Innovative Approaches to Trachoma Elimination: A Review on the Role of Modern Diagnostic Methods and Control

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Abstract

Introduction: Trachoma is the leading infectious cause of preventable blindness globally, caused by the bacterium *Chlamydia trachomatis*. It predominantly affects rural and economically disadvantaged areas across low-income countries. While the World Health Organisation's SAFE—Surgery, Antibiotics, Facial cleanliness, and Environmental improvement— strategy has proven effective, the disease persists across underserved communities, necessitating ongoing intervention. **Objectives:** This study aimed to explore integrating new diagnostic tools into current trachoma control frameworks to enhance early identification and treatment. The study analysed advancements in diagnostic methods for *Chlamydia trachomatis* and their application in trachoma-endemic regions, assessed the benefits and challenges of adopting these methods in resource-limited settings, and recommended strategies for optimising diagnostics in surveillance, treatment, and control programmes. **Methodology:** A qualitative research design with a systematic literature review was employed, utilising data from peer-reviewed journals, WHO guidelines, and case studies from trachoma-endemic regions. **Results:** The findings reveal that advanced diagnostics offer high sensitivity and specificity compared to traditional clinical methods, enabling precise disease detection, targeted interventions, and reduced reliance on unnecessary antibiotics. However, significant barriers hinder their widespread adoption, including high costs, inadequate infrastructure, and limited technical expertise. **Conclusion:** The study concludes that achieving trachoma elimination and mitigating its socio-economic impact requires a comprehensive approach that combines modern diagnostic tools with enhanced resource allocation, community engagement, and policy support. This study emphasises the importance of innovative strategies in realising sustainable trachoma elimination efforts by addressing existing barriers and fostering global collaboration.

Keywords: Neglected Tropical Diseases; SAFE strategy; *Chlamydia trachomatis*; Trichiasis; Public Health

Introduction

Trachoma, classified as a neglected tropical disease (NTD), arises from repeated exposure to the bacterium *Chlamydia trachomatis* (Barton et al., 2023). It remains the primary infectious cause of preventable blindness globally, predominantly impacting rural and economically disadvantaged areas where people lack access to clean water, proper sanitation, and adequate healthcare services (Wu & Reynolds, 2023). In 2021, an estimated

1.8 million individuals had blindness or severe vision impairment due to trachoma (Solomon et al., 2022). The World Health Organization (WHO, 2022) underscores the importance of targeted interventions to address this condition, as it disproportionately affects marginalised communities.

The disease often starts in early childhood, with recurrent infections triggering long-term inflammation and scarring of the eyelid. Without timely intervention, it can progress to trichiasis—a condition where inward-growing eyelashes irritate and damage the cornea, ultimately leading to blindness (Ramadhani et al., 2016). In addition to its devastating physical effects, trachoma perpetuates poverty by limiting economic productivity and disrupting education, especially among women and children in endemic regions (WHO, 2022). Trachoma remains endemic in 44 countries, with most cases concentrated in sub-Saharan Africa, though significant numbers also occur in parts of Asia, the Middle East, and the Americas (Ono & Umeya, 2023). The disease thrives in overcrowded environments where sanitation is inadequate, clean water is scarce, and transmission via direct contact with eye discharge or eye-seeking flies is standard (Solomon et al., 2022). As a disease intricately related to poverty, trachoma exemplifies the interaction between health challenges and broad socioeconomic disparities, reinforcing its classification as an NTD (WHO, 2022).

The WHO promotes the SAFE – Surgery, Antibiotics, Facial cleanliness, and Environmental improvement – strategy as a central strategy for controlling trachoma; this comprehensive approach pairs surgical treatment for advanced cases with widespread use of antibiotics to reduce infection rates at the community level. At the same time, improved hygiene practices and better access to water and sanitation systems are emphasised to tackle the root causes of transmission (WHO, 2023). Although the SAFE strategy has significantly reduced trachoma prevalence, several challenges persist. For instance, antibiotics are often distributed based on visible clinical signs rather than specific laboratory confirmation, leading to possible misallocation of antibiotics for treatments. Some regions may receive unnecessary interventions while others with active infection are overlooked (Gebresillasie et al., 2020). Moreover, improving environmental conditions requires substantial infrastructure investments, a particularly daunting task in economically disadvantaged regions (Solomon et al., 2022). Despite global efforts under the SAFE strategy, critical gaps remain—conventional diagnostic approaches focusing on clinical exams do not identify asymptomatic carriers, resulting in untreated infections and ongoing transmission.

