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Occupational Exposure Duration and Declining Peak Expiratory Flow Among Traditional Compressor Divers

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ABSTRACT

Despite the widespread practice of traditional compressor-assisted diving in coastal Indonesia, evidence regarding its impact on pulmonary function remains limited. This cross-sectional study examined the association between occupational exposure duration and Peak Expiratory Flow (PEF) among 57 male traditional divers in Southeast Sulawesi. Using a standardized peak flow meter and structured questionnaires, the study found a mean PEF of 472.61 ± 90.55 L/min. Simple linear regression demonstrated a significant negative association (B = -3.99; p = 0.033), indicating that each additional year of diving decreases PEF by an average of 3.99 L/min, with work duration explaining 8.0% of the PEF variation (R^2 = 0.080). Ultimately, longer occupational exposure significantly reduces pulmonary function, underscoring the urgent need for routine respiratory screening and community-based health monitoring for early detection of pulmonary decline in coastal maritime workers.

Meskipun praktik penyelaman kompresor tradisional tersebar luas di pesisir Indonesia, bukti mengenai dampaknya terhadap fungsi paru masih terbatas. Studi potong lintang ini menguji hubungan antara durasi paparan kerja dengan Arus Puncak Ekspirasi (APE) pada 57 penyelam tradisional laki-laki di Sulawesi Tenggara. Melalui pengukuran menggunakan peak flow meter terstandar dan kuesioner terstruktur, didapatkan nilai rata-rata APE sebesar 472,61 ± 90,55 L/menit. Analisis regresi linear sederhana menunjukkan hubungan negatif yang signifikan (B = -3,99; p = 0,033), yang berarti setiap penambahan satu tahun masa kerja akan menurunkan APE rata-rata sebesar 3,99 L/menit. Durasi kerja ini menjelaskan 8,0% dari variasi nilai APE (R^2 = 0,080). Dapat disimpulkan bahwa durasi paparan kerja yang lebih lama secara signifikan menurunkan fungsi paru. Temuan ini menegaskan pentingnya penapisan pernapasan rutin dan pemantauan kesehatan kerja berbasis masyarakat untuk deteksi dini penurunan fungsi paru pada kelompok pekerja tersebut.

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Introduction

Traditional diving remains an important informal occupation in many coastal regions of Indonesia, particularly among communities that depend on marine resources for their livelihoods. Traditional divers commonly engage in fishing, sea cucumber collection, lobster harvesting, and other underwater activities using simple equipment and non-standardized surface-supplied air compressor systems. Unlike professional divers, they often work without formal occupational safety training, standardized decompression procedures, or adequate respiratory

protection, increasing their vulnerability to occupational injuries and chronic health problems. Repeated exposure to hyperbaric pressure, prolonged underwater activities, and contaminated compressed air may contribute to decompression sickness, pulmonary barotrauma, neurological disorders, and chronic respiratory impairment (Denoble, Vann, & Pollock, 2018; WHO, 2022).

Indonesia is the world's largest archipelagic nation with more than 17,500 islands and approximately 6.8 million km² of marine waters, relies heavily on marine resources to support coastal livelihoods and national food security (FAO, 2023); (FAO, 2024). In many eastern Indonesian provinces, including Southeast Sulawesi, compressor-assisted diving remains widely practiced because it enables fishers to access deeper fishing grounds and extend underwater working time. However, these activities are largely conducted within informal occupational settings characterized by limited occupational health protection and unsafe diving practices, placing traditional divers at increased risk of adverse health outcomes (Maharja, Maharja, Saputra, Panggeleng, & Hermawan, 2025). Southeast Sulawesi is recognized as one of Indonesia's major maritime provinces, where fisheries and marine resource harvesting constitute important economic activities among coastal populations. Despite its economic significance, compressor assisted diving exposes workers to various occupational hazards, including barotrauma, decompression sickness, neurological disorders, and diving related paralysis. Recent evidence from Indonesia indicates that inadequate safety knowledge, unsafe diving practices, and insufficient occupational safety measures significantly increase the risk of adverse health outcomes among traditional compressor divers.

