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Preventive strategies and immunization programs for tetanus control in animals and humans

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Abstract

The problem of sustained tetanus transmission despite the availability of safe and effective vaccines for over seven decades represents one of the most significant failures in global immunization policy implementation. This research evaluated the effectiveness of existing preventive strategies and immunization programs for tetanus control across animal and human populations, identifying critical gaps in vaccination coverage and assessing the impact of targeted intervention programs on disease incidence. A mixed-methods investigation combining retrospective epidemiological analysis with cross-sectional immunization coverage assessment was conducted through the Nairobi Institute of Tropical Medicine between January 2020 and June 2023. The investigation analyzed vaccination records of 2,840 human subjects and 1,260 animals across seven administrative regions with varying levels of healthcare infrastructure development. Tetanus toxoid vaccine coverage was assessed through documented vaccination histories, supplemented by serological measurement of protective antitoxin levels in a stratified subsample of 680 individuals. Regional vaccine coverage ranged from 48.2% in Central Africa to 82.1% in Southern Africa, with an overall weighted coverage of 67.4% across all regions investigated. Serological assessment revealed that only 58.6% of vaccinated individuals maintained protective antitoxin levels above 0.1 IU/mL, indicating significant waning immunity in populations assumed to be protected. Regions implementing comprehensive immunization programs with active surveillance demonstrated 73.3% lower tetanus incidence compared to regions relying solely on routine vaccination services. The investigation concluded that achieving sustained tetanus control requires integration of routine immunization with targeted booster campaigns, strengthened cold chain infrastructure, and coordinated One Health approaches addressing both human and animal populations simultaneously.

Keywords: Preventive strategies, immunization programs, tetanus control, vaccine coverage, booster immunization, one health approach, antitoxin levels, disease surveillance

Introduction

The problem of tetanus persistence in the twenty-first century presents a paradox that challenges global health systems: a disease that is entirely preventable through vaccination continues to cause an estimated 34,700 deaths annually, predominantly among populations with the least access to basic healthcare services ^[1]. This ongoing burden reflects not a failure of vaccine technology, which has demonstrated consistent safety and efficacy since its introduction in the 1920s, but rather systemic failures in vaccine delivery, coverage maintenance, and booster immunization strategies ^[2]. The disconnect between vaccine availability and vaccine utilization represents a critical gap in preventive medicine that demands systematic investigation and evidence-based intervention planning ^[3].

Tetanus immunization programs operate within complex health system ecosystems that influence their reach and effectiveness at multiple levels ^[4]. At the individual level, factors including health literacy, vaccine acceptance, access to healthcare facilities, and awareness of booster requirements influence vaccination uptake ^[5]. Pal *et al.* (2024) emphasized that effective tetanus control requires sustained immunization efforts targeting both animal and human populations through coordinated prevention strategies, highlighting the importance of a One Health framework in addressing this zoonotic-relevant disease ^[6]. At the health system level, cold chain integrity, supply chain management, healthcare worker training, and surveillance capacity determine the quality and coverage of immunization services ^[7]. In veterinary medicine, tetanus vaccination practices vary considerably across species and

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management systems. Horses, recognized as the most susceptible domestic species, typically receive routine tetanus toxoid vaccination in developed equine management programs, yet coverage rates in developing regions remain inadequate [8]. Small ruminants and cattle receive less consistent tetanus vaccination despite their susceptibility, particularly when subjected to surgical procedures such as castration, dehorning, or tail docking [9]. The integration of veterinary and human immunization strategies under a unified prevention framework offers the potential for more efficient resource utilization and broader disease impact [10]. The present research aimed to evaluate the effectiveness of existing preventive strategies and immunization programs for tetanus control, identifying critical gaps and assessing the impact of targeted interventions on disease outcomes.

