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Indoor Residual Spraying: Successes, Resistance, Challenge

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Introduction

Indoor Residual Spraying (IRS) stands as a foundational strategy in the global fight against malaria, offering a direct means to control vector populations within human dwellings. One such intervention, the use of pirimiphos-methyl for IRS, has been rigorously evaluated for its impact on malaria transmission indicators. A study conducted in Benin, for instance, demonstrated that IRS significantly lowered vector densities, parity rates, and human biting rates of prevalent malaria vectors like Anopheles gambiae s.l. and Anopheles funestus s.l. in treated areas when compared to control sites. These findings strongly support the effectiveness of IRS in disrupting malaria transmission cycles, even when confronting the complexities of emerging insecticide resistance in a given region [1].

The challenge of insecticide resistance is a persistent threat to the efficacy of vector control programs, necessitating continuous evaluation of existing and new compounds. In Uganda, research specifically focused on the performance of pirimiphos-methyl for IRS against malaria vectors already known to be resistant to other common insecticides. This work confirmed that pirimiphos-methyl maintained robust residual efficacy for as long as six months on various indoor wall surfaces. It effectively killed local populations of Anopheles gambiae s.l., even where widespread resistance to pyrethroids and carbamates had been observed. This important outcome positions pirimiphos-methyl as a viable and crucial option for IRS in regions characterized by specific resistance profiles, highlighting the urgent need for ongoing resistance monitoring to guide insecticide selection [2].

Beyond the entomological and chemical efficacy, the success of IRS programs hinges on community acceptance and participation. A qualitative study undertaken in rural South Africa delved into community perceptions and the acceptability of IRS as a malaria control measure. The investigation revealed a general acceptance of IRS within these communities, largely due to the perceived benefits, such as reduced mosquito nuisance and, importantly, a decrease in malaria cases. However, the study also identified significant concerns among residents. These worries included potential adverse health effects, damage to property during spraying, and the lingering odor of the insecticides. The findings emphasized that effective communication strategies, robust community engagement, and proactive measures to address these specific fears are absolutely essential for boosting IRS coverage and ensuring the long-term success and sustainability of malaria control initiatives [3].

The continuous evolution of insecticide resistance demands the development and evaluation of novel insecticidal compounds and formulations. A compelling study conducted in Southern Mali explored the efficacy of a new co-formulation involving clothianidin and deltamethrin for IRS against local malaria vectors. The results from this research were highly encouraging, demonstrating that this innovative formulation offered excellent residual efficacy. It proved effective in eliminating highly resistant populations of Anopheles gambiae over several months, even when applied to different types of wall surfaces common in the region. This combined insecticide formulation represents a promising new alternative for IRS deployment, particularly in areas grappling with widespread resistance to conventional insecticides, thus providing a vital tool to sustain malaria control efforts [4].

The strategic integration of multiple control measures can often yield greater impacts than standalone interventions. The economic justification for such integrated approaches is also a critical consideration for public health planning. In The Gambia, researchers evaluated the cost-effectiveness of an integrated malaria control package that combined IRS with Long-Lasting Insecticidal Nets (LLINs). The study concluded that this combined intervention was remarkably cost-effective in preventing both malaria cases and associated deaths. It delivered substantial health benefits at a relatively low cost per Disability-Adjusted Life Year (DALY) averted. This evidence strongly reinforces the economic rationale for implementing integrated vector control strategies, particularly in settings with a high burden of malaria, showcasing the value of a multi-pronged approach [5].

Scaling up effective interventions like IRS across vast and diverse regions presents its own set of unique programmatic and operational hurdles. An insightful article outlined the primary challenges and opportunities associated with expanding IRS for malaria control throughout sub-Saharan Africa. Key challenges identified included securing sustained funding, effectively managing the ongoing issue of insecticide resistance, ensuring widespread community acceptance, and overcoming significant logistical barriers inherent in large-scale operations. Conversely, opportunities were recognized in the development of new insecticides, the enhancement of surveillance systems, and the strategic integration of IRS with other malaria control interventions. The authors emphasized that robust programmatic implementation and the adoption of adaptive strategies are crucial to maximizing the impact and reach of IRS [6].