Repeated exposure to hyperbaric environments may progressively affect pulmonary physiology through airway inflammation, pulmonary microtrauma, impaired lung elasticity, and reduced expiratory airflow (Balestra, Mrakic-Sposta, & Virgili, 2023; Salik & Ozcan, 2021). In addition, non standardized compressor systems may expose divers to contaminants such as oil vapor, particulate matter, hydrocarbons, and carbon monoxide, further increasing the risk of respiratory dysfunction (Denoble et al., 2018). Pulmonary function assessment is therefore an essential component of occupational health surveillance among traditional divers. Peak Expiratory Flow (PEF) is a practical, inexpensive, and portable indicator of respiratory performance that can be easily implemented for community based pulmonary screening, particularly in remote coastal areas where spirometry is often unavailable (Blanc et al., 2022; Fishwick & Barber, 2022; Miller et al., 2021). Reduced PEF values may indicate airflow limitation, impaired respiratory muscle performance, or early pulmonary dysfunction associated with occupational exposure. Because spirometry is often unavailable in remote coastal communities, PEF measurement may provide a practical alternative for early respiratory monitoring among vulnerable occupational populations.

Several studies have demonstrated that occupational exposure duration, smoking behavior, age, body mass index, and prolonged underwater activity may contribute to pulmonary function decline among divers and other occupational groups exposed to respiratory hazards. Long term diving activity has been associated with reduced expiratory flow rates, restrictive pulmonary patterns, and chronic respiratory symptoms among occupational divers (Danes et al., 2024; Wolf, Brubakk, Neuman, & Møllerløkken, 2014). Furthermore, cumulative exposure to hyperbaric conditions may progressively impair respiratory function through repeated pulmonary microtrauma and chronic inflammatory responses (Balestra et al., 2023). According to Centers for Disease Control and Prevention, smoking habits may exacerbate pulmonary decline by increasing oxidative stress, airway inflammation, and mucus hypersecretion, thereby accelerating respiratory dysfunction in divers exposed to hazardous underwater environments (CDC, 2023).

Despite increasing concern regarding occupational health among traditional divers, evidence regarding chronic pulmonary function impairment among traditional compressor assisted divers in Indonesia remains limited. Most previous studies involving traditional divers have primarily focused on decompression sickness, neurological manifestations, and acute diving injuries rather than long-term respiratory impairment associated with cumulative occupational exposure (Blogg, Tillmans, & Lindholm, 2023; Mishra et al., 2023). In addition, respiratory assessment among traditional divers is rarely conducted using simple field-based pulmonary screening approaches applicable to occupational and community nursing practice. This evidence gap limits the development of preventive respiratory surveillance and occupational health interventions for traditional divers in low-resource coastal communities.

Chronic respiratory impairment among traditional divers may remain underrecognized because pulmonary symptoms often develop gradually and are frequently perceived as a normal consequence of aging or long-term diving activity. In many low resource coastal communities, limited access to occupational health services and pulmonary function testing may delay identification of early respiratory decline. Consequently, traditional divers may continue occupational exposure despite progressive pulmonary impairment, increasing the risk of long-term respiratory morbidity and reduced quality of life (WHO, 2022).

The novelty of this study lies not only in its focus on traditional compressor assisted divers as an understudied occupational population, but also in its emphasis on Peak Expiratory Flow assessment as a feasible community based respiratory screening approach in remote coastal settings. Unlike conventional spirometry, which may be difficult to implement in resource limited maritime communities, PEF measurement offers a low cost and portable method that may support early identification of pulmonary decline among high risk divers. While previous studies involving traditional divers have predominantly focused on decompression illness, neurological disorders, and acute diving injuries, evidence regarding long term pulmonary function among traditional compressor assisted divers remains limited. Furthermore, respiratory health surveillance is rarely implemented in low resource coastal communities where traditional diving is common. This study contributes to the limited evidence by examining the association between occupational exposure duration and Peak Expiratory Flow among traditional compressor assisted divers in Southeast Sulawesi using a practical community based respiratory screening approach. The findings are expected to support occupational and community nursing initiatives aimed at early detection of respiratory health problems among vulnerable maritime workers.

Research Methodology

Study Design

A cross sectional study was conducted among traditional compressor assisted divers in Soropia District, Southeast Sulawesi, Indonesia. The study was carried out between May and July 2024 in several coastal communities where traditional diving activities are commonly performed as a primary occupational source of income. Traditional divers in this region typically engage in fishing and marine harvesting activities using non-standardized surface supplied air compressor systems.

