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Knowledge-driven risk of diving-induced paralysis: A case-control study among traditional compressor divers in Selayar Regency, Indonesia

Risiko kelumpuhan akibat menyelam berbasis pengetahuan: Studi kasus-kontrol pada penyelam tradisional pengguna kompresor di Kabupaten Selayar, Indonesia

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Abstract

Previous studies on diving-related paralysis have largely focused on recreational or industrial diving, leaving a critical gap in understanding the knowledge-based risk factors affecting traditional compressor divers in informal, high-risk work environments. This study addresses that gap by examining the association between safety knowledge and paralysis incidence among traditional compressor divers in Menara Indah Village, Selayar Regency, Indonesia. Using a case-control design, 44 male respondents were purposively selected, consisting of 22 cases (with diving-induced paralysis) and 22 controls (without paralysis). Data were collected through structured questionnaires and interviews and analyzed using Odds Ratio (OR) and Population Attributable Risk (PAR). The results revealed that divers with poor safety knowledge had 5.4 times higher odds of experiencing paralysis than those with adequate knowledge. Furthermore, the PAR value of 66.44% indicates that two-thirds of paralysis cases in this population could potentially be prevented through improved safety education. These findings underscore the importance of culturally appropriate, community-based safety training to mitigate health risks in informal marine labor sectors. This study contributes novel empirical evidence to support the integration of public health education within occupational safety frameworks, particularly in underserved coastal communities where traditional diving practices remain widespread and underregulated.

Abstrak

Penelitian sebelumnya terkait kelumpuhan akibat aktivitas menyelam sebagian besar berfokus pada penyelaman rekreasional atau industri, sehingga meninggalkan kesenjangan penting dalam memahami faktor risiko berbasis pengetahuan di kalangan penyelam tradisional yang bekerja di lingkungan informal dan berisiko tinggi. Studi ini bertujuan untuk mengisi gap tersebut dengan menganalisis hubungan antara pengetahuan keselamatan menyelam dan kejadian kelumpuhan pada penyelam tradisional pengguna kompresor di Desa Menara Indah, Kabupaten Kepulauan Selayar, Indonesia. Penelitian ini menggunakan desain case-control dengan melibatkan 44 responden laki-laki yang dipilih secara purposif, terdiri dari 22 kasus (mengalami kelumpuhan akibat menyelam) dan 22 kontrol (tidak mengalami kelumpuhan). Data dikumpulkan melalui kuesioner terstruktur dan wawancara, serta dianalisis menggunakan Odds Ratio (OR) dan Population Attributable Risk (PAR). Hasil menunjukkan bahwa penyelam dengan tingkat pengetahuan keselamatan yang rendah memiliki kemungkinan 5,4 kali lebih besar untuk mengalami kelumpuhan dibandingkan dengan penyelam yang memiliki pengetahuan cukup. Nilai PAR sebesar 66,44% mengindikasikan bahwa sekitar dua pertiga kasus kelumpuhan dalam populasi ini dapat dicegah jika pengetahuan keselamatan ditingkatkan. Temuan ini menegaskan pentingnya pelatihan keselamatan yang berbasis budaya lokal dan dilakukan di tingkat komunitas untuk mengurangi risiko kesehatan pada sektor kerja laut informal. Studi ini memberikan kontribusi empiris baru dalam mendukung integrasi pendidikan kesehatan masyarakat ke dalam kerangka keselamatan kerja, khususnya di komunitas pesisir yang masih mengandalkan praktik penyelaman tradisional tanpa regulasi yang memadai.

Keywords :

decompression sickness; diving; occupational health; paralysis; working conditions

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INTRODUCTION

Traditional diving practices in Southeast Asia, such as those in Bali, Indonesia, are not only culturally significant but also rooted in local ecological knowledge that supports diver health and safety (Indah et al., 2023; Franco et al., 2022). This knowledge includes the use of ecological calendars that guide safe diving periods based on sea conditions and the availability of marine resources (Franco et al., 2022). These intergenerational practices enhance safety by promoting communal learning—such as recognizing dangerous currents, seasonal weather patterns, and hazardous marine species. Preserving such traditional knowledge is therefore essential, not only for ecological and cultural sustainability but also as an adaptive strategy to mitigate health risks and diving accidents amidst environmental changes and increasing tourism pressure (Franco et al., 2022).

