes illiterate, primary, or preparatory education.

3.5. Work-Related Accidents and Occupational Characteristics

Referring to occupational characteristics, the frequency of work-related accidents was statistically significantly higher (67.2%) among delivery drivers who were on the job for 25 months or more, compared to those who worked less than 25 months (P = 0.023). Regarding the types of products delivered, the frequency of accidents was highest among delivery drivers who delivered medications and cosmetics (62.5%), followed by those who delivered

Table 2. Frequency and distribution of work-related accidents among the delivery drivers (n = 172).

Variable	Total (n= 172) n (%)
The overall prevalence of having at least one work-related accident during career duration	98 (57.0)
Variable Total (n= 98) n (%)	
Number of work-related accidents for each driver	
<3	55 (56.1)
≥ 3	43 (43.9)
Having at least one-time post-accident injury	98 (100.0)
Site of injury due to the accident(s) ^a	
Scalp	17 (17.3)
Eye(s)	3 (3.1)
Nose	18 (18.4)
Mouth	13 (13.3)
Trunk	15 (15.3)
Upper limb(s)	34 (34.7)
Lower Limb (s)	79 (80.6)
Type of injury due to the accident(s) ^a	
Contusion	92 (93.9)
Cut wound	17 (17.3)
Laceration	14 (14.3)
Fracture	25 (25.5)
Others (abrasion, dislocation, burn)	4 (4.1)
Cause of accident	
Collision with another vehicle	90 (91.8)
Collision with an object	2 (2.0)
Trip, slip, or fall	6 (6.1)
Required hospital assistance	51 (52.0)

^a Categories are not mutually exclusive.

food and/or groceries (61.4%), compared to those who delivered other products (38.2%). The difference was statistically significant (p = 0.048). Regarding the type of vehicle used, the frequency of accidents was higher among delivery drivers who used motorcycles (64.1%) than among those who used bicycles or other vehicles (p = 0.007). However, no statistically significant differences were observed for other occupational characteristics (Table 4).

Table 3. Work-related accidents among the delivery drivers and their socio-demographic characteristics (n = 172).

Variable	Total (172)	Work-related accidents		Test of significance P-Value
		No n=74 n (%)	Yes n=98 n (%)	
<i>Age in years</i>				
18-24	78	38(48.7)	40(51.3)	$\chi^2=0.4.94$ P=0.176
25-30	60	23(38.3)	37(61.7)	
31-40	22	6(27.3)	16(72.7)	
>40	12	7(58.3)	5(41.7)	
<i>Education level</i>				
Basic education and less	16	11(68.8)	5(31.3)	$\chi^2=8.918$ P=0.012
Secondary school	86	41(47.7)	45(52.3)	
University student or graduate	70	22(31.4)	48(68.6)	
<i>Residence</i>				
Rural	57	26(45.6)	31(54.4)	$\chi^2=0.233$ P=0.629
Urban	115	48(41.7)	67(58.3)	
<i>Marital status</i>				
Single	112	53(47.3)	59(52.7)	MEP=0.106 [#]
Married	52	20(38.5)	32(61.5)	
Divorced	8	1(12.5)	7(87.5)	
<i>Family income per month</i>				
In debt	26	9(34.6)	17(65.4)	$\chi^2=4.48$ P=0.213
Just meet routine expenses	94	39(41.5)	55(58.5)	
Meet routine expenses and emergencies	39	22(56.4)	17(43.6)	
<i>Able to save/invest money</i>	13	4(30.8)	9(69.2)	
<i>Smoking status</i>				
Non-smoker	81	46(56.8)	35(43.2)	$\chi^2=12.222$ P=0.002
Ex-smoker	25	9(36.0)	16(64.0)	
Current smoker	66	19(28.8)	47(71.2)	

χ^2 : Chi-Square test, FET: Fisher's Exact Test, MEP: Monte Carlo Exact probability, [#]95% CI [0.100-0.112], 10,000 iterations.

3.6. Work-Related Accidents and Driving Experience

Delivery drivers with more than 5 years of driving experience had a statistically significant higher frequency of work-related accidents ($P < 0.001$). Moreover, there was a statistically significant difference in the frequency of work-related accidents among delivery drivers who indicated using mobile phones while driving ($P = 0.001$) or having traffic violations before ($P = 0.011$). However, the frequency of accidents did not show any statistically significant differences in relation to other driving/riding experience or risky behaviors among delivery drivers (Table 5).

3.7. Predictors of Work-Related Accidents

To identify the predictors of work-related accidents among delivery drivers, we applied a multi-variable logistic regression model using the Wald forward selection method. In the final step of the analysis, it was found that being a university student or graduate (AOR = 2.86, 95% CI: 1.35-6.08), having more than 5 years of driving experience (AOR = 4.62, 95% CI: 2.15-9.94), and using a mobile phone while driving (AOR = 3.22, 95% CI: 1.56-6.64) were significantly associated with significant increased odds of work-related accidents. In contrast, delivering products other than food, groceries, medications, or cosmetics was significantly associated with

Table 4. Work-related accidents among the delivery drivers and their occupational characteristics (n = 172).

Variable	Total (172)	Work-related accidents		Test P-Value
		No n=74 n (%)	Yes n=98 n (%)	
<i>Work duration (months)</i>				
6-12	60	34(56.7)	26(43.3)	$\chi^2=7.561$
13-24	45	18(40.0)	27(60.0)	P=0.023
≥25	67	22(32.8)	45(67.2)	
<i>Number of working hours/ days</i>				
≤8	67	34(50.7)	33(49.3)	$\chi^2=2.67$
>8	105	40(38.1)	65(61.9)	P=0.102
<i>Number of working hours/ weeks</i>				
≤48	61	31(50.8)	30(49.2)	$\chi^2=2.34$
>48	111	43(38.7)	68(61.3)	P=0.126
<i>Average daily driving hours (n=169)</i>				
<5	7	1 (14.3)	6 (85.7)	$\chi^2=2.48$
5-10	123	52 (42.3)	71 (57.7)	P=0.288
>10	39	18 (46.2)	21 (53.8)	
<i>Time of work shift</i>				
Daytime only	41	20 (48.8)	21 (51.2)	$\chi^2=2.35$
Both daytime and nighttime	92	41 (44.6)	51 (55.4)	P=0.504
Nighttime only	13	5 (38.5)	8 (61.5)	
Rotating shifts	26	8 (30.8)	18 (69.2)	
<i>Employer category</i>				
Delivery company or online marketplace	101	46 (45.5)	55 (54.5)	$\chi^2=6.519$
Individual shops, restaurants, or pharmacies	60	20 (33.3)	40 (66.7)	P=0.038
No (self-employed)	11	8 (72.7)	3 (27.3)	
<i>Type of products delivered</i>				
Food and/ or groceries	113	44 (38.6)	70 (61.4)	$\chi^2=6.082$
Medication & cosmetics	24	9 (37.5)	15 (62.5)	P=0.048
Others	34	21 (61.8)	13 (38.2)	
<i>Type of vehicle used</i>				
Bicycle	45	24 (53.3)	21 (46.7)	$\chi^2=9.953$
Motorcycle	117	42 (35.9)	75 (64.1)	P=0.007
Others	10	8 (80.0)	2 (20.0)	
<i>Other jobs besides delivery</i>				
No	161	71 (44.1)	90 (55.9)	FET,
Yes	11	3 (27.3)	8 (72.7)	P=0.355
<i>Perceived time pressure</i>				
	159	64 (40.3)	95 (59.7)	$\chi^2=6.59$ P=0.01

χ^2 : Chi-Square test, FET: Fisher's Exact Test.

a reduced likelihood of such accidents (AOR = 0.33, 95% CI: 0.13-0.83) (Table 6).

AORs are mutually adjusted for all other variables in this final multivariable model. The variables significant in bivariate analysis ($p < 0.05$) were entered into a forward stepwise (Wald)

logistic regression: education level, smoking status, work duration, employer category, type of products delivered, type of vehicle used, perceived time pressure, driving experience, use of a mobile phone while driving, and having traffic violations before.

Table 5. Work-related accidents among the delivery drivers and their driving/riding experience and risky behaviors.