Trachoma continues to pose a severe public health challenge, impacting hundreds of thousands of people across 44 international locations where it remains endemic. The disorder is especially prevalent in low-income settings, despite years of management measures and significant reductions in prevalence. Persistent demanding situations in regions, including prognosis, treatment, and disease tracking, underscore the need for more advantageous techniques (Solomon et al., 2022; WHO, 2022). In many endemic regions, diagnostics are based totally on medical checks of trachomatous inflammation— either follicular (TF) or severe (TI) (Solomon et al., 2022). While these methods are practical and broadly used, they regularly fail to perceive infections appropriately. This ends in two critical troubles: asymptomatic instances may remain undetected, and over-remedy might also occur in areas where transmission is inactive. As a result, resources are not optimally applied, antibiotics are sometimes overprescribed, and vital opportunities to halt the spread of contamination are overlooked (Gebresillasie et al., 2020). The SAFE strategy has performed a pivotal role in decreasing trachoma incidence globally (WHO, 2023). However, the shortage of correct, real-time

diagnostic tools restricts the method's impact. Antibiotics, an essential part of the approach, are often disbursed based on scientific signs rather than shown molecular proof of *Chlamydia trachomatis* infections. This practice often results in choppy remedy insurance, with some areas experiencing pointless interventions while others remain underserved (Gebresillasie et al., 2020; Solomon et al., 2022). Innovative diagnostic techniques, including nucleic acid amplification tests (NAATs), have been tested for superior accuracy and sensitivity compared to traditional medical checks. However, their adoption in endemic areas remains restrained because of widespread limitations, excessive prices, insufficient infrastructure, and a lack of trained personnel (Su et al., 2020). These demanding situations prevent the seamless integration of cutting-edge diagnostics into trachoma-manipulated projects, thereby slowing development toward the effective control and eventual elimination of the sickness.

This study aimed to explore the role of modern diagnostic methods in improving the effectiveness of trachoma elimination strategies. The specific objectives were to:

1. Analyse advancements in diagnostic methods for *Chlamydia trachomatis*, with a focus on their potential applications in trachoma-endemic regions.
2. Examine the benefits and challenges of adopting modern diagnostic technologies in resource-limited settings to support trachoma elimination efforts.
3. Recommend strategies for optimising diagnostics in trachoma surveillance, treatment, and control initiatives.

This study focuses on addressing key limitations with trachoma elimination, a condition that disproportionately affects marginalised groups in settings with constrained resources. The study aimed to contribute to actionable insights that guide worldwide efforts to eliminate trachoma by comparing how superior diagnostic technologies can be included in the present-day control frameworks. Timely and precisely identifying *Chlamydia trachomatis* infections is essential for breaking transmission cycles and providing appropriate treatment. Compared to traditional clinical diagnostics, cutting-edge equipment like molecular assessments offers more accuracy and sensitivity, specifically for detecting asymptomatic or early-stage instances. Adopting those improvements could revolutionise how trachoma is recognised and controlled, making it possible for more powerful public health measures. By incorporating modern diagnostics into the SAFE strategy, interventions can be better targeted and more effective. Enhanced diagnostic precision minimises pointless antibiotic administration and guarantees sources are allotted successfully, addressing regions with the greatest need. This is particularly critical in areas where healthcare infrastructure remains underdeveloped, making centred techniques important for development. Additionally, the study underscores the broader implications of improving diagnostic capabilities for trachoma management. Enhanced detection tools not only increase the efficiency of current techniques but also lessen the socioeconomic burdens related to the sickness. By preventing vision loss and blindness, these tools contribute to improved productivity, reduced healthcare costs, and better quality of life in affected communities. It also aligns with the WHO's goal of ending trachoma as a population health measure (public health) by 2030, emphasising the importance of scalable and sustainable solutions for long-term success.