Population and Sample

The study population consisted of active traditional male divers working in coastal areas of Soropia District. Participants were recruited using purposive sampling based on predefined inclusion and exclusion criteria. Inclusion criteria included: (1) actively working as a traditional compressor assisted diver for at least one year, (2) aged ≥18 years, and (3) willing to participate in the study. Divers with a history of diagnosed chronic pulmonary disease, acute respiratory infection during data collection, severe cardiovascular disorders, or inability to perform Peak Expiratory Flow measurement were excluded from the study.

The minimum sample size was calculated using the Slovin formula based on an estimated population of 64 active traditional compressor assisted divers in the study area. Using a 5% margin of error, the minimum required sample size was 55 participants. To enhance representativeness and account for potential non response, all eligible divers meeting the inclusion criteria were invited to participate. A total of 57 respondents were successfully recruited and included in the final analysis.

Variables and Measurements

The questionnaire was adapted from previously validated instruments used among Indonesian traditional diving communities, particularly the studies by Embuai, Denny, and Setyaningsih (2020), Yuliana, Mahmud, and Sumiaty (2021), and Maharja and Ikhsan (2023), which assessed individual characteristics, diving exposure, occupational safety behaviors, and decompression related health outcomes among traditional divers. The

instrument was subsequently reviewed by occupational health experts and modified to ensure contextual relevance to compressor assisted traditional divers in Southeast Sulawesi Prior to data collection, the adapted questionnaire underwent pilot testing among traditional divers with characteristics similar to the target study population. The pilot assessment was conducted to evaluate question clarity, comprehensibility, and contextual suitability. Minor revisions were subsequently made to improve wording consistency and ensure the applicability of the instrument within the local diving community before field implementation.

Independent variables included age, body mass index (BMI), smoking status, diving frequency, and occupational exposure duration (work duration). Age was measured in years, while BMI was calculated using body weight divided by height squared (kg/m^2). Smoking status was categorized as smoker or non smoker based on self-reported smoking behavior. Diving frequency was defined as the average number of diving sessions performed per week.

The dependent variable in this study was Peak Expiratory Flow (PEF), measured in liters per minute (L/min). Pulmonary function was assessed using a Rossmax Peak Flow Meter (PF120, Rossmax International Ltd., Taiwan), a portable device manufactured according to EN ISO 23747 standards. Peak Expiratory Flow measurements were performed following standardized procedures recommended by the American Thoracic Society (ATS) and the European Respiratory Society (ERS). Each participant performed three maximal expiratory maneuvers from full inspiration while standing, and the highest recorded value was used for analysis.

Occupational exposure duration was defined as the total number of years respondents had actively worked as traditional compressor assisted divers. In the present study, work duration was used as a proxy indicator of cumulative occupational diving exposure because detailed quantitative exposure measurements, including diving depth, duration per dive session, decompression profile, ascent pattern, compressor air quality, and respiratory protective practices, were not routinely documented among traditional divers in the study setting.

Data Collection Procedure

Data collection was conducted through direct interviews and field based pulmonary assessment. Demographic, occupational, and behavioral characteristics were collected using structured questionnaires administered by trained researchers. Anthropometric measurements were performed using calibrated instruments. Peak Expiratory Flow measurements were conducted in open field settings following standard respiratory assessment procedures to ensure consistency across participants.

Prior to field implementation, the adapted questionnaire underwent content validation and pilot testing. Content validity was assessed through expert review involving specialists in occupational health nursing and community health with experience in coastal and maritime health research. The experts evaluated the relevance, clarity, comprehensiveness, and contextual appropriateness of each questionnaire item. Recommendations from the review process were incorporated to improve wording and ensure consistency with the study objectives.

Subsequently, the revised questionnaire was pilot tested among traditional divers with characteristics similar to the target study population but who were not included in the final sample. The pilot assessment was conducted to evaluate item clarity, comprehensibility, response consistency, and feasibility of administration. Minor modifications were made based on participant feedback prior to data collection.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics version 25 (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to summarize respondent characteristics and study variables. Continuous variables were presented as means and standard deviations (mean ± SD), while categorical variables were reported as frequencies and percentages. Bivariate analysis was performed to evaluate the relationship between independent variables and Peak Expiratory Flow. Pearson correlation analysis was used for normally distributed variables. Variables demonstrating statistical or clinical relevance were subsequently explored using simple linear regression analysis to quantify the association between occupational exposure duration and Peak Expiratory

Flow. Regression results were reported as unstandardized coefficients (B), standardized beta coefficients (β), 95% confidence intervals (95% CI), R^2, adjusted R^2, F-statistics, and p-values. Statistical significance was established at $p < 0.05$.