Variable	Total ^a (n = 169)	Work-related accident		Test of significance P-Value
		No (n=71) n (%)	Yes (n=98) n (%)	
<i>Driving experience (years)</i>				
≤5	93	51(54.8)	42(45.2)	$\chi^2=13.966$
>5	76	20(26.3)	56(73.7)	P<0.001*
Don't have a driver's license	66	33(50)	33(50)	$\chi^2=2.836$ P=0.092
Don't have training in driving (self-taught/friends & family)	80	38(47.5)	42(52.5)	$\chi^2=1.878$ P=0.171
Don't examine the vehicle daily before driving	27	15(55.6)	12(44.4)	$\chi^2=2.420$ P=0.120
The mirrors, horn, and backlight don't work well	45	23(51.1)	22(48.7)	$\chi^2=2.084$ P=0.149
Don't adhere to speed limits	33	12(36.4)	21(63.6)	$\chi^2=0.537$ P=0.464
Drive while tired	167	71(42.5)	96(57.5)	$\chi^2=1.466$ P=0.226
Don't comply with wearing PPE like helmets and seatbelts	91	38(41.8)	53(58.2)	$\chi^2=0.005$ P=0.942
Don't leave a safety gap with other vehicles	38	21(55.3)	17(44.7)	$\chi^2=3.534$ P=0.06
Don't respect traffic lights & road signs	27	13(48.1)	14(51.9)	$\chi^2=0.497$ P=0.481
Use a mobile phone while driving	98	31(31.6)	67(68.4)	$\chi^2=10.315$ P=0.001*
Had traffic violations before	69	21(30.4)	48(69.6)	$\chi^2=6.415$ P=0.011*

^a 3 participants making deliveries on foot excluded, χ^2 : Chi-Square test, *statistically significant.

Table 6. Predictors of work-related accidents among the delivery drivers (n = 172).

Variable	B	P-Value	AOR (95%CI)
<i>Education level</i>			
Basic education and less (r)			1
University student or graduate	1.051	0.006	2.86(1.35-6.08)
<i>Type of products delivered</i>			
Food and/ or groceries (r)			1
Other than food, groceries, medications, or cosmetics	-1.106	0.019	0.33(0.13-0.83)
<i>Driving experience in years</i>			
≤5 (r)			1
>5	1.531	<0.001	4.62(2.15-9.94)
<i>Use a mobile phone while driving (r)</i>	1.169	0.002	3.22(1.56-6.64)

r: reference group, AOR: adjusted odds ratio, β : Regression coefficient, CI: Confidence Interval.
Constant= -0.926, Overall % predicted =71%, Model χ^2 , p-value=47.786, <0.001.

4. DISCUSSION

The most vulnerable road users—pedestrians, cyclists, and motorcyclists—account for over half of all road traffic fatalities [27]. In Egypt, the Central Agency for Public Mobilization and Statistics (CAPMAS) reported 55,991 road traffic injuries (RTIs) in 2022, an 8.7% increase from 51,511 in 2021. Dakahlia Governorate had the highest number, with 12,051 cases. Delivery drivers face higher crash risks due to greater exposure, especially motorcyclists [29]. This study examines work-related accidents and their predictors among delivery drivers. About 57.0% reported at least one work-related road accident, and 43.9% experienced more than three. Studies from Italy and China show a high prevalence: Boniardi et al. [30] found that 39.0% of delivery riders were involved in at least one collision in the past year. In comparison, Wang et al. [31] reported that 76.5% experienced crashes within 1.5 years of starting the profession. Christie and Ward [32] noted that young male drivers who rely on vulnerable modes such as bicycles and motorcycles are at high risk. Nearly 80% of our sample were 30 or younger, all male, and about 94% used mainly motorcycles or bicycles. Factors contributing to accidents include heavy workloads, strict deadlines, poor road conditions, distraction, limited driving skills (e.g., on wet roads), and heavy loads [30, 31, 33]. Our study found that being a university student or graduate was independently associated with a higher odds of work-related accidents (AOR=2.86, 95% CI [1.35–6.08], $p=0.006$). This contradicts previous research suggesting educated riders have better safety awareness and lower violation rates [34, 35]. Wang et al. [36] indicated that education does not directly affect crash risk but influences it indirectly through familiarity with traffic regulations. Consistent with our findings, higher education levels correlated positively with traffic accident rates in Indian states [37], possibly because more educated drivers may be overconfident and pass other vehicles recklessly [37, 39]. Surprisingly, drivers with over five years of experience were more likely to have work-related accidents (AOR=4.62, 95%CI [2.15–9.94], $p<0.001$). While lack of experience is often cited as a risk, more experienced drivers may become

desensitized to hazards, overestimate their skills, or drive more recklessly, especially given longer exposure and fatigue [22, 35, 38, 39]. Furthermore, our study findings showed that using mobile phones while driving was an independent predictor of the likelihood of work-related accidents (AOR=3.22, 95%CI [1.56–6.64], $p=0.002$). Similarly, in a meta-analysis by Elvik [40], the risk of an accident was at least three times greater for those who used a mobile phone while driving (MPUWD) than for those who did not. MPUWD is distracting, occurs frequently, and poses a significant risk of crashes for delivery drivers [32, 33].

The study found a higher, but statistically insignificant, rate of accidents among delivery drivers working over 48 hours weekly. This trend may reflect fatigue from extended hours. Numerous studies link driver fatigue to increased accident risk, rising with longer hours, more deliveries, and greater travel distances [19, 30, 41, 42]. Drivers delivering products other than food, groceries, medication, or cosmetics were less likely to experience work-related accidents (AOR=0.33, 95%CI [0.13–0.83], $p=0.019$). The pressure to make quick deliveries often leads to risky behavior and accidents [42]. Food, groceries, and medication deliveries face strict deadlines, unlike more flexible schedules for items like electronics. Useche et al. [43] highlighted that stress and fatigue in food delivery can cause crashes. Christie and Ward [32] found that less pressured riders violate traffic less and have fewer collisions. Flexible deadlines also help riders avoid adverse weather, reducing accidents. While time pressure is a known risk factor linked to stress and risky driving [19, 20, 33], it was not an independent predictor in our multivariate analysis, possibly operating through behaviors like mobile phone use, product type, or experience. Most (94.2%) respondents were motorcycle or bicycle riders, who are more prone to crash injuries [44]. All those involved in accidents reported injuries, mostly minor but some severe—mostly affecting the lower limbs (80.6%) and requiring hospital care (52%). Boniardi et al. [30] noted similar injury patterns in Italy. The most common cause of accidents was collisions with other vehicles (91.8%). Some studies report collisions with vehicle doors [45, 46], while others cite solo injuries during non-vehicle

crashes [46, 47]. Recent research suggests targeted safety interventions, including training on safe riding, infrastructure improvements like motorcycle lanes, and enforcement of rest breaks and manageable delivery quotas [48-52]. First aid training is also recommended to help responders reduce injury severity. These findings support a comprehensive strategy involving policymakers, employers, and platform developers to enhance delivery workers' safety.

4.1 Strengths and Limitations

Our study has both strengths and limitations. To our knowledge, it is the first to explore work-related accidents and predictors among delivery drivers in Egypt, filling a significant gap in occupational health research. However, limitations include its cross-sectional design with stepwise forward logistic regression, which identifies associations but cannot establish causality, requiring future studies for confirmation. Self-reported data may introduce bias, including underreporting of risky behaviors. The small, non-probability sample limits representativeness and generalizability. All participants were male due to the local demographic, limiting the assessment of gender differences and the applicability to female drivers. Excluding drivers with chronic conditions that may affect accident risk also limits understanding of their role. Participation was limited to available, willing drivers at the time of data collection. Since the study was conducted in Mansoura City, caution is advised when generalizing findings to all Egyptian drivers or similar occupational groups elsewhere.

Several methodological aspects should also be noted. The questionnaire, though validated by experts, lacked formal reliability metrics. Data collection was performed by a single interviewer without standardized training, possibly introducing bias. The multivariate logistic regression did not include model diagnostics such as goodness-of-fit, multicollinearity, or residual analysis. Although age was a potential confounder, with 80% of participants under 30, the approach to age adjustment in the multivariate model needs clarification. These limitations affect the study's generalizability and robustness.

5. CONCLUSION

The current cross-sectional study revealed that a considerable proportion of delivery drivers reported work-related accidents. Factors significantly associated with accident occurrence included being a university student or graduate, having more than five years of driving experience, and using a mobile phone while driving. These findings underscore the importance of targeted preventive measures—such as road safety training, regulation of mobile phone use, and tailored awareness campaigns—to support and safeguard this occupational group.