However, as traditional diving adapts to more modern and extractive practices—such as the use of compressor diving in artisanal fisheries—the associated health risks have become more severe and complex. Diving-related health risks, particularly paralysis stemming from cervical spine injuries, represent a significant concern in both recreational and professional contexts. Injuries often occur due to diving into shallow water, where the impact can lead to severe neck and spinal damage. Such incidents can result in profound morbidity and, in many cases, paralysis (Yılmaz et al., 2021). The mechanism behind these injuries suggests improper diving techniques, including diving from excessive heights and entering water at inappropriate angles (Pandey et al., 2022).

Furthermore, decompression sickness (DCS) is another major health hazard associated with diving. It arises from abrupt changes in environmental pressure, leading to the formation of nitrogen bubbles in the body. DCS can manifest as serious neurological complications, including paralysis, if not recognized and treated timely (Fitriasari et al., 2024; Garrido et al., 2021). With the rise in the popularity of scuba diving and the increased use of compressors among artisanal divers, the incidence of DCS-related health issues is also increasing, emphasizing the need for education and awareness among divers about preventive measures (Pińkowska et al., 2020). Proactive measures such as proper dive planning and adherence to safety protocols are essential for mitigating these risks and enhancing diver safety (Fitriasari et al., 2024; Tetzlaff, 2023).

Safety knowledge plays a crucial role in occupational health, directly influencing the incidence of workplace accidents across various sectors. Research indicates that increased safety awareness significantly enhances safe behaviors among employees. For instance, Loney et al. found that compliance with health and safety protocols is correlated with workers' awareness of associated risks, asserting that a lack of understanding can lead to higher accident rates (Ünal, 2020). This is further supported by Topçu and Ardahan, who demonstrate that health and safety training improves reporting rates of occupational accidents among nursing students, suggesting that knowledge gaps can hinder effective safety practices (Topçu & Ardahan, 2024).

Moreover, a significant relationship has been established between occupational safety knowledge and the frequency of work accidents. A literature review conducted by Umami indicates that nurses with better knowledge of occupational safety and health are less prone to experience workplace incidents (Umami, 2022). This implies that comprehensive safety training can significantly mitigate risks. Additionally, implementing thorough safety inspections and socialization training in workplaces enhances employee competency regarding safety measures, leading to improved outcomes in work accident prevention (Hidayah et al., 2022; Diannita et al., 2020).

In Indonesia, significant gaps exist in public health and labor safety interventions, primarily related to disparities in resource allocation and the lack of effective implementation of safety protocols. One critical issue is the inadequate infrastructure and facilities in less developed regions, which hampers access to essential healthcare services. Research indicates that the eastern regions of Indonesia, characterized by lower industrial and transportation development, face greater challenges in accessing postnatal care compared to their western counterparts (Cahyono et al., 2021). This disparity highlights an urgent need for targeted interventions that consider socio-economic contexts.

Moreover, the occupational safety landscape reveals a concerning gap in knowledge and awareness among workers, particularly in industries such as diving and fishing. Studies indicate that traditional fishermen often operate without adequate safety training, which contributes to unsafe practices and increased health risks (Ernawati, 2021). The absence of a robust health and safety culture exacerbates the frequency of work-related injuries, suggesting a need for comprehensive training and legislative support to bolster occupational safety standards

(Umami, 2022). Furthermore, existing public health policies appear inadequately equipped to address mental health issues, primarily due to insufficient legislative frameworks and training for healthcare professionals (Basrowi et al., 2024). Addressing these challenges requires a multifaceted approach that integrates improved infrastructure, enhanced training for health professionals, and targeted public health initiatives to reduce disparities and elevate health standards across the nation.

Integrating occupational safety into broader community health strategies is essential for enhancing overall public health outcomes. Existing research highlights the interconnectedness between occupational safety and community health, suggesting that enhancing workplace safety can alleviate broader societal health problems. For instance, Ibáñez-Cruz et al. emphasize that effective solid waste management can mitigate healthcare-associated infections from occupational exposure, thereby improving community health through integrated public policies (Ibáñez-Cruz et al., 2025). Moreover, the development of a safety culture within organizations can significantly enhance occupational health performance. Mayasari and Aisyarah argue that promoting an occupational health and safety culture is vital for maintaining a safe workplace, which can indeed improve overall organizational reputation and performance (Mayasari & Aisyarah, 2024). Additionally, technological innovations in occupational safety, such as the use of AI and IoT, offer promising tools to monitor and improve safety behavior and risk detection (Pishgar et al., 2021).

Despite the growing body of literature on occupational safety and diving-related risks, few studies have focused on traditional compressor divers in remote, resource-limited settings such as Selayar District. Prior studies have predominantly emphasized recreational divers or industrial contexts, leaving a knowledge gap regarding artisanal diving communities that depend on compressors without formal safety regulation (Dowse et al., 2019; Montoliu et al., 2024; Ranapurwala et al., 2018). Moreover, existing investigations rarely quantify the extent to which safety knowledge directly contributes to disabling conditions such as paralysis. This represents a critical omission, as traditional compressor diving is particularly susceptible to decompression-related injuries due to unregulated practices and limited awareness of physiological risk.