Ethical Consideration

This study received ethical approval from the Health Research Ethics Committee of the Faculty of Medicine, Universitas Halu Oleo, Indonesia, with ethical clearance number (Approval No: 070/UN29.17.1.3/ETIK/2024). All participants received explanation regarding the study objectives and procedures before participation. Written informed consent was obtained from all respondents prior to data collection. Confidentiality and anonymity of participant information were maintained throughout the research process

Result

A total of 57 traditional compressor-assisted divers participated in this study. Table 1 presents the demographic, occupational, behavioral, and pulmonary function characteristics of the respondents. The mean age of respondents was 38.42 ± 9.51 years, indicating that most participants were within productive working age. The average Body Mass Index (BMI) was 22.18 ± 2.97 kg/m², which generally falls within the normal nutritional category.

Regarding occupational characteristics, the mean work duration as traditional divers was 15.37 ± 8.46 years, reflecting prolonged occupational exposure among respondents. The average diving frequency was 4.68 ± 1.72 times per week. The mean Peak Expiratory Flow (PEF) value among respondents was 472.61 ± 90.55 L/min. Most respondents were smokers (71.9%), while only 28.1% were non-smokers.

Table 1.
The Characteristics of the Respondents

Variable	Mean ± SD	n	%
Age (years)	38.42 ± 9.51	–	–
Body Mass Index (kg/m²)	22.18 ± 2.97	–	–
Work Duration (years)	15.37 ± 8.46	–	–
Diving Frequency (times/week)	4.68 ± 1.72	–	–
Peak Expiratory Flow (L/min)	472.61 ± 90.55	–	–
Smokers	–	41	71.9
Non-smokers	–	16	28.1

A total of 57 traditional compressor assisted divers participated in this study. Overall, respondents were predominantly middle aged adults with normal body mass index and substantial occupational diving exposure. Most participants were active smokers and engaged in regular diving activities. Pulmonary assessment demonstrated considerable variability in Peak Expiratory Flow values among participants, suggesting heterogeneity in respiratory performance within the study population.

Table 2.
Bivariate Analysis of Factors Associated with Peak Expiratory Flow

Variable	r	p-value
Age	-0.182	0.176
Body Mass Index	0.091	0.502
Smoking Status	-0.141	0.296
Diving Frequency	-0.089	0.504
Work Duration	-0.283	0.033*

Bivariate analysis was conducted to evaluate the relationship between respondent characteristics and Peak Expiratory Flow. As presented in Table 2, work duration demonstrated a statistically significant negative correlation with PEF (r = -0.283; p = 0.033), indicating that longer occupational exposure was associated with lower pulmonary function values. No significant correlations were observed for age, body mass index, smoking status, or diving frequency.

To examine the relationship between occupational exposure duration and pulmonary function, a simple linear regression analysis was performed using work duration as the independent variable and Peak Expiratory Flow as the dependent variable.

Table 3.
Simple Linear Regression Analysis of Factors Associated with Peak Expiratory Flow

Variable	B	Standardized β	95% CI	p-value
Work Duration	-3.99	-0.283	-7.61 – -0.37	0.033*
Model Statistics				
R	-0.283			
R^2	0.080			
Adjusted R^2	0.064			
F-statistic	4.805			
Model p-value	0.033*			

As shown in Table 3, occupational exposure duration was significantly associated with Peak Expiratory Flow among traditional compressor assisted divers. The regression model demonstrated a statistically significant overall fit (F = 4.805; p = 0.033) and explained approximately 8.0% of the variation in PEF values (R^2 = 0.080; adjusted R^2 = 0.064). Work duration showed a significant negative association with PEF (B = -3.99; standardized β = -0.283; 95% CI: -7.63 to -0.34; p = 0.033). The regression coefficient indicates that each additional year of diving work was associated with an average decrease of approximately 3.99 L/min in Peak Expiratory Flow. Although the proportion of explained variance was modest, the findings suggest that prolonged occupational exposure may be associated with gradual reductions in pulmonary function among traditional compressor assisted divers.