SUPPLEMENTARY MATERIAL: Available online.

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INFORMED CONSENT STATEMENT: Informed consent was obtained from all subjects involved in the study.

DECLARATION OF INTEREST: The authors declare no conflict of interest.

AUTHOR CONTRIBUTION STATEMENT: M.E. identified the research gap and developed the study idea. M.E., K.D., and O.Y. prepared the study protocol, methodology, sampling strategy, and questionnaire. O.Y. conducted the literature review, participated in writing, interviewed participants, collected data, performed statistical analysis, contributed to writing the results, preparing tables, and drafting the discussion, and served as the corresponding author. O.Y. and K.D. prepared the reference list. M.E., K.D., and A.E. contributed to the interpretation of results, statistical analysis, table preparation, and writing and reviewing the discussion and conclusion.

All authors reviewed and approved the final manuscript.

DECLARATION ON USE OF AI: No chatbot was used.

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Work-Related Accidents and Their Predictors Among Delivery Drivers in Egypt: A Cross-Sectional Study

SUPPLEMENTARY MATERIAL

Personal history	
Name:	
Code number:	
1-Age:years	
2-Gender:	<input type="checkbox"/> Male <input type="checkbox"/> Female
3-Education:	<input type="checkbox"/> Basic education and less <input type="checkbox"/> Secondary school (general/ technical) <input type="checkbox"/> University student or graduate
4-Residence	<input type="checkbox"/> Rural <input type="checkbox"/> Urban
5-Marital status	<input type="checkbox"/> Single <input type="checkbox"/> Married <input type="checkbox"/> Divorced <input type="checkbox"/> Widower
6-Family income	Monthly per capita income from all sources (total monthly income/number of family members) (El-Gilany et al., 2012): <input type="checkbox"/> In debt <input type="checkbox"/> Just meet routine expenses <input type="checkbox"/> Meet routine expenses and emergencies <input type="checkbox"/> Able to save/invest money
7-Smoking history	<input type="checkbox"/> Current smoker <input type="checkbox"/> Ex-smoker <input type="checkbox"/> Non-smoker

Safety measures and risky behaviors		
26-Your driving experience years		
27-Average daily driving hours (Bolbol& Zalat, 2018)		
<input type="checkbox"/> less than 5 hours <input type="checkbox"/> from 5 to 10 hours <input type="checkbox"/> more than 10 hours		
Answer the following by yes or no	√	X
28-Do you have a driver's license?		
29-Did you have training in driving? No = (self-taught/friends & family)		
30-Do you examine the vehicle daily before driving?		
31-Do the mirrors, horn, and backlight work well?		
32-Do you adhere to speed limits?		
33-Do you drive while tired?		
34-Do you comply with wearing personal protective equipment like helmets and seatbelts?		
35-Do you leave a safety gap with other vehicles?		
36-Do you respect traffic lights & road signs?		
37-Do you use a mobile phone while driving?		
38-Have you ever had traffic violations?		
39-Have you had any work-related accidents before? If yes is the answer, 40-How many accidents?		
41-What is the site of injury due to the accident(s)? (you can choose more than one answer)		
<input type="checkbox"/> Scalp <input type="checkbox"/> Trunk <input type="checkbox"/> Eye(s) <input type="checkbox"/> Upper limb(s) <input type="checkbox"/> Nose <input type="checkbox"/> Lower Limb (s) <input type="checkbox"/> Mouth		
42-What is the type of injury due to the accident(s)? (you can choose more than one answer)		
<input type="checkbox"/> Contusion <input type="checkbox"/> cut wound <input type="checkbox"/> laceration <input type="checkbox"/> fracture <input type="checkbox"/> others, specify.....		
43-Were you hospitalized?		
<input type="checkbox"/> No <input type="checkbox"/> Yes (duration: days)		
44-What was the cause?		

Thanks for the cooperation

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Breathing the Job: Impaired Pulmonary Function in Hairdressers due to Occupational Chemical Exposure

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KEYWORDS: Occupational Disease; Respiratory System; Hairdresser

ABSTRACT

Background: Hairdressers are occupationally exposed to harmful factors in the working environment and many cosmetic products. During the professional use of these products, there is exposure to many irritating, allergic, and carcinogenic chemicals, mainly through the skin and respiratory tract, and it is known that these occupational exposures are much more frequent and long-lasting than personal exposures. Hairdressing is one of the occupational groups with a high risk of respiratory diseases. In this study, we aimed to determine the extent to which the hairdressing profession affects respiratory functions. **Methods:** The present study included 50 people who had worked in hairdressing for at least three years, especially with hair products, had not been diagnosed with respiratory disease before this job, and did not smoke, and 50 healthy people with similar demographic characteristics. All respiratory complaints and sociodemographic information of the hairdressers were determined. Pulmonary function tests (PFTs) were performed on hairdressers and a healthy group, including FEV1, FVC, PEF, and FEV1/FVC ratio. **Results:** In the present study, we found that the hairdressing profession significantly increased the risk of respiratory symptoms. In addition, the increase in working hours as a hairdresser was associated with increased respiratory complaints, while hairdressers showed a statistically significant decrease in PFT values compared to the healthy group. **Conclusions:** Exclusion of smoking in our study reveals the occupational exposure more clearly. Our study provides additional evidence of a possible significant association between chemical exposure and increased respiratory symptom prevalence and decreased lung function.

1. INTRODUCTION

Physical, chemical, biological, ergonomic and psychological hazards originating from the work environment adversely affect the health of the employee and cause occupational diseases and accidents. Hairdressers are periodically faced with the negative effects of various chemical and mechanical applications in the workplace by constantly working on their feet and intensively in closed environments

such as hairdressers and beauty salons [1]. Thousands of chemicals are used in the production of cosmetic products. During the use of these products, there is exposure to a large number of irritant, allergic and carcinogenic potential chemicals mainly through the skin and respiratory tract. It is a known fact that occupational exposures are much more and long-lasting than personal exposures [2, 3]. The health of hairdressers is adversely affected by the chemicals they use. The products used (hair dye,

hair spray, permanent oils, bleaching agents, shampoo, etc.) and workplace working conditions (dust, smoke, vapour, cigarette smoke, etc.) lead to occupational diseases with both allergen and irritant effects especially on inexperienced workers [4-6]. Specific chemicals frequently used and reported to have adverse effects on humans include formaldehyde in hair keratin treatments and shampoos, ammonium compounds in hair colours and nail cleaners, ammonium acetate, polyvinyl and ethanol in hair sprays, persulfate salts such as sodium persulfate and potassium persulfate in hair bleaches. There are ammonium, potassium, solvents and phenylene diamine in hair dyes, glycerol thioglycolate in permanent hair curlers, styrene and 1,4 dioxane in hair extension adhesives, phthalates as fixative, hydrogen peroxide in emulsions and creams [7, 8].

The most common chemicals used by hairdressers are hair dye and hair spray. People's well-groomed and healthy hair and hair style have a positive effect on their environment. For this reason, hair dyes used by the whole society, especially women, are used routinely and unconsciously, regardless of their negative effects on human health. The cosmetic industry has had to conduct research on the development and introduction of hair dyes to meet the demands of mankind [9]. The hair dyes used today took their new form with the development and application of synthetic dyes after the Second World War [10, 11]. Although different chemicals have been used in time, paraphenylenediamine, hydrogen peroxide solution, ammonia and other chemicals in hair dyes cause skin problems by penetrating through the scalp and intoxication, various health problems and even death by oral ingestion [12].

Especially in hair keratin care procedures, which have been increasing in recent years, formaldehyde in keratin-containing solutions above certain ratios may pose a health risk. Formaldehyde is a chemical whose use in cosmetic products is restricted and can be found in products for preservative purposes at a maximum of 0.2%. Formaldehyde is a substance recognised as carcinogenic by major cancer agencies. In addition to its long-term carcinogenic effects, formaldehyde entering the body through inhalation can cause throat and eye burns and respiratory complaints. In some states of the USA, Canada and the European Union,

this practice known as Brazilian Blow Drying, which contains high formaldehyde, is prohibited. Studies have shown that most of the materials used in the market contain formaldehyde either above or very close to the threshold values [13]. The study of Pierce et al. shows that the formaldehyde concentration is 11.5% in Brazilian Blowout products, 8.3% in Global Keratin products and 3% in Coppola products, while it is stated that Brazilian Keratin Treatment and similar products sold in the USA and various other countries with the label "formaldehyde free" contain formaldehyde at unacceptably high values (up to 11%) [14]. In a report prepared by the Centre of Disease Control in the USA, according to the results of a field study conducted in a hairdressing salon in Ohio, it is shown that there is almost 11% formaldehyde in products sold as formaldehyde free and that this creates very serious risks [15].