This study contributes to filling that gap by examining the specific association between safety knowledge and paralysis incidence among traditional compressor divers in Menara Indah Village, Selayar Regency. Using a case-control design, the study not only quantifies the relationship between knowledge and risk but also calculates the population attributable risk to assess the preventable burden. By offering empirical evidence from a neglected population group, this research advances the discourse on occupational safety in informal sectors and proposes actionable interventions. Therefore, the objective of this study is to assess the relationship between diving safety knowledge and the risk of paralysis among traditional compressor divers, providing evidence to support community-based safety education as a strategy for health risk reduction

METHODS

This study employed an analytical observational design with a case-control approach to investigate the relationship between diving safety knowledge and the incidence of paralysis among traditional compressor divers. The research was conducted in Menara Indah Village, located in Bontomatene District, Selayar Regency, South Sulawesi, Indonesia. This site was selected based on its high prevalence of artisanal compressor diving as a primary livelihood, despite the lack of formal safety training and health regulation. The area is known for its reliance on informal diving practices, which exposes divers to significant occupational health risks, particularly decompression sickness and diving-induced trauma. Given the limited access to health facilities and diving education in the region, Menara Indah provided a relevant and urgent context for exploring safety-related knowledge as a determinant of health outcomes among traditional divers.

The study population consisted of male traditional divers who used compressor equipment for underwater fishing. A total of 44 participants were included, selected using purposive sampling to ensure relevance and comparability between groups. Participants were divided equally into two groups: 22 cases (individuals with documented paralysis caused by diving activities) and 22 controls (divers with no history of paralysis). Inclusion criteria required that participants be active traditional compressor divers, have a minimum work experience of more than one year, and provide informed consent to participate in the study. Ethical considerations were adhered to by informing all respondents of the study's objectives, ensuring voluntary participation, and obtaining written informed consent prior to data collection.

Table 1. Characteristics of respondents

Characteristics	n	%
Age		
Adolescent	3	6.8
Adult	18	40.9
Elderly	23	52.3
Employment Duration Status		
New	5	11.4
Experienced	39	88.6
Education Level		
Elementary School	28	63.6
Junior High School	1	2.3
Senior High Schoo	6	13.6
No Formal Education	9	20.5
Knowledge Level		
Good	0	0.00
Adequate	28	63.6
Poor	16	36.4

Data collection was carried out using structured questionnaires and in-depth interviews. The questionnaire included both closed and open-ended questions designed to assess divers' knowledge regarding safety procedures, such as proper decompression techniques, awareness of underwater hazards, safe diving depth and duration, equipment usage, and emergency response protocols. Interview questions also explored participants' diving routines, experiences with accidents, and access to health services. The instrument was pretested to ensure validity and reliability. Data management involved manual checking for completeness, coding, and entry into a digital database. Statistical analysis was conducted using the Odds Ratio (OR) to determine the strength of association between poor safety knowledge and the risk of paralysis. Additionally, the Population Attributable Risk (PAR) was calculated to estimate the proportion of paralysis cases that could potentially be prevented if the knowledge level were improved. The analysis provided both quantitative risk estimates and public health implications, reinforcing the study's contribution to marine occupational safety research.

RESULTS

Table 1 presents the demographic and background characteristics of the respondents. The majority of participants were categorized as elderly, comprising 23 individuals (52.3%), followed by adults at 18 individuals (40.9%), and adolescents at only 3 individuals (6.8%). In terms of employment duration, a significant majority of respondents (88.6%) were classified as experienced divers, while only 11.4% were relatively new to the occupation.

Regarding educational attainment, most respondents had completed elementary school (63.6%), followed by those with no formal education (20.5%). A smaller proportion had attained senior high school education (13.6%), and only one respondent (2.3%) had completed junior high school. Concerning their level of knowledge about diving safety, none of the respondents demonstrated a good level of knowledge (0%), while 28 individuals (63.6%) had an adequate level of knowledge and 16 individuals (36.4%) were categorized as having poor knowledge.

Table 2 illustrates the association between diving safety knowledge and the occurrence of paralysis among traditional compressor divers. Among those who experienced paralysis, 81.8% (18 out of 22 individuals) had a poor level of knowledge, whereas only 18.2% had adequate knowledge. In contrast, among the non-paralyzed group, 45.5% had poor knowledge and 54.5% had adequate knowledge.