Figure 1 bellow illustrates the association between occupational exposure duration and Peak Expiratory Flow (PEF) among traditional compressor-assisted divers. Scatter plot illustrating the relationship between occupational exposure duration (years) and Peak Expiratory Flow (L/min) among traditional compressor-assisted divers. The regression line indicates a negative association between work duration and pulmonary function, suggesting lower PEF values among divers with longer occupational exposure.

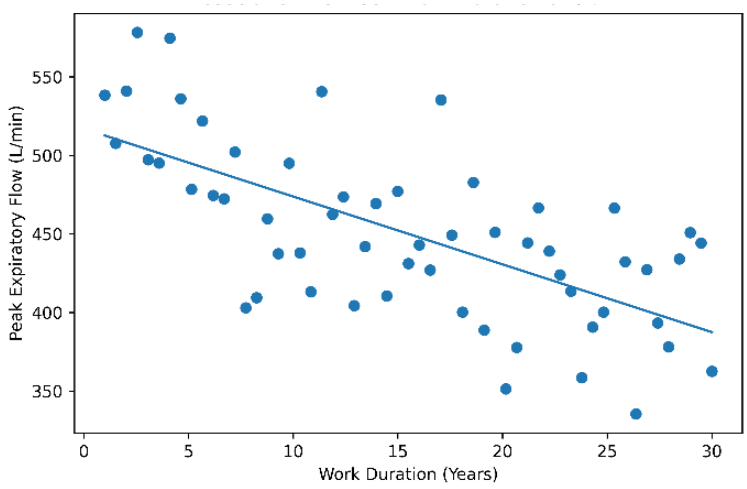

Figure 1. Association Between Work Duration and Peak Expiratory Flow Among Traditional Divers

The regression line visually supports the results of the simple linear regression analysis, in which work duration demonstrated a statistically significant negative association with Peak Expiratory Flow. Divers with longer occupational exposure duration generally tended to exhibit lower PEF values, consistent with the observed regression trend.

Discussion

This study demonstrated a significant association between occupational exposure duration and Peak Expiratory Flow among traditional compressor assisted divers in Southeast Sulawesi. Divers with longer work duration tended to exhibit lower PEF values, suggesting that prolonged occupational exposure may be linked to gradual reductions in pulmonary function. Although the observed association was modest, the findings provide evidence that cumulative occupational exposure may play a role in respiratory health among traditional divers working in resource limited coastal environments.

Several mechanisms may explain the observed association between occupational exposure duration and pulmonary function. Traditional compressor-assisted divers are repeatedly exposed to hyperbaric environments, fluctuating pressure conditions, and prolonged respiratory workloads during underwater activities (Denoble et al., 2018; Mark, Garrido, Nowak, Radon, & Wengenroth, 2021; Salik & Ozcan, 2021). In addition, the use of non standardized compressor systems may increase exposure to contaminated compressed air and other environmental respiratory hazards. Repeated exposure to these conditions over many years may be associated with airway inflammation, structural pulmonary changes, reduced lung elasticity, and impaired expiratory airflow, ultimately contributing to lower Peak Expiratory Flow values.

The present findings are consistent with previous occupational and diving health studies reporting reduced pulmonary function among individuals exposed to prolonged respiratory and environmental hazards. Studies involving occupational divers and other high-risk worker populations have demonstrated that cumulative exposure to hazardous work environments may be associated with declines in respiratory capacity and increased susceptibility to chronic respiratory disorders. Repetitive exposure to underwater pressure changes may also place long term physiological stress on pulmonary tissues, potentially affecting respiratory performance over time.

Although occupational exposure duration was significantly associated with Peak Expiratory Flow, the regression model explained only a modest proportion of the observed variation in pulmonary function. This finding suggests that respiratory health among traditional divers is likely influenced by multiple occupational, environmental, behavioral, and physiological factors beyond work duration alone such as oil vapor, hydrocarbon particles, particulate matter, and carbon monoxide originating from poorly maintained compressors (WHO, 2022). Variables such as diving depth, dive duration, decompression practices, compressor air quality, smoking intensity, physical fitness, and respiratory protective behaviors may also contribute to pulmonary function outcomes and should be explored in future studies. Unlike professional divers who typically undergo periodic health examinations and standardized dive planning, traditional divers often rely solely on practical experience and informal knowledge, increasing the risk of cumulative occupational injury and delayed recognition of respiratory impairment.