In this study, our aim is to investigate how and to what affect the chemicals in products used by hairdresser employees of Turkey have health risks and to determine how much the chemicals in the products used affect the respiratory functions of hairdresser employees as a result of long-term exposure by pulmonary function test.

2. METHODS

This study was received the necessary permissions and ethics approval. The study included 50 people who had worked in hairdressers for at least 3 years, especially those who worked with hair products, did not have a diagnosis of respiratory disease before doing this job, did not smoke and passive smoke and 50 healthy people with similar demographic characteristics. The sample size was determined based on feasibility and availability, with the aim of ensuring equal numbers in both groups to increase statistical comparability. All respiratory complaints and sociodemographic information of hairdresser employees were determined. Forced expiratory first second volume (FEV1), forced vital capacity (FVC), peak flow rate (PEF) and FEV1/FVC ratio were determined in the pulmonary function tests measured with "Geratherm Spirostik Blue" mobile spirometry of the hairdresser group and the control group. These values were compared between both groups.

2.1. Statistical Analyses

A statistical analysis of the data was performed using IBM SPSS 25.0. Age, height, weight, BMI, gender, respiratory complaints, FEV1, FVC, PEF, and FEV1/FVC values were analyzed. Descriptive statistics for continuous variables with a normal distribution are reported as mean and standard deviation; for non-normally distributed variables, median and Q1–Q3 are reported. For normally distributed parameters, an independent-samples t-test was used, and for non-normally distributed parameters, a Mann–Whitney U test was used. Cohen's *d* was used to calculate effect size for parametric tests ($0.2 \leq d < 0.5$ for minor effects, $0.5 \leq d < 0.8$ for medium effects, and $d > 0.8$ for large effects), and Rank Biserial Correlation was used to calculate effect size for nonparametric tests ($0.1 \leq r < 0.3 \rightarrow$ Small effect, $0.3 \leq r < 0.5 \rightarrow$ Medium effect, $r \geq 0.5 \rightarrow$ Large effect). For comparisons of more than two groups, a one-way ANOVA was used for data fitting the normal distribution, and a Kruskal–Wallis test was used for data not fitting the normal distribution. Pearson and Spearman analyses were used for correlational comparisons.

3. RESULTS

One hundred and seven hairdressers from different regions of the province were visited, and the necessary information was given. In our region, hairdressers do not routinely receive regular examinations by occupational health physicians unless they work in large registered workplaces. All participating hairdressers work in their own small workplaces. Fifty hairdressers who met our inclusion criteria and 50 healthy controls with similar demographic

characteristics were included in the study. In our healthy group, people similar to the hairdresser group in terms of gender, age, height, weight, and BMI were included in the study. Demographic data of both groups are given in Table 1.

When we looked at the working years of the hairdressers, the minimum was 3 years, the maximum was 30 years, and the average was 14.41 ± 8.06 . The number of hairdressers working between 3–7 years was 15, no hairdressers were working between 8–11 years, and the number of hairdressers working between 12–30 years was 35. Ten of the hairdressers started this job as children. Among the hairdressers, 20 were primary school graduates, 24 were high school graduates, and 6 were university graduates. All hairdressers received master-apprentice training as vocational training. Officially, 27 of them received hairdressing training through apprenticeship programs at vocational training centers, eight graduated from the hairdressing department of vocational high schools, and two graduated from the Hair Care and Beauty Services department of a college. In contrast, 13 of them did not receive any formal education.

When we look at the respiratory complaints of hairdressers such as shortness of breath, wheezing, cough and sputum before and after performing this profession; hairdressers did not have these complaints before performing this profession, but after performing this profession, four people were diagnosed with asthma (The asthma diagnoses were based on previously documented medical records of participants. These diagnoses did not distinguish between allergic and irritant asthma), 1 of them was from hairdressers working between 3–7 years, the others were from hairdressers working 12 years or more. Eleven hairdressers had shortness of breath;

Table 1. Demographic data of the groups.

	Hairdressers Group (n:50)	Control Group (n:50)
Age (years, mean \pm SD)	35.86 \pm 9.64	34.22 \pm 8.98
Gender (F/M)	39/11	39/11
Height (cm, mean \pm SD)	162.95 \pm 8.02	166.77 \pm 7.55
Weight (kg, mean \pm SD)	70.14 \pm 11.03	69.64 \pm 10.45
BMI (kg/m ² , mean \pm SD)	26.41 \pm 3.27	24.93 \pm 2.66

two of them had been working between 3 and 7 years, and the others had been working 12 years or more. Six hairdressers had cough, seven had wheezing, and six had sputum complaints, all of whom had worked for 12 years or more. Four hairdressers had a runny nose, 2 of them were from hairdressers working between 3-7 years, the others were from hairdressers working 12 years or more. These complaints were found to be exacerbated by hair dyeing and colouring procedures, especially keratin application, and hair sprays sprayed during hair styling.

We found that hair salons lacked designated areas for hair dyeing, bleaching, coloring, or keratin treatments. Indoor ventilation was provided through doors, windows, pedestal fans, and air-conditioning units. Hair salons located in residential areas with higher socioeconomic status were equipped with air-conditioning-based ventilation systems. In contrast, in areas with lower socioeconomic status, ventilation was mainly achieved by keeping the salon door open or, when available, through windows. Among the 32 hair salons equipped with air-conditioning systems, only two additionally had dedicated ventilation systems designed to remove unpleasant odors, fumes, or airborne gaseous and particulate contaminants from the indoor environment. Eleven salons used pedestal fans for air circulation, while the remaining seven relied solely on natural ventilation by opening doors or windows. Although salons were generally operated in enclosed indoor environments during hair treatments, some hairdressers performed keratin treatments outdoors due to the severe discomfort caused by chemical volatiles. Based on commonly used workplace product labels in our study, the most frequently encountered chemicals were formaldehyde derivatives, ammonia, persulfates, toluene, alcohols, acids, parabens, silicone derivatives, acetone, and peroxides. No dust or chemical measurements of indoor air have ever been carried out in any of

the hairdressing salons. Hairdressing salons were only inspected for hygiene during the COVID-19 pandemic. Apart from this inspection, no inspection has been carried out so far.

It was determined that hair dyeing, colouring, and keratin procedures were performed more frequently in hairdressing salons in residential centres with high socio-economic levels. In contrast, in those with low socio-economic levels, they were performed very rarely. When we asked our participating hairdressers about the frequency of the specific tasks they perform, they could not provide precise numbers. However, when we ranked the most frequently performed procedures from highest to lowest, hair dyeing came first, followed by hair bleaching and coloring, and keratin treatment came third. Regarding the use of protective safety measures in hairdressing salons, we found that they wear work clothes and gloves during hair dyeing and colouring, they wear both gloves and masks during the keratin process, but sometimes they wear work clothes, and in summer, they do not wear masks; otherwise, no protective safety measures are taken.

The FVC (expected %) value, FEV1 (expected %) value, FEV1/FVC (%) ratio, and PEF (expected %) value for both groups are given in Table 2. When we looked at the respiratory function tests that were lower limit of normal in both groups, one hairdresser had an FEV1 value of 73%, three hairdressers had an FEV1/FVC ratio between 70-80%, four hairdressers had a PEF value below 80%, 24 hairdressers had a PEF value below 70%, and 10 healthy individuals had a PEF value below 70%. When comparing the two groups, FVC, FEV1, PEF, and FEV1/FVC values were statistically significantly lower in the hairdresser group than in the healthy group. This significant difference had a large effect size in FVC and FEV1 values, and a medium effect size in FEV1/FVC and PEF values (Table 2).

Table 2. Spirometric data of the groups.