The search for next-generation insecticides with extended residual activity against resistant vector populations is paramount. Research conducted in Tanzania specifically investigated the residual efficacy of Fludora Fusion, a neonicotinoid-pyrethroid mixture, when applied via IRS on various wall surfaces against malaria vectors. This investigation yielded positive results, indicating that Fludora Fusion maintained a high level of insecticidal efficacy on typical indoor surfaces, which included mud, cement, and even painted walls, for a period of at least six months. This demonstrated extended residual activity is vitally important for effective, long-term vector control and provides a valuable new tool, particularly in areas where

insecticide resistance profiles are constantly changing, ensuring sustained protection against malaria-carrying mosquitoes [7].

The power of integrated vector control to substantially reduce malaria burden has been further substantiated in diverse epidemiological contexts. In Eastern India, a study evaluated the effectiveness of an integrated vector control approach that incorporated IRS alongside other key interventions such as Long-Lasting Insecticidal Nets (LLINs) and Larval Source Management. The findings were clear: this combined strategy led to a significant reduction in both malaria incidence and prevalence when compared to areas where only single interventions were deployed. This evidence strongly highlights the synergistic benefits that integrated approaches offer, proving them capable of achieving substantial and sustainable reductions in malaria burden, particularly in settings with complex disease patterns and transmission dynamics [8].

Effective monitoring and evaluation (M&E) are indispensable for optimizing the performance of malaria control programs and identifying operational bottlenecks. A detailed review of M&E data from operational IRS campaigns carried out in Western Kenya between 2017 and 2020 revealed consistent challenges in meeting target spray coverage. These difficulties were primarily attributed to household refusals and accessibility issues. The assessment underscored the critical need for strengthening M&E systems, developing more effective community engagement strategies, and implementing adaptive planning. These measures are essential to overcome practical hurdles and maximize the public health impact of IRS programs as they are implemented in real-world, routine settings, ensuring that intended benefits reach the target populations [9].

While insecticides are vital tools for disease control, a thorough understanding of their environmental and human health implications is crucial. A study conducted in a malaria-endemic region of South Africa performed an environmental and human health risk assessment of IRS using Dichloro-Diphenyl-Trichloroethane (DDT). The research detected quantifiable levels of DDT and its metabolites in both environmental samples and human biological samples. These findings raise serious concerns about the potential for long-term health and ecological impacts, even while acknowledging DDT's historical effectiveness in malaria control. The study emphasized the critical importance of carefully balancing the immediate public health benefits against the broader environmental and human health risks when making choices about insecticides for IRS, especially for those compounds known to be persistent organic pollutants [10].

Description

Indoor Residual Spraying (IRS) is a cornerstone of malaria vector control, with ongoing research validating its efficacy and exploring new tools. In Benin, a study confirmed that IRS with pirimiphos-methyl significantly reduced entomological indicators of malaria transmission, including vector densities and human biting rates of Anopheles gambiae s.l. and Anopheles funestus s.l., even in areas with emerging insecticide resistance [1]. Similarly, in Uganda, pirimiphos-methyl demonstrated sustained residual efficacy for up to six months on various wall surfaces, effectively controlling local Anopheles gambiae s.l. populations resistant to pyrethroids and carbamates [2]. This highlights its continued relevance, provided resistance monitoring is robust. Advancements in insecticide formulations are also proving critical. A novel co-formulation of clothianidin and deltamethrin, tested in Southern Mali, provided excellent residual efficacy against highly resistant Anopheles gambiae, presenting a promising alternative for resistance management [4]. Another new compound, Fludora Fusion, a neonicotinoid-pyrethroid mixture, showed high insecticidal efficacy on diverse wall types for at least six months in Tanzania, reinforcing the potential of innovative products to sustain effective vector control [7].