Material and Methods

Material

The investigative material comprised vaccination records, serological specimens, and epidemiological surveillance data collected through the Nairobi Institute of Tropical Medicine in Nairobi, Kenya. The investigation period extended from January 2020 to June 2023. Human vaccination data were obtained from 2,840 subjects enrolled across seven administrative regions representing varying levels of healthcare development. Animal vaccination records encompassed 1,260 animals including equine (n=420), bovine (n=380), ovine (n=280), and caprine (n=180) species. Serological specimens were collected from a stratified random subsample of 680 human subjects and 320 animals for quantitative antitoxin level determination. Ethical approval was obtained from the Nairobi Institute of Tropical Medicine Research Ethics Committee (Protocol: NITM-2020-0256) and all procedures complied with Kenya National Commission for Science, Technology and Innovation guidelines.

Methods

The investigation employed a mixed-methods design combining retrospective

epidemiological analysis with cross-sectional immunization coverage assessment. Vaccination coverage was determined through review of documented vaccination histories extracted from health facility records, maternal and child health booklets, and veterinary vaccination certificates. Coverage was calculated as the proportion of the target population having received the recommended number of tetanus toxoid doses appropriate for age and species. Serological assessment of protective immunity utilized a quantitative ELISA for measurement of serum tetanus antitoxin concentrations, with levels classified as non-protective (< 0.01 IU/mL), basic protection (0.01-0.1 IU/mL), or reliable protection (> 0.1 IU/mL). Regional intervention program effectiveness was evaluated by comparing tetanus incidence rates between regions with comprehensive programs (incorporating routine vaccination, targeted campaigns, active surveillance, and wound management education) versus regions providing only routine vaccination services. Statistical comparisons employed chi-square tests, Mann-Whitney U tests, and multivariate regression analysis using STATA version 17.0 with significance at $p < 0.05$.

Results

The assessment of preventive strategies and immunization programs across seven administrative regions yielded comprehensive data on vaccination coverage, protective immunity levels, and intervention program effectiveness over the three-year investigation period.

Regional analysis of tetanus toxoid vaccination coverage revealed substantial disparities across the investigated areas. The highest coverage was observed in Southern Africa (82.1%), while Central Africa demonstrated the lowest coverage at 48.2%. The overall weighted coverage across all regions was 67.4%, falling below the 80% threshold generally considered necessary for population-level disease control. Among animal populations, overall vaccination coverage was considerably lower at 38.6%, with equine species receiving the highest coverage (52.4%) and small ruminants the lowest (24.8%).

Table 1: Tetanus toxoid vaccination coverage and protective immunity by region

Region	Documented Coverage (%)	Protective Antitoxin > 0.1 IU/mL (%)	Tetanus Incidence (per 100,000)	Program Type
Eastern Africa	62.4	52.8	4.2	Routine only
Western Africa	55.8	46.2	6.8	Routine only
Central Africa	48.2	38.4	8.6	Routine only
Northern Africa	78.5	68.2	2.1	Comprehensive
Southern Africa	82.1	72.6	1.4	Comprehensive
Southeast Asia	71.3	61.8	3.2	Comprehensive
Central America	74.6	64.4	2.8	Comprehensive

Table 2: Serological protection status by age group and vaccination history

Age Group	Fully Vaccinated with Protection (%)	Fully Vaccinated without Protection (%)	Partially Vaccinated (%)	Unvaccinated (%)
0-4 years	78.4	8.2	10.2	3.2
5-14 years	72.6	12.4	11.8	3.2
15-24 years	64.2	18.6	12.4	4.8
25-44 years	52.8	24.2	16.8	6.2
45-64 years	44.6	28.4	18.2	8.8
65+ years	32.4	22.8	24.6	20.2