	Hairdressers Group (n:50)	Control Group (n:50)	P	Effect size
FVC (%)	84.46±16.41	98.43±11.8	0.002	0.977
FEV1 (%)	79.35±11.58	94.52±13.31	<0,001	1.216
FEV1/FVC	85.85(81.69-91.50)	93.10(88.2-97.38)	0.004	0.436
PEF (%)	46.58(39.44-60.47)	60.75(48.56-78.08)	0.014	0.372

When the groups were compared in terms of age, FVC values ($p=0.005$) and FEV1 values ($p=0.002$) of the hairdressers over 25 years of age were significantly lower than the healthy group over 25 years of age, while no statistical significance was found between the groups aged 25 years and under. When the groups were compared in terms of gender, no statistical significance was found. It was observed that respiratory complaints of hairdressers increased with increasing age and working years, but there was no correlation between PFT values and age and working years.

4. DISCUSSION

When we look at the studies, the results we obtain are consistent with the literature. In these studies, various types of acute respiratory symptoms, as well as chronic and recurrent asthma symptoms, were detected shortly after exposure to low molecular weight chemicals in hairdressing salons [16]. In Hollund's survey of adult hairdressers, a remarkable increase in respiratory complaints related to contact with occupational chemicals was observed compared with previous years. In the data obtained, the most common complaints were 71% runny nose, 41% shortness of breath, 39% tearing, 37% wheezing, and 34% cough lasting longer than two weeks, along with 34% eczema [1]. In Moscato's study, it was found that the most common agent causing asthma was ammonium persulfate salts, and half of the 47 hairdressing patients who came with suspicion of occupational asthma were diagnosed with asthma. In contrast, the respiratory complaints in the other half were evaluated as irritative, temporary reactions to specific agents used in hairdressing salons [17]. It is reported that among occupational diseases among hairdressers, respiratory diseases are increasing [18-20]. It is stated that the rate of occupational asthma is 29% of all occupational lung diseases, and this rate will increase, especially in developing countries [21, 22]. In addition to the chemical products, the concentrations of volatile organic compounds in hairdressing and beauty centres are also substantial. Some of the volatile organic compounds that may cause occupational exposure are isopropyl acetate, ethanol, acetone, methyl and ethyl methacrylate,

n-butyl acetate, ethyl acetate, 2-butane, 2-propanol, hexamethyl disiloxane, toluene, and xylene. It is stated that the effect of low-level occupational exposure to volatile organic compounds (such as ethanol, acetone, toluene, 2-propanol, 2-butanone, ethyl acetate, and n-butyl acetate) should not be ignored in the irregularities in oxidative stress and DNA damage indicators observed in beauty salon workers [23].

In this study, specifically identifying hairdressers who were non-smokers and not exposed to passive smoking was particularly challenging. This significantly reduced the number of eligible participants and resulted in a relatively small sample. Sample size will affect generalizability, but strict selection criteria have strengthened internal validity by minimizing critical confounding factors.

In our study, we were unable to measure chemical concentrations in indoor air; however, according to the hairdressers' statements, powerful, pungent odors were present, particularly during bleaching, dyeing, and keratin treatment procedures. These odors caused eye irritation and tearing, as well as nasal burning and a runny nose. In this study, we found that hairdressers' respiratory complaints increased significantly. In addition, the increase in working hours as a hairdresser was associated with an increase in respiratory complaints. When the PFT values of hairdressers were compared with those of the healthy group, a statistically significant decrease was observed: shortness of breath, cough, wheezing, and sputum complaints were more common among hairdressers who had worked for 12 years or more. While the PFT values of hairdressers over the age of 25 were much lower than those of the healthy group in the same age group, there was no significant difference between the groups aged 25 and under. According to our study, we did not observe any effect of gender. Smoking is one of the most critical factors affecting respiratory functions. The most crucial distinction between our study and others is that our study group consisted of non-smokers, non-passive smokers, and hairdressers without any prior respiratory complaints or diagnoses. Excluding these features from our study group reinforces the possibility of a causal role for occupational exposure.

5. CONCLUSIONS

As a result of this study, there is potentially high exposure from frequent use of chemical hair products, particularly during hair bleaching and coloring, and hair keratin treatments. The decrease in lung function among hairdressers may also be influenced by unmeasured factors, and longitudinal studies are definitely needed to determine causality. Our study provides clear additional evidence that there may be significant associations between the hairdressing profession and increased prevalence of respiratory symptoms and decreased lung function. This evidence suggests that insufficient attention is being paid to the occupational respiratory risks encountered in hairdressing in the developing world. The training of hairdressers and workplace preventive measures need to be updated in light of these results. Effective measures to reduce these occupational risks among hairdressers include the use of less harmful substances, as well as emphasising the use of appropriate personal protective equipment, improving salon ventilation conditions, regulating and inspecting working conditions in hairdressing salons, and periodic occupational physician evaluations for hairdressers. Safety assessments of hair products are primarily aimed at consumers, but exposure among professional hairdressers who do this work regularly is significantly higher. These data reveal that regulations for these chemicals used in hairdressing salons need to be improved. It is necessary to raise awareness among everyone, especially members of the profession, about this issue. Occupational exposure should be considered in the safety assessment of hairdressing products, and the assessment should not focus solely on consumer safety. We regret to report that none of the hair salons we surveyed had measured dust or chemical levels in their indoor air. Unfortunately, due to financial constraints, we were unable to conduct environmental monitoring and biomarker analyses in our study. This is one of the most critical limitations of the study. Air quality measurements should be undertaken frequently and monitored in hair salons. The production of the cosmetic products used must be controlled, and their contents must be inspected. The use of HEPA-filtered vacuum cleaners and

HEPA-filtered air conditioners should be a priority in hairdressing salons. Finally, the adequacy of hairdressing training in terms of health and safety should be ensured and legalised.

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INSTITUTIONAL REVIEW BOARD STATEMENT: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Harran University Ethics Committees. (Reference No. HRU/22.06.27).

INFORMED CONSENT STATEMENT: Informed consent was obtained from all subjects involved in the study.

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AUTHOR CONTRIBUTION STATEMENT: Z.D.G. was involved in the design of the study, investigation, data collection, curation, interpretation, and analysis, writing- original draft, and writing – review & editing. E.D. was involved in the design of the study, investigation, data collection, curation, and analysis, writing- original draft, and Writing – review & editing. R.G. was involved in the study design, data interpretation, and writing the original draft. H.Y.S.A. was involved in data collection, writing the original draft, and review & editing. All authors have read and approved the final article.

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Investigation of the Association Between COVID-19 and Hepatitis B Vaccination Among Healthcare Workers: A Cross-Sectional Study in Turkey

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ABSTRACT

Backgrounds: Vaccination is a cornerstone of public health. While COVID-19 vaccination became globally prioritized during the pandemic, Hepatitis B immunization has remained a mandatory occupational requirement in Turkey, particularly among healthcare workers (HCWs). This study evaluated Hepatitis B immunization and factors associated with COVID-19 vaccination among Turkish HCWs. **Methods:** A retrospective cross-sectional study was conducted between February 1 and August 15, 2024, at Mersin City Training and Research Hospital. Employees and trainee students who underwent periodic health examinations were included. Participants were grouped as physicians, non-physician HCWs, and non-healthcare professionals. Data included demographics, vaccination history, hematological and biochemical parameters, and clinical characteristics. Logistic regression identified factors associated with COVID-19 vaccination status. **Results:** Of 4,048 participants, 92.1% received at least one COVID-19 vaccine dose and 90.0% were vaccinated against Hepatitis B. Physicians demonstrated the highest coverage for both vaccines. Male gender (OR=1.37, 95% CI: 1.04–1.80), non-physician HCW status (OR=2.51, 95% CI: 1.33–4.75), non-healthcare professional status (OR=2.99, 95% CI: 1.55–5.77), and behaviorally linked elevated platelet count (OR=1.54, 95% CI: 1.04–2.28) were independently associated with COVID-19 non-vaccination. A prior history of Hepatitis B vaccination showed a strong protective effect against COVID-19 non-vaccination (OR=0.30, 95% CI: 0.23–0.40). **Conclusions:** Vaccine uptake varied across occupational groups, with physicians achieving the highest rates. Prior compliance with mandatory Hepatitis B vaccination was positively associated with COVID-19 vaccine acceptance, emphasizing the role of previous immunization behavior in new vaccine adoption. Occupational health policies integrating vaccination counseling and follow-up are essential to improve coverage among non-physician HCWs.