The findings of this study are consistent with previous occupational and diving medicine studies reporting pulmonary decline associated with prolonged diving exposure. Salik and Ozcan (2021) reported that prolonged occupational diving exposure was associated with reduced expiratory flow parameters and chronic respiratory symptoms among professional divers. Similarly, Blanc et al. (2022) demonstrated that chronic occupational exposure to hazardous respiratory environments may contribute to reduced pulmonary capacity and airflow limitation. Repetitive pulmonary stress associated with diving may additionally induce subclinical inflammatory responses and structural airway changes that gradually impair respiratory performance over time. Recent evidence also suggests that long term hyperbaric exposure may contribute to airway remodeling and small airway dysfunction among occupational divers exposed to repetitive underwater activities.

Pulmonary impairment among traditional divers may initially occur in a subclinical form before clinically significant respiratory symptoms become apparent. Repetitive exposure to hyperbaric environments may induce subtle inflammatory and structural changes within small airways and alveolar tissues that gradually accumulate over time. Because these alterations may progress slowly and remain asymptomatic during early stages, traditional divers may not recognize declining respiratory function until more substantial pulmonary impairment develops. This condition highlights the importance of periodic respiratory surveillance among occupational diving populations, particularly in communities with limited access to specialized pulmonary evaluation (Dong, Brenner, & Harris, 2021).

Interestingly, age, smoking status, body mass index, and diving frequency were not significantly associated with Peak Expiratory Flow in the bivariate analysis. Although the present study focused primarily on occupational exposure duration, respiratory health among traditional divers is likely influenced by complex interactions between occupational, environmental, and behavioral factors. The findings suggest that cumulative occupational diving exposure may have played a more prominent role than smoking status in this study population. However, this interpretation should be considered cautiously because pulmonary function is multifactorial and may be influenced by additional variables not measured in the present study.

Although smoking status was not significantly associated with Peak Expiratory Flow in the present study, nearly three quarters of the participants were active smokers, indicating that tobacco exposure remains an important occupational health concern among traditional divers. The absence of a statistically significant association should not be interpreted as evidence that smoking has no impact on respiratory health. Rather, pulmonary function among traditional divers is likely determined by the combined influence of occupational and behavioral exposures. Repeated hyperbaric exposure, chronic inhalation of compressed air contaminants, and cumulative occupational stress may impose substantial physiological burdens on the respiratory system, potentially making the independent contribution of smoking more difficult to detect within this relatively homogeneous occupational cohort (Blanc et al., 2022; Salik & Ozcan, 2021).

In addition, smoking was classified dichotomously as smoker or non smoker without quantifying cumulative tobacco exposure, such as pack years or smoking intensity. This simplified categorization may have reduced the ability to identify dose response relationships between smoking and pulmonary function, as previous studies have demonstrated that cumulative tobacco exposure is more strongly associated with airflow limitation than smoking status alone (CDC, 2023; GOLD, 2024). Furthermore, the relatively small sample size and the unequal distribution between smokers and non smokers may have limited the statistical power to detect modest associations. Future studies should therefore incorporate quantitative smoking exposure measures together with detailed occupational exposure assessments to better elucidate their independent and combined effects on respiratory function.

Another possible explanation for the relatively modest pulmonary decline observed in some respondents is the healthy worker effect, a phenomenon commonly encountered in occupational epidemiology. Traditional divers experiencing severe respiratory impairment or significant physical limitation may have already reduced or discontinued diving activities and therefore were not represented within the active working population included in this study. Consequently, the study population may have consisted predominantly of relatively healthy individuals who remained physically capable of performing repetitive underwater occupational activities (Blanc et al., 2022).

The absence of a significant association between age and PEF differs from previous studies reporting age-related pulmonary decline (Miller et al., 2021). However, traditional divers in this study generally began diving activities at relatively young ages and continued working for many years, resulting in prolonged cumulative occupational exposure that may exert greater influence on respiratory function than chronological aging itself. Likewise, diving frequency was not significantly associated with PEF, possibly because cumulative work duration better reflects long-term occupational burden than weekly diving frequency alone. Divers with fewer weekly dives may still accumulate substantial lifetime exposure if they have worked for many years in hazardous diving environments.