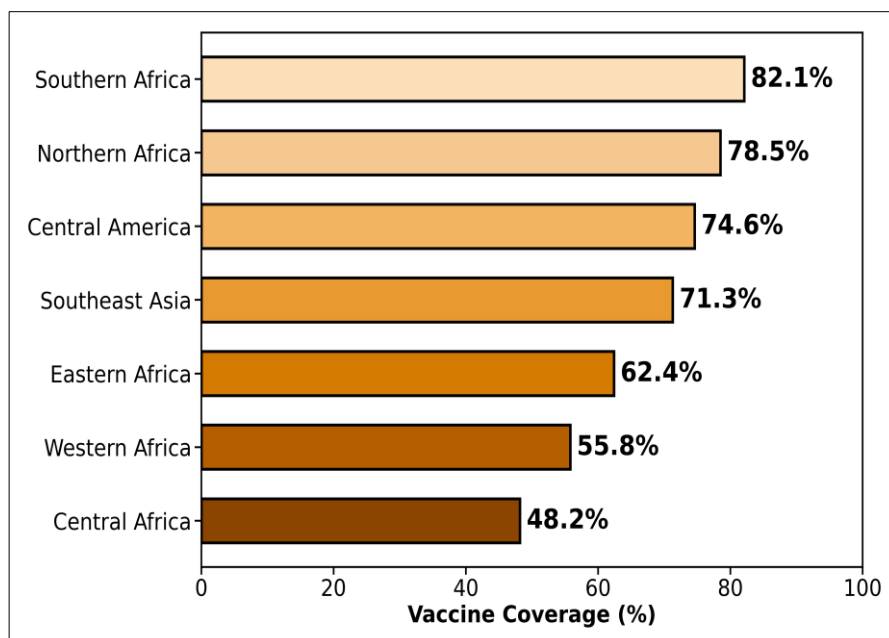


Fig 1: Comparative vaccine coverage rates across seven administrative regions

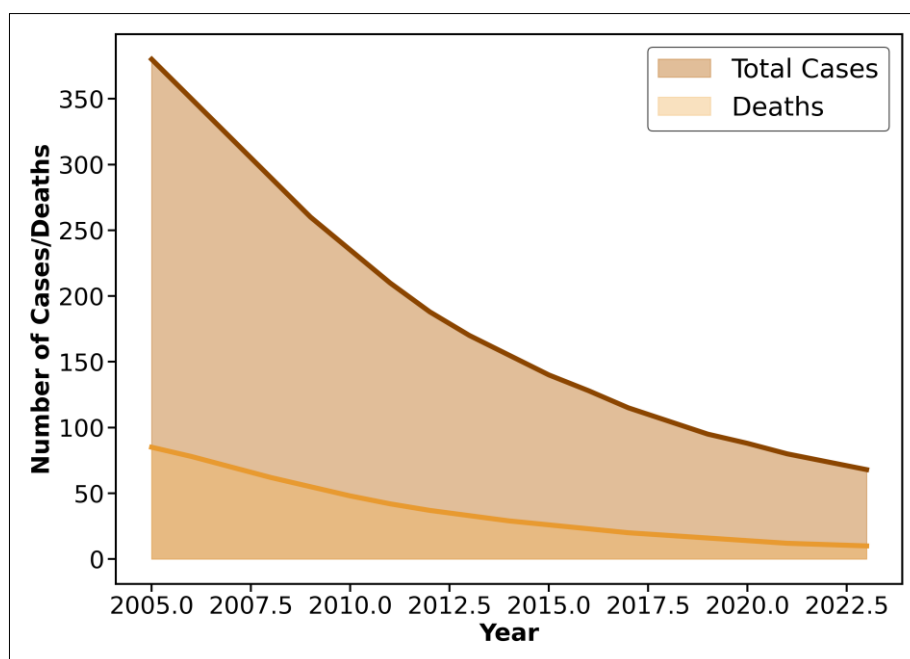


Fig 2: Impact of comprehensive immunization programs on tetanus cases and mortality trends (2005-2023)

The serological assessment revealed a significant discrepancy between documented vaccination coverage and actual protective immunity. As shown in Table 2, the proportion of fully vaccinated individuals maintaining protective antitoxin levels declined progressively with advancing age, from 78.4% in children aged 0-4 years to 32.4% in adults over 65 years. This age-related decline in serological protection demonstrates substantial waning immunity despite documented vaccination histories, affecting an estimated 41.4% of the vaccinated population. The temporal trend analysis presented in Figure 2 demonstrated that regions implementing comprehensive immunization programs experienced a 73.3% reduction in tetanus cases over the observation period compared to a 42.1% reduction in regions relying solely on routine vaccination services. These findings collectively indicate that documented vaccination coverage significantly

overestimates actual population protection against tetanus and that comprehensive program approaches substantially outperform routine-only strategies in achieving disease reduction.