1. INTRODUCTION

Vaccination remains one of the most effective public health strategies, preventing morbidity and mortality from infectious diseases worldwide. Among healthcare workers (HCWs),

immunization is both a personal health measure and a professional obligation to protect patients and the community. The Hepatitis B vaccine has long been recommended for HCWs because of increased exposure to blood-borne pathogens [1, 2]. In Turkey, a nationwide Hepatitis B

vaccination program was introduced in 1998 as part of the National Immunization Plan, and HCWs are required to demonstrate serologic protection or receive booster doses during periodic occupational health surveillance [3-5]. The COVID-19 pandemic underscored the urgent need for widespread vaccination in both the general population and frontline professionals [6-8].

Although both vaccines are integral to occupational and public health, comparative studies of Hepatitis B and COVID-19 uptake among HCWs are limited. Most available research examines Hepatitis B vaccination [9-11] or COVID-19 vaccine acceptance [12-15] separately, without cross-vaccine evaluation. Disparities in coverage often stem from hesitancy, accessibility, awareness, and risk perception [16, 17]. Furthermore, differences in vaccine uptake may reflect behavioral, institutional, and perceptual factors that influence compliance with immunization programs [10, 18, 19]. The COVID-19 pandemic also reshaped attitudes toward immunization, providing an opportunity to investigate whether historical vaccination patterns influence acceptance of novel vaccines [20-22].

In this context, the present study was designed to test the hypothesis that healthcare workers with a prior history of Hepatitis B vaccination would be more likely to accept COVID-19 vaccination. By exploring this relationship, we aimed to determine whether prior compliance with a long-established occupational immunization program (HBV) could predict COVID-19 vaccine acceptance. Although HBV vaccination is included in the Turkish National Immunization Plan, real-world coverage and antibody protection among HCWs may vary by occupational experience, training level, and perceived risk. Understanding these variations has both clinical and policy relevance for improving compliance with mandatory immunization programs [23-26].

In Turkey, data comparing vaccination uptake between physician and non-physician HCWs, as well as non-healthcare staff, remain scarce. This study aimed to evaluate both Hepatitis B and COVID-19 vaccination status simultaneously in Turkish HCWs, assess vaccination rates for both

Hepatitis B and COVID-19, identify occupational and demographic disparities, and determine clinical and laboratory correlates of COVID-19 vaccine non-uptake.

2. METHODS

Between February 1 and August 15, 2024, all hospital employees (physicians, nurses, paramedics, radiation workers, office staff, administrative and accounting personnel) and trainee students (nursing, physiotherapy, medical secretaryship, radiology technology) who presented for periodic health examinations at the Occupational Health and Safety Unit of Mersin City Training and Research Hospital were eligible. Inclusion required completion of screening tests and examination forms. Exclusion applied to those who did not complete the required assessments. Of the 4,230 employees working at the institution during the study period, 4,048 met the inclusion criteria and were enrolled, yielding a participation rate of 95.7%.

Occupational categories were defined in detail to ensure reproducibility: physicians included medical doctors and dentists; non-physician healthcare workers comprised nurses, paramedics, laboratory and radiology technicians, physiotherapists, and trainee healthcare students; non-healthcare professionals included administrative, accounting, technical, and support personnel.

This retrospective cross-sectional study used data from examination forms and electronic medical records. Variables included age, gender, occupation, COVID-19 vaccination status (dose number, type: CoronaVac® [31], Comirnaty® [32]), prior COVID-19 infection, Hepatitis B vaccination status, hematological parameters (Hb, WBC, lymphocytes, neutrophils, platelets), and biochemical parameters (creatinine, urea, AST, ALT). Blood samples were collected after ≥ 8 hours of fasting. Laboratory parameters were classified according to institutional reference ranges (Mersin City Training and Research Hospital Central Laboratory, 2024): hemoglobin 12.0–16.0 g/dL, leukocytes $4.0\text{--}10.0 \times 10^9/\text{L}$, neutrophils $2.0\text{--}7.5 \times 10^9/\text{L}$,

lymphocytes $1.0\text{--}4.0 \times 10^9/\text{L}$, platelets $150\text{--}450 \times 10^9/\text{L}$, ALT $0\text{--}41 \text{ U/L}$, AST $0\text{--}40 \text{ U/L}$, urea $15\text{--}45 \text{ mg/dL}$, creatinine $0.5\text{--}1.2 \text{ mg/dL}$, and eGFR $\geq 60 \text{ mL/min/1.73 m}^2$ considered normal. Values outside these ranges were defined as abnormal. Abnormal laboratory values were determined using reference standards. eGFR was calculated using the 2021 CKD-EPI equation [33], with $<60 \text{ mL/min/1.73 m}^2$ considered reduced. Occupations were categorized as physicians, non-physician HCWs, and non-healthcare professionals.

According to institutional occupational health policy, HCWs who were non-responders to the Hepatitis B vaccine were offered a full revaccination course and antibody re-testing. For COVID-19, vaccination was strongly recommended but not mandatory; unvaccinated employees were required to sign an informed refusal form and could continue working in compliance with infection control measures.

Normality of numerical variables was assessed with the Kolmogorov-Smirnov test. Data were expressed as medians (IQR) or counts (%). Comparisons by COVID-19 vaccination status used the Mann-Whitney U test (numerical) and Chi-square/Fisher's exact tests (categorical). Logistic regression identified independent predictors of COVID-19 vaccination status, with ORs and 95% CIs reported. Significance was set at $p < 0.05$. Analyses were performed using IBM SPSS v21.0 (IBM Corp., Armonk, NY, USA).

Ethics approval was granted by the Mersin University Non-Interventional Clinical Research Ethics Committee (23.10.2024, no. 2024/979). The study complied with the Declaration of Helsinki. Informed consent was waived due to its retrospective nature.

3. RESULTS

3.1. Participant Characteristics

Of 4,048 individuals, 70.3% were female, with a median age of 30 years (IQR 22–42). Chronic diseases were reported by 7.8%. Elevated leukocyte and platelet counts were found in 17.9% and

7.3% of participants, respectively. These values were defined according to institutional reference ranges (leukocytes $>10 \times 10^9/\text{L}$; platelets $>450 \times 10^9/\text{L}$). Among the total institutional workforce of 4,230 employees, the participation rate was 95.7%, indicating strong representativeness of the hospital population. Detailed demographic, occupational, and laboratory characteristics are provided in Table 1, which has been reorganized to improve readability and grouped by variable type (demographic, clinical, laboratory).

3.2. Vaccination Status

Overall, 92.1% received ≥ 1 COVID-19 vaccine dose, and 90.0% were Hepatitis B vaccinated. Physicians exhibited the highest coverage for both vaccines (COVID-19: 97.7%), followed by non-physician HCWs (91.3%) and non-healthcare professionals (91.8%). Across all groups, COVID-19 vaccination rates exceeded Hepatitis B rates (Figure 1).

3.3. Comparison by COVID-19 Vaccination

Unvaccinated participants were significantly younger (median 21 vs. 30 years, $p < 0.001$), more likely male, less often physicians ($p < 0.001$), and had lower Hepatitis B vaccination rates (71.4% vs. 91.6%, $p < 0.001$). High platelet counts (11.0% vs. 7.0%, $p = 0.019$) and low hemoglobin (21.4% vs. 5.8%, $p = 0.017$) were more frequent among unvaccinated individuals (Table 2).

In addition, a subgroup analysis was performed for healthcare workers who were unvaccinated for both COVID-19 and Hepatitis B ($n = 91$, 2.2%). Compared with all other participants, this group was significantly younger (median 21 years, IQR 16–24 vs. 30 years, IQR 15–68; $p < 0.001$, Mann-Whitney U test), and predominantly male (34.1%) and non-physician healthcare workers, including trainee students (75.8%). Laboratory findings, including hemoglobin and platelet counts, showed no statistically significant differences compared with the rest of the cohort. These findings suggest that early-career status and limited risk perception may contribute to dual non-vaccination behavior among younger staff (Table 2).