Although the regression model explained a relatively modest proportion of variance in Peak Expiratory Flow ($R^2 = 0.080$), occupational exposure duration remained a statistically significant factor of pulmonary decline. This finding suggests that respiratory function among traditional divers is likely influenced by multiple biological, environmental, and occupational factors not fully captured within the current model. Variables such as dive depth, compressor maintenance quality, decompression practices, environmental pollutants, nutritional status, and chronic inflammatory conditions may substantially influence pulmonary function among traditional divers. In occupational field studies involving complex environmental exposures, relatively low explanatory models are not uncommon because respiratory outcomes are multifactorial and highly heterogeneous across individuals (Field, 2018).

Traditional compressor assisted divers represent a vulnerable occupational group frequently excluded from formal occupational health protection systems. Limited access to health insurance, preventive screening, standardized diving equipment, and occupational safety training may increase susceptibility to long term respiratory complications. In many coastal communities, economic dependence on diving activities may also compel workers to continue diving despite physical symptoms or declining health conditions. These occupational inequities highlight the importance of strengthening community-based occupational health interventions tailored to informal maritime workers (Blanc et al., 2022; WHO, 2022).

An important implication of this study is the potential application of Peak Expiratory Flow assessment as a practical respiratory screening approach among traditional divers in remote coastal settings. In many low resource maritime communities, access to spirometry and comprehensive pulmonary examination remains limited due to infrastructure and resource constraints. Portable peak flow meters may therefore provide a feasible alternative for early respiratory monitoring and periodic occupational health surveillance conducted by community and occupational health nurses. Early identification of declining pulmonary function may support timely intervention before severe respiratory impairment develops. Integrating simple respiratory screening into community based occupational health programs may therefore strengthen preventive maritime health strategies among traditional diving communities.

The findings have important implications for community and occupational nursing practice, particularly in coastal areas where traditional diving remains a major source of livelihood. Nurses working in community settings can play an important role in implementing routine respiratory screening using simple and affordable tools such as peak flow meters to facilitate early detection of pulmonary impairment. In addition, community based health education programs focusing on safe diving practices, smoking cessation, respiratory health promotion, and occupational risk awareness may help reduce long-term respiratory health problems among traditional divers. Periodic nurse led respiratory surveillance programs may also support early referral and management of individuals experiencing pulmonary function decline.

This study contributes important evidence regarding chronic respiratory health among traditional divers in Indonesia, a population that remains underrepresented in occupational and respiratory health literature. By focusing on pulmonary function decline associated with cumulative occupational exposure, this study expands current understanding beyond acute decompression illness and emphasizes the need for preventive respiratory surveillance and occupational health interventions among traditional compressor-assisted divers.

Study Limitations

This study had several limitations that should be considered when interpreting the findings. First, the cross sectional design limited the ability to establish temporal or causal relationships between occupational exposure duration and pulmonary function decline. Although longer work duration was significantly associated with reduced Peak Expiratory Flow (PEF), exposure and outcome variables were measured simultaneously, preventing determination of whether prolonged diving exposure directly caused pulmonary impairment or whether other unmeasured factors contributed to declining respiratory function. Longitudinal studies are

therefore needed to evaluate progressive pulmonary changes and clarify causal pathways between cumulative diving exposure and respiratory decline among traditional divers.

Second, this study involved a relatively small sample recruited from a single coastal district in Southeast Sulawesi, which may limit the generalizability of the findings to other traditional diving populations in Indonesia or different maritime regions. Traditional diving practices may vary substantially across communities in terms of diving depth, compressor equipment quality, environmental conditions, occupational safety behaviors, and frequency of exposure. Consequently, the findings should be interpreted within the specific occupational and sociocultural context of traditional divers in Soropia District. Furthermore, the sample size was determined using the Slovin formula based on the finite population of active traditional divers rather than an a priori statistical power analysis. Although this approach is commonly applied in community based field research involving relatively small populations, future analytical studies are encouraged to employ formal power analysis methods, such as G*Power, to optimize sample size estimation for regression models. Future multicenter studies involving larger and more diverse diver populations are also necessary to strengthen external validity and improve population level inference.