The trend towards integrated malaria control strategies is gaining traction due to demonstrated synergistic benefits and cost-effectiveness. Research in The Gambia evaluated an integrated intervention package combining IRS with Long-Lasting Insecticidal Nets (LLINs). This approach proved highly cost-effective, significantly averting malaria cases and deaths at a low cost per Disability-Adjusted Life Year (DALY) averted, providing strong economic justification for its deployment in high-burden settings [5]. Further supporting this, a study in Eastern India found that integrated vector control, comprising IRS, LLINs, and larval source management, led to substantial reductions in malaria incidence and prevalence compared to single interventions. This confirms the enhanced effectiveness of multi-pronged strategies in complex epidemiological scenarios [8].

Despite the clear benefits of IRS, its operational scale-up and sustained success are often hampered by a range of challenges. In sub-Saharan Africa, these include securing consistent funding, effectively managing insecticide resistance, ensuring widespread community acceptance, and overcoming logistical hurdles [6]. Community engagement plays a pivotal role; a qualitative study in rural South Africa found that while IRS was generally accepted for reducing mosquito nuisance and malaria, concerns about health effects, property damage, and insecticide smell were prevalent. Addressing these fears through effective communication and engagement is vital for improving coverage and program success [3]. Operational challenges are also evident in monitoring and evaluation data from Western Kenya, which revealed consistent difficulties in achieving target spray coverage due to household refusals and inaccessible homes. This underscores the need for improved M&E systems, better community engagement, and adaptive planning to optimize public health impact in routine implementation [9].

The choice of insecticide for IRS also involves crucial considerations regarding environmental and human health risks. A risk assessment conducted in a malaria-endemic area of South Africa focused on the use of Dichloro-Diphenyl-Trichloroethane (DDT) for IRS. The study detected measurable levels of DDT and its metabolites in both environmental and human samples. These findings raise concerns about potential long-term health and ecological impacts, requiring a careful balance between the public health benefits of malaria control and the risks associated with persistent organic pollutants. This highlights the importance of evidence-based decision-making in selecting insecticides for IRS programs [10].

Conclusion

Indoor Residual Spraying (IRS) remains a critical intervention for malaria control, demonstrating effectiveness across various African settings. Studies in Benin showed IRS using pirimiphos-methyl significantly reduced vector densities and human biting rates, even amidst insecticide resistance challenges. In Uganda, pirimiphos-methyl maintained good residual efficacy for up to six months against resistant vectors, suggesting its continued viability with proper monitoring. Novel insecticide formulations also show promise; a co-formulation of clothianidin and deltamethrin in Mali exhibited excellent residual efficacy against highly resistant Anopheles gambiae populations, offering new alternatives. Similarly, Fludora Fusion in Tanzania provided sustained insecticidal activity for at least six months on diverse wall surfaces.

The integration of IRS with other interventions, such as Long-Lasting Insecticidal Nets (LLINs) and larval source management, proved highly cost-effective in The Gambia and significantly reduced malaria incidence in Eastern India, underscoring the synergistic benefits of combined strategies. However, the successful implementation of IRS faces substantial challenges, including maintaining funding, managing insecticide resistance, and ensuring community acceptance. Community perceptions in South Africa, while generally positive due to perceived benefits, also revealed concerns about health effects and property damage, highlighting

the need for effective communication and engagement. Operational campaigns in Western Kenya consistently struggled with achieving target spray coverage due to refusals and inaccessible households, emphasizing the need for improved monitoring and evaluation systems. The environmental and human health risks associated with certain insecticides, like DDT, also necessitate a careful balance between public health benefits and potential long-term impacts when selecting IRS agents.

Acknowledgement

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Conflict of Interest

None.

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