Table 1. Demographic, occupational, clinical and laboratory data in HCWs (N=4048)

Variable	Statistic
<i>Age, median (IQR)</i>	30.0 (22.0-42.0)
<i>Gender, n (%)</i>	
Male	1204 (29.7)
Female	2844 (70.3)
<i>Occupation, n (%)</i>	
Physician	472 (11.7)
Nurse	1244 (30.7)
Paramedic	149 (3.7)
Radiation worker	97 (2.4)
Trainee students of health sciences	1285 (31.7)
Non-healthcare professional	801 (19.8)
<i>Chronic disease, n (%)</i>	
Having at least one chronic disease, n (%)	315 (7.8)
Having multiple chronic diseases, n (%)	33 (0.8)
Hypothyroidism, n (%)	44 (1.1)
Hypertension, n (%)	37 (0.9)
Coronary artery disease, n (%)	30 (0.7)
Diabetes mellitus, n (%)	28 (0.7)
Hepatitis, n (%)	23 (0.6)
Cancer, n (%)	16 (0.4)
Asthma, n (%)	15 (0.4)
Musculoskeletal system disease, n (%)	10 (0.2)
Anemia, n (%)	9 (0.2)
Psychiatric disorders, n (%)	4 (0.1)
COPD, n (%)	2 (0.1)
Others*, n (%)	34 (0.8)
<i>COVID-19 vaccine</i>	
HCWs receiving vaccine, n (%)	3730 (92.1)
Total dose, median (IQR)	3.0 (2.0-4.0)
Sinovac dose, median (IQR)	1.0 (0-2.0)
Biontech dose, median (IQR)	2.0 (1.0-2.0)
<i>History of COVID-19, n (%)</i>	195 (4.8)
<i>History of second episode of COVID-19, n (%)</i>	13 (0.3)
<i>History of hospitalization due to COVID-19, n (%)</i>	17 (0.4)
<i>HCWs receiving Hepatitis B vaccine, n (%)</i>	3643 (90.0)
<i>Hemoglobin level, n (%)</i>	
Low	659 (16.3)
Normal	3308 (81.7)
High	81 (2.0)

Variable	Statistic
<i>Leukocyte count, n (%)</i>	
Low	8 (0.2)
Normal	3315 (81.9)
High	725 (17.9)
<i>Neutrophil count, n (%)</i>	
Low	86 (2.1)
Normal	3750 (92.6)
High	212 (5.2)
<i>Lymphocyte count, n (%)</i>	
Low	86 (2.1)
Normal	3750 (92.6)
High	212 (5.2)
<i>Platelet count, n (%)</i>	
Low	23 (0.6)
Normal	3729 (92.1)
High	296 (7.3)
<i>eGFR<60 mL/min/1.73 m², n (%)</i>	11 (0.3)
<i>Elevated urea, n (%)</i>	18 (0.4)
<i>Elevated ALT, n (%)</i>	190 (4.7)
<i>Elevated AST, n (%)</i>	88 (2.2)

*Other uncategorized diseases; ALT, alanine transaminase; AST, aspartate transaminase; COPD, chronic obstructive pulmonary disease; COVID-19, Coronavirus Disease 2019; eGFR, estimated glomerular filtration rate; IQR, interquartile range; HCW, healthcare worker.

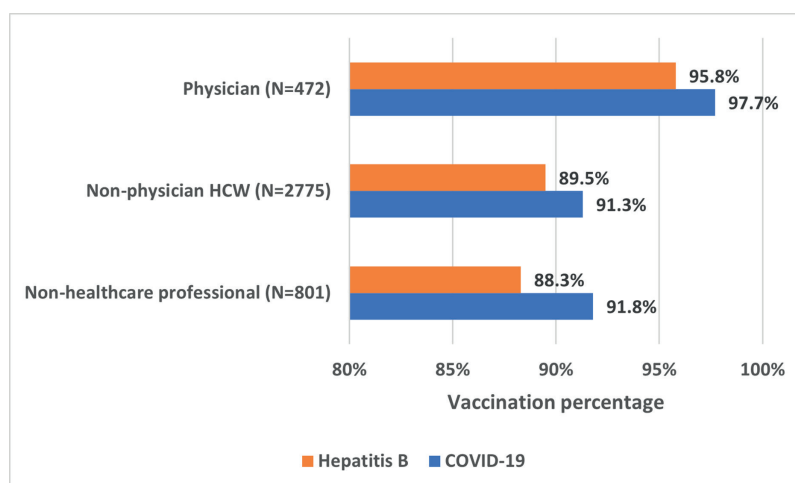


Figure 1. The vaccination rates for both COVID-19 and Hepatitis B.

Table 2. Comparison of characteristics according to COVID-19 vaccination status and subgroup analysis of dual-unvaccinated healthcare workers (N = 4,048).

Variable	Vaccinated (N=3730)	Unvaccinated (N=318)	p-value	Unvaccinated, both (N=91)	Others (N=3975)	p-value
Age, median (IQR)	30.0 (22.0-42.0)	21.0 (19.0-34.0)	<0.001*	21(16-24)	30(15-68)	<0.001*
Gender, n (%)			0.572†			0.362†
Male	1105 (29.6)	99 (31.1)		31(34.1)	1173(29.6)	
Female	2625 (70.4)	219 (68.9)		60(65.9)	2784(70.4)	
Occupation, n (%)			<0.001†			0.017†
Doctor	461 (12.4)	11 (3.5)		2(2.2)	470(11.9)	
Non-physician HCW	2534 (67.9)	241 (75.8)		69(75.8)	2706(68.4)	
Non-healthcare professional	735 (19.7)	66 (20.8)		20(22)	781(19.7)	
Chronic disease, n (%)	296 (7.9)	19 (6.0)	0.210†	5(7.1)	310(7.8)	0.31†
History of COVID-19, n (%)	187 (5.0)	8 (2.5)	0.046†	4.4(1.1)	194(4.9)	0.131‡
COVID-19 re-infection, n (%)	13 (0.3)	-	0.421‡	0(0)	13(0.3)	1.000‡
COVID-19, hospitalization n (%)	17 (0.5)	-	0.392‡	0(0)	17(0.4)	1.000‡
Vaccinated for Hepatitis B, n (%)	3416 (91.6)	227 (71.4)	<0.001†	-	-	-
Laboratory tests						
Hemoglobin level, n (%)			0.017†			0.072†
Low	591 (5.8)	68 (21.4)		20(22.0)	639(16.1)	
Normal	3067 (82.2)	241 (75.8)		67(73.6)	3241(81.9)	
High	72 (1.9)	9 (2.8)		4(4.4)	77(1.9)	
Leukocyte count, n (%)			0.793†			0.694†
Low	7 (0.2)	1 (0.3)		0(0)	8(7.8)	
Normal	3058 (82.0)	257 (80.8)		72(79.1)	3243(82)	
High	665 (17.8)	60 (18.9)		19(20.9)	706(17.8)	
Neutrophil count, n (%)			0.359†			0.837†
Low	22 (0.6)	4 (1.3)		1(1.1)	25(0.6)	
Normal	283 (88.0)	278 (87.4)		79(86.3)	3482(88.0)	
High	425 (11.4)	36 (11.3)		11(12.1)	450(11.4)	
Lymphocyte count, n (%)			0.430†			0.245†
Low	77 (2.1)	9 (2.8)		0(0)	86(2.2)	

Variable	Vaccinated (N=3730)	Unvaccinated (N=318)	<i>p</i> -value	Unvaccinated, both (N=91)	Others (N=3975)	<i>p</i> -value
<i>Normal</i>	3454 (92.6)	296 (93.1)		88(96.7)	3663(92.5)	
<i>High</i>	199 (5.3)	13 (4.1)		3(3.3)	209(5.3)	
Platelet count, <i>n</i> (%)			0.019†			0.161†
<i>Low</i>	20 (0.5)	3 (0.9)		1(1.1)	22(0.6)	
<i>Normal</i>	3449 (92.5)	280 (88.1)		79(86.3)	3650(92.2)	
<i>High</i>	261 (7.0)	35 (11.0)		11(12.1)	285(7.2)	
<i>eGFR</i> <60 mL/min/1.73 m ² , <i>n</i> (%)	11 (0.3)	-	1.000‡	0(0)	11(0.3)	1.000‡
<i>Elevated urea</i> , <i>n</i> (%)	18 (0.5)	-	0.392‡	0(0)	1.000‡	1.000‡
<i>Elevated ALT</i> , <i>n</i> (%)	182 (4.9)	8 (2.5)	0.056†	3(3.3)	85(2.1)	0.449‡
<i>Elevated AST</i> , <i>n</i> (%)	79 (2.1)	9 (2.8)	0.403†	2(2.2)	188(4.8)	0.445‡

Column percentages are presented. Bold *p*-values indicate statistical significance.