Third, pulmonary assessment in this study was limited to Peak Expiratory Flow measurements and did not include comprehensive spirometric parameters such as Forced Vital Capacity (FVC), Forced Expiratory Volume in one second (FEV1), or FEV1/FVC ratio. In addition, although the regression model demonstrated statistical significance, its explanatory power was relatively modest, accounting for only 8.0% of the variation in Peak Expiratory Flow values. This finding suggests that pulmonary function among traditional divers is likely influenced by numerous occupational, environmental, behavioral, and physiological factors that were not captured in the present study. Consequently, the observed association should be interpreted cautiously, and future studies incorporating more comprehensive exposure assessments and larger sample sizes are warranted.

Fourth, occupational exposure assessment in this study was relatively limited because work duration was used as a proxy indicator of cumulative diving exposure. Several important exposure-related variables, including diving depth, duration per dive session, ascent rate, decompression practices, compressor maintenance quality, breathing gas contamination, use of personal protective equipment, and previous history of decompression sickness, were not quantitatively measured. These factors may substantially influence pulmonary function and could partly explain the relatively modest explanatory power of the regression model ($R^2 = 0.080$). Respiratory health among traditional divers is likely influenced by complex interactions among occupational, environmental, behavioral, and physiological factors not fully captured within the present study framework.

Fifth, smoking behavior was measured using self reported information without detailed quantification of smoking intensity or cumulative tobacco exposure such as pack years. Consequently, this study could not comprehensively evaluate the dose-response relationship between smoking and pulmonary decline. Recall bias and underreporting may also have occurred because occupational history and smoking behavior were primarily obtained through participant interviews. Although standardized procedures and field verification were conducted during data collection, some degree of information bias may still have been present.

Sixth, healthy worker effect may have influenced the study findings. Traditional divers with severe respiratory impairment or disabling medical conditions may have already stopped diving activities and therefore were not represented in the study population. As a result, active divers included in this study may represent relatively healthier individuals who remained physically capable of performing occupational diving activities. This phenomenon may have contributed to underestimation of the true magnitude of pulmonary impairment associated with prolonged occupational diving exposure.

Several occupational variables, including smoking behavior and work duration, were obtained through self reported interviews and may therefore be subject to recall bias or reporting inaccuracies. Finally, limited healthcare access and the absence of routine occupational health surveillance in coastal communities may have contributed to underrecognition of chronic respiratory symptoms among respondents. Many traditional divers may perceive respiratory complaints as a normal consequence of aging or occupational activity and therefore

may not seek medical evaluation. In addition, the absence of baseline pulmonary data prior to diving exposure prevented direct comparison between pre exposure and current respiratory function status.

Despite these limitations, this study provides important preliminary evidence regarding pulmonary function decline among traditional compressor assisted divers in Indonesia, a population that remains underrepresented in occupational and respiratory health research. The findings highlight the need for future longitudinal studies incorporating larger sample sizes, comprehensive spirometric assessment, environmental exposure measurements, and more detailed occupational risk evaluation to better understand long-term respiratory consequences among traditional divers.

Conclusion

This study found that occupational exposure duration was significantly associated with Peak Expiratory Flow among traditional compressor-assisted divers in Southeast Sulawesi. Divers with longer work duration tended to demonstrate lower PEF values, suggesting that prolonged occupational exposure may be linked to gradual reductions in pulmonary function. Although the observed association was modest, the findings highlight the potential importance of occupational exposure in respiratory health among traditional divers.

From a nursing perspective, these findings support the implementation of routine respiratory screening using simple community-based tools such as peak flow meters, particularly for divers with long occupational histories. Community and occupational health nurses may play an important role in promoting respiratory health, delivering occupational safety education, facilitating smoking cessation counseling, and conducting periodic pulmonary monitoring within coastal communities. Future studies involving larger populations, longitudinal designs, and more comprehensive assessments of diving exposure are recommended to further clarify respiratory health outcomes among traditional compressor-assisted divers.

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Conflict of Interest

The authors declare that there are no financial, personal, or institutional conflicts of interest regarding the publication of this study.

Credit Author Statement

Arfiyan Sukmadi: Conceptualization, methodology, investigation, formal analysis, data curation, visualization, writing original draft. **Arwan Arif Rahman:** Validation, resources, supervision, writing review and project administration.

Declaration of Generative AI and AI-assisted Technologies in the Manuscript Preparation Process

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) to assist with language refinement, grammatical editing, manuscript organization, and improvement of academic writing clarity. After

using this tool, the authors carefully reviewed, revised, and validated the content as needed and take full responsibility for the final content of the published article.

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