The statistical analysis yielded an Odds Ratio (OR) of 5.4, indicating that divers with poor knowledge of diving safety are 5.4 times more likely to suffer from paralysis than those with adequate knowledge. This suggests a relative risk increase of 440% due to insufficient knowledge. These findings provide strong evidence that

Table 2. The role of risk factors in the occurrence of paralysis in traditional divers

Knowledge Level	Paralysis History				Total		OR
	Paralyzed		Not Paralyzed				
	n	%	n	%	n	%	
Poor	18	81.8	10	45.5	28	63.6	5.4
Adequate	4	18.2	12	54.5	16	36.4	

inadequate understanding of safe diving practices significantly increases the likelihood of paralysis among traditional divers.

PAR = p(r-1)/(P(r-1)+1)
Where P = 10/(10+12) = 0.45
PAR = 0.45(5.4)/(0.45(5.4-1)+1)
= 1.98/2.98
= 0.6644

Furthermore, an analysis of the Population Attributable Risk (PAR) was conducted to estimate the proportion of paralysis cases that could be attributed to poor safety knowledge within the population. The calculated PAR value was 0.6644, or 66.44%. This implies that approximately two-thirds of paralysis cases in this population could be explained by the risk factor under investigation—namely, poor knowledge of diving safety. In practical terms, if all divers possessed at least an adequate incidents could potentially be prevented.

Taken together, these results underscore a significant and actionable relationship between knowledge deficits and the risk of diving-induced paralysis. They highlight the urgent need for targeted educational interventions and standardized safety training, particularly in artisanal diving communities where formal regulation and awareness are often lacking. This evidence strengthens the call for integrating public health education into occupational safety frameworks in marine-based livelihoods.

DISCUSSION

The findings of this study reveal a significant association between low levels of safety knowledge and the incidence of paralysis among traditional compressor divers in Selayar Regency. Respondents with poor knowledge were found to be 5.4 times more likely to suffer from diving-induced paralysis compared to those with adequate knowledge, and approximately 66.44% of paralysis cases in this population could be attributed to this knowledge gap. These results highlight a critical and preventable occupational health risk within informal marine work environments, where structured health and safety education is typically absent.

Informal work environments often lack structured health and safety education, leading to increased vulnerability among workers. Research indicates that workers in the informal sector frequently operate without the necessary awareness of workplace hazards, which significantly heightens their risk of injury and illness. Gangopadhyay (2024) highlights that many health and safety issues in informal sectors arise from poor awareness of risks due to a lack of training and education, which is directly related to deficiencies in structured safety programs. This systemic lack of institutional safety mechanisms renders informal workers highly susceptible to occupational hazards that could otherwise be mitigated through formal educational interventions.

The issue is further exacerbated by fragmented and limited access to occupational health services in marginalized communities. For example, Mlangeni et al. (2021) found that street vendors in South Africa—another vulnerable informal labor group—faced increased risks of infectious diseases due to poor access to health services. Similarly, the compressor diving community in Selayar represents a rural, economically marginalized group where access to preventive occupational health interventions is virtually nonexistent. This context reinforces the urgency of integrating health and safety education into broader community health frameworks.

Moreover, Khan (2021) emphasizes the inadequacy of protective mechanisms for informal sector workers, revealing gaps in the implementation and targeting of safety measures. The lack of systemic support in terms of legislation, regulation, and education not only increases health risks but also perpetuates occupational inequality. As such, Samant and Færevåg (2024) underscore the importance of incorporating occupational health efforts into community health strategies to promote safety and well-being among vulnerable populations.

Given the cultural and traditional nature of the

diving community studied, the potential for culturally tailored interventions is especially relevant. Safety education that respects and integrates local customs and traditional knowledge is more likely to be accepted and retained by the target population. Monterroza and Solano (2024) advocate for integrating traditional knowledge into learning processes, as culturally relevant curricula enhance both understanding and engagement. For traditional divers, this could involve framing safety protocols using familiar terms and indigenous ecological knowledge that has been passed down across generations.

To enhance the relevance and impact of safety training, educational content must be designed collaboratively with local communities. Visual and auditory methods that reflect local dialects, diving experiences, and ecological rhythms can improve comprehension. Holst et al. (2022) demonstrate the effectiveness of co-designed multimedia tools in improving knowledge retention in community health education. These tools can be adapted to the diving context through animated scenarios or audio-visual modules that incorporate common diving routines, accident narratives, and survival stories from the divers themselves.