*Mann-Whitney-U test.

†Chi-square test.

‡Fisher's exact test.

ALT, alanine transaminase; *AST*, aspartate transaminase; *COVID-19*, Coronavirus Disease 2019; *eGFR*, estimated glomerular filtration rate; *IQR*, interquartile range; *HCW*, healthcare worker.

3.4. Multivariable Analysis

Independent predictors of COVID-19 non-vaccination included younger age (OR=0.96, 95% CI: 0.94–0.97), male gender (OR=1.37, 95% CI: 1.04–1.80), non-physician HCW status (OR=2.51, 95% CI: 1.33–4.75), non-healthcare professional status (OR=2.99, 95% CI: 1.55–5.77), and elevated platelet count (OR=1.54, 95% CI: 1.04–2.28). Hepatitis B vaccination history showed a protective effect (OR=0.30, 95% CI: 0.23–0.40) (Table 3). Here, “protective effect” indicates that prior HBV vaccination was associated with a 70% lower likelihood of COVID-19 non-vaccination after multivariable adjustment (OR<1). The findings remained consistent even after excluding participants with chronic diseases or abnormal laboratory values, indicating that the model results were robust and not driven by these subgroups.

4. DISCUSSION

This study provides the first direct comparison of Hepatitis B and COVID-19 vaccination status among Turkish HCWs. Overall vaccination

coverage was high, particularly among physicians, reflecting their higher medical knowledge, perceived risk, and adherence to occupational protocols [9, 12, 17]. Non-physician HCWs and non-healthcare professionals demonstrated lower coverage, highlighting gaps in institutional reinforcement and educational strategies [10, 16, 34].

The higher COVID-19 vaccination uptake relative to Hepatitis B suggests the strong influence of pandemic urgency, institutional campaigns, and perceived threat severity [10, 13, 35]. These findings align with international data showing greater vaccine acceptance among HCWs than the general population [36]. However, the persistent lower uptake in non-physician HCWs underscores the need for targeted strategies, including mandatory onboarding immunization, booster monitoring, and continuous workplace education [2, 9, 11]. In Turkey, HBV vaccination has been included in the National Immunization Plan since 1998, and healthcare workers are required to demonstrate anti-HBs seroprotection or receive booster doses during occupational health surveillance [3–5]. COVID-19 vaccination, although voluntary since 2023, has been strongly

Table 3. Unadjusted and multiple logistic regression analyses for being unvaccinated for COVID-19 (N=4048).

Variable	Unadjusted		Multiple	
	OR (95% CI)	<i>p</i> -value	OR (95% CI)	<i>p</i> -value
<i>Age (1-year increase)</i>	0.95 (0.93-0.96)	<0.001	0.96 (0.94-0.97)	<0.001
<i>Male gender</i>	1.07 (0.84-1.38)	0.572	1.37 (1.04-1.80)	0.024
<i>Occupation*</i>				
Non-physician HCW	3.99 (2.16-7.35)	<0.001	2.51 (1.33-4.75)	0.005
Non-healthcare professional	3.76 (1.97-7.20)	<0.001	2.99 (1.55-5.77)	0.001
<i>History of COVID-19</i>	0.49 (0.24-1.00)	0.051	0.91 (0.43-1.91)	0.793
<i>Hemoglobin*</i>				
Low	1.45 (1.10-1.94)	0.008	1.34 (0.99-1.80)	0.057
High	1.59 (0.79-3.22)	0.197	1.12 (0.53-2.37)	0.774
<i>Platelet count*</i>				
Low	1.85 (0.55-6.26)	0.324	1.77 (0.51-6.18)	0.370
High	1.65 (1.14-2.40)	0.008	1.54 (1.04-2.28)	0.033
<i>Vaccinated for Hepatitis B</i>	0.23 (0.18-0.30)	<0.001	0.30 (0.23-0.40)	<0.001

Bold p-values indicate statistical significance.

**Physicians, normal hemoglobin level, and normal platelet count were accepted as reference for occupation, hemoglobin, and platelet count variables, respectively.*

CI, confidence interval; HCW, healthcare worker; COVID-19, Coronavirus Disease 2019.

encouraged by the Ministry of Health and hospital administrations to sustain pandemic preparedness. These national regulations likely explain the overall high vaccination rates observed in this cohort.

A novel contribution of this study was the identification of a small subgroup of healthcare workers (2.2%) who were unvaccinated for both COVID-19 and Hepatitis B. This group was significantly younger, predominantly male, and mostly composed of trainee students and non-physician HCWs. Their dual non-vaccination behavior highlights the role of early-career status, limited occupational experience, and possibly lower risk perception. Such behavior underlines the importance of incorporating vaccination counseling into medical and allied-health curricula and reinforcing immunization before clinical placement. From a clinical and occupational health standpoint, recognizing and monitoring this subgroup is crucial for preventing workplace outbreaks and ensuring patient safety. Institutional policies should therefore mandate vaccination verification at the time of recruitment and training. These findings

emphasize the need for targeted education and vaccination programs aimed at students and newly employed personnel before clinical exposure begins.

An important novel finding was the association between elevated platelet count and COVID-19 non-vaccination. Thrombocytosis is linked with systemic inflammation and may reflect psychobiological stress responses, which in turn correlate with vaccine hesitancy [37-39]. Although causality cannot be established, this observation suggests potential immune-psychological mechanisms influencing vaccination decisions. It is noteworthy that both vaccines administered in this cohort—Comirnaty® (mRNA) and CoronaVac® (inactivated)—are not associated with vaccine-induced thrombocytosis; therefore, the observed association is likely behavioral or stress-related rather than biological. Clinically, this raises the possibility that subtle hematological variations may indirectly reflect psychosocial determinants of health behavior. Integrating hematologic screening with occupational counseling may thus help identify workers at risk of non-compliance

with vaccination programs. Further longitudinal studies are required to clarify these relationships.

The strong protective effect of prior Hepatitis B vaccination on COVID-19 uptake supports the hypothesis that positive vaccination history fosters acceptance of new vaccines. This behavioral consistency, confirmed in other studies linking past vaccination behavior with COVID-19 acceptance [25, 26], suggests that individuals with strong preventive health orientation are more likely to comply with new immunization campaigns. This finding has direct implications for clinical practice: assessing prior vaccination records during occupational health examinations can help predict vaccine acceptance and guide personalized counseling. Routine verification of immunization status during periodic health assessments could serve as an early intervention to address potential hesitancy. This reinforces the value of comprehensive, routine immunization programs in preparing populations for future public health emergencies [20-22, 27-29]. From a clinical and occupational health perspective, these results highlight the need for systematic follow-up of vaccination records, integration of vaccine counseling into periodic health examinations, and workplace-based campaigns to sustain vaccine confidence. The decision to evaluate Hepatitis B rather than influenza vaccination as a comparator was intentional, as HBV immunization is mandatory, routinely documented, and reflects long-term occupational health compliance, making it a more stable behavioral indicator than seasonal influenza vaccination [30].

Strengths of this study include its large sample size, inclusion of trainee students, and integration of clinical and laboratory data. However, some limitations should be acknowledged. The retrospective and single-center design may restrict causal inference and generalizability. Additionally, behavioral, psychological, and socioeconomic factors influencing vaccine decisions were not assessed because no questionnaire-based data were collected—this represents an important methodological limitation that may have restricted the interpretation of underlying attitudes and motivations. Behavioral, psychological, and

socioeconomic factors influencing vaccine decisions were not assessed because no questionnaire-based data were collected, as noted by the reviewer. Furthermore, information on antibody response or long-term seroprotection was unavailable. Future research should combine quantitative clinical data with behavioral and psychometric measures to better understand the determinants of vaccine hesitancy among HCWs.

5. CONCLUSION

Vaccination uptake among Turkish HCWs varies by occupation, with physicians achieving the highest coverage. Prior immunization history predicts COVID-19 vaccine acceptance, underscoring the importance of institutional strategies and continuous education. Tailored interventions for non-physician HCWs are needed to sustain high coverage in both routine and emergency contexts.

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INFORMED CONSENT STATEMENT: Informed consent was waived due to its retrospective nature.

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