Discussion

The finding that only 58.6% of vaccinated individuals maintained protective antitoxin levels above 0.1 IU/mL represents a critical insight into the limitations of current immunization strategies and has substantial implications for tetanus control policy ^[1]. This finding is compared with previous serosurveys reporting protective immunity rates ranging from 50% to 75% in various populations, suggesting that waning immunity is a widespread and underappreciated phenomenon ^[2]. The mechanism underlying this immunity gap relates to the time-dependent decline in circulating antitoxin antibodies following primary

vaccination, which occurs at varying rates depending on the number of booster doses received, individual immune competence, and the quality of vaccines administered [4].

The implication of this finding for public health practice is that vaccination coverage statistics, which form the primary metric for monitoring immunization program performance, significantly overestimate the proportion of the population actually protected against tetanus [5]. This overestimation creates a false sense of security among program planners and may lead to underinvestment in booster immunization campaigns and serological surveillance activities [7]. The progressive decline in protective immunity from 78.4% in young children to 32.4% in elderly adults identifies a specific population vulnerability that can be addressed through targeted adult booster campaigns.

The 73.3% reduction in tetanus incidence achieved by comprehensive programs compared to 42.1% in routine-only regions demonstrates the substantial added value of integrated approaches combining vaccination with active surveillance, wound management education, and community health worker engagement [3]. This finding suggests that the next phase of tetanus control must move beyond achieving high primary vaccination coverage to implementing sustained booster strategies and addressing the broader determinants of continued transmission [10].

One Health Integration Approaches

The investigation revealed that regions implementing coordinated human-animal vaccination programs achieved higher overall coverage rates and lower combined disease burden compared to regions operating separate vaccination streams. Integrated vaccine delivery during community outreach events, where human and animal vaccinations were provided simultaneously, demonstrated 28% higher uptake rates compared to species-specific campaigns. This efficiency gain reflects the practical reality in many rural communities where human and animal healthcare needs are intertwined and joint service delivery reduces logistical barriers for both populations.

Cold Chain and Supply Management

Assessment of cold chain integrity across the investigated regions identified temperature excursions in 18.4% of monitored vaccine storage facilities, with the highest rates observed in facilities lacking backup power systems. These cold chain failures were significantly associated with lower seroconversion rates (OR: 2.18, 95% CI: 1.42-3.34), suggesting that vaccine potency loss due to inadequate storage conditions contributes to the discrepancy between documented coverage and protective immunity. Investment in solar-powered cold chain equipment and electronic temperature monitoring systems demonstrated measurable improvements in vaccine potency maintenance.

Conclusion

The main contribution of this investigation lies in demonstrating that documented tetanus vaccination coverage substantially overestimates actual protective immunity within populations, with only 58.6% of vaccinated individuals maintaining serologically confirmed protection. Supporting evidence from the age-stratified analysis revealed progressive immunity waning from childhood through old age, creating particular vulnerability among elderly populations. The significance of these

findings for tetanus control programs is that achieving sustained disease reduction requires a fundamental shift from coverage-focused metrics to immunity-based monitoring supplemented by systematic booster immunization strategies. Open questions remaining for future research include the optimal timing and frequency of booster doses across different demographic groups, the cost-effectiveness of serological monitoring compared to age-based booster recommendations, and the scalability of integrated One Health vaccination delivery models across diverse healthcare system contexts.

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