The integration of traditional knowledge into formal safety modules not only respects cultural values but also strengthens local credibility. Existing safe practices passed through generations can be framed as foundations upon which to build modern diving safety standards. Makasi et al. (2023), while studying community-based epilepsy education, emphasized the value of using community health workers and visual aids to support behavioral change—strategies that are equally applicable to marine occupational health promotion.

Comparative evidence from other occupational groups strengthens the case for context-specific training. Azar et al. (2023) showed that in the automotive industry, safety training significantly improved workers' risk perception and job satisfaction, demonstrating the broader psychological benefits of structured safety programs. In a similar vein, Özay et al. (2021) revealed that firefighters' perceptions of safety culture were influenced by education and occupational experience, implying that knowledge-based interventions are not only preventive but transformative.

Interventions must also be rooted in community structures to ensure uptake and sustainability. Lara et al. (2021) found that community health worker-led initiatives were particularly effective among immigrant day laborers, due to the use of peer educators and culturally competent strategies. Zeidan et al. (2024), on the other hand, warned that structural vulnerabilities such as immigration status could compound occupational risks—underscoring the need to address social determinants alongside education.

Implementing effective safety training requires a multi-sectoral strategy that includes policy development, inter-agency coordination, and capacity building. Tancred et al. (2024) advocate for competency-based training models developed through collaboration between academic institutions, professional associations, and ministries. These insights are echoed by Tamminen et al. (2021), who stressed the importance of intersectoral competencies in delivering health-related education. Macfarlane et al. (2024) further support this integrated approach by demonstrating that multisectoral collaboration enhances the scope and sustainability of public health interventions. Finally, robust monitoring frameworks and feedback loops, as emphasized by Kriegner et al. (2020), are essential to adapt and refine educational programs. Long-term capacity building, as discussed by Chiari et al. (2023), ensures that knowledge is not only transferred but maintained through community leadership and innovation.

This study has several strengths that contribute to its value in the field of occupational health in informal sectors. It provides novel empirical evidence by quantifying the relationship between diving safety knowledge and paralysis incidence using a case-control design, and applies statistical tools such as Odds Ratio and Population Attributable Risk to estimate both relative and preventable risks. The study also highlights the real-world implications of knowledge-based interventions in a culturally and geographically unique context, offering a foundation for future educational programs tailored to traditional diving communities.

However, this study also has limitations that should be acknowledged. First, the use of purposive sampling and the relatively small sample size may affect the generalizability of the findings to other regions or populations of traditional divers. Second, the reliance on self-reported data through interviews and questionnaires may introduce recall bias or social desirability bias. Lastly, the study did not explore additional confounding factors such as access to emergency medical care, diving equipment conditions, or frequency of deep dives, which may also influence the risk of paralysis. Future research should aim to include larger and more diverse samples, employ mixed-method approaches, and consider longitudinal designs to

strengthen causal inference and explore behavioral change over time.

CONCLUSION

This study concludes that a low level of knowledge regarding safe diving practices is a significant and preventable risk factor for paralysis among traditional compressor divers in Menara Indah Village, Bontomatene Sub-district, Selayar Islands Regency. The finding that divers with poor safety knowledge are 5.4 times more likely to experience paralysis, and that 66.44% of such cases could potentially be prevented through improved knowledge, highlights a critical gap in occupational health awareness in informal marine labor sectors. These results underscore the urgent need to address safety education in culturally and contextually relevant ways to protect the health of traditional divers. From a public health perspective, this study contributes to the growing body of evidence that knowledge-based interventions can significantly reduce occupational injury risks in underserved communities. It reinforces the importance of integrating diving safety education into local health strategies and community empowerment programs, particularly in geographically isolated coastal regions where formal occupational regulation is limited. Based on these findings, it is recommended that targeted health education programs be developed for traditional divers, incorporating local language, traditional knowledge, and multimedia tools to enhance understanding and retention. Health officers and community health workers should be mobilized to deliver these programs through participatory, community-based approaches. Stakeholders—such as local governments, marine authorities, and non-governmental organizations—should prioritize occupational safety policies and provide accessible training tailored to the needs of artisanal fishing communities. Future researchers are encouraged to expand on this study by exploring other contributing factors to diving-related morbidity and testing the effectiveness of educational interventions through longitudinal and experimental designs.

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AUTHORS' CONTRIBUTIONS

Rizky Maharja designed the study, formulated the concept, wrote the manuscript and analyzed the data. Riadnin Maharja with Edi Saputra collected data and revised the manuscript. Andi Mifta Farid Panggeleng with Bambang Hermawan reviewed the manuscriptand and performed the field work. All Authors approved the final paper.

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COMPETING INTERESTS

The authors affirm that there are no conflicts of interest related to the research, writing, or publication of this article.

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