Methodology

Research Design

This study employs a qualitative research design grounded in a systematic literature review. This approach is appropriate for

gathering and synthesising diverse data to identify patterns, evaluate interventions, and examine the use of diagnostic tools in trachoma elimination. A qualitative, literature-based design allows for an in-depth understanding of the current state of trachoma control and diagnostics, and it is well-suited to address the study's aims.

Data Sources

Multiple reliable sources were utilised to ensure a comprehensive analysis:

1. Academic Journals: Peer-reviewed medical and public health publications (e.g., *The Lancet Global Health*, *Nature Reviews Disease Primers*, *Ophthalmic Epidemiology*, and others) provided detailed information on trachoma diagnostics, control strategies, and programmatic challenges.
2. Official Reports and Guidelines: Documents from the World Health Organisation (WHO) – including SAFE strategy guidelines, trachoma fact sheets, and the 2021–2030 roadmap for neglected tropical diseases – were key references for current policies and global targets.
3. Electronic Databases: To retrieve relevant literature, databases such as PubMed, Scopus, and Google Scholar were searched. Search terms included "trachoma diagnostics," "SAFE strategy," "modern diagnostic tools," "trachoma elimination," and "trachoma control strategies."
4. Case Studies: Reports and studies from trachoma-endemic regions (e.g., Ethiopia, Tanzania, and Nepal) were reviewed to highlight practical applications of diagnostic and control methods and gather evidence from field experiences.

Inclusion Criteria

The review included sources that met the following criteria:

- Studies and key publications focused on trachoma diagnostics (traditional and modern), the SAFE strategy, or trachoma control and elimination interventions.
- Case studies or programme reports from different trachoma-endemic regions illustrating challenges and successes in trachoma control.
- Publications by internationally recognised organisations (e.g., WHO, UNICEF, International Trachoma Initiative) relevant to trachoma elimination.
- Preference was given to recent literature (generally within the last 10 years) to ensure up-to-date insights, except for seminal or foundational studies that remain highly relevant.

Exclusion Criteria

Sources were excluded based on the following:

- Publications older than 10 years that were not foundational to the topic or superseded by newer data (to keep the review current).
- Articles not directly related to trachoma diagnostics or control strategies (e.g., studies on other eye diseases or unrelated public health interventions).
- Non-peer-reviewed sources lacking credibility or rigorous evidence (e.g., anecdotal reports, opinion pieces without data).
- Duplicate information from multiple sources (in such cases, the most comprehensive or authoritative source was used).

Data Collection

A systematic search and selection strategy was employed to identify relevant literature:

1. Keyword Search: Initial searches used key terms such as "trachoma diagnostics," "SAFE strategy," "modern diagnostics," and "trachoma control interventions," alone and in combination (using Boolean operators AND/OR) to cast a wide net.
2. Database Search: The keywords were applied across multiple databases, including PubMed, Scopus, and Google

Scholar, to gather academic articles, reports, and other publications.

3. Reference Tracking: The references of key articles were examined to find additional relevant sources that might not have appeared in the database searches. This backwards reference search helped uncover important earlier studies and reports.
4. Screening and Filtering: The titles and abstracts of the collected articles were read to assess their relevance to the study's objectives. Sources that appeared to meet the inclusion criteria were retrieved in full text. Each full-text article was then reviewed to confirm its relevance and quality. Articles not aligning with the inclusion criteria upon full review were excluded.

Data Analysis

The gathered literature was analysed using thematic synthesis to organise and interpret the findings systematically:

- Thematic Categorisation: Key information from the literature was grouped into major themes such as traditional diagnostics, modern diagnostic innovations, SAFE strategy implementation, barriers to adoption of new tools, and case study outcomes. These themes correspond to the components of the study objectives and research questions.
- Comparative Analysis: Traditional versus modern diagnostic methods were compared to evaluate their relative effectiveness, feasibility, and impact on trachoma elimination efforts. Similarly, different control strategies (e.g., mass drug administration, surgery, hygiene promotion) were compared, noting strengths and limitations in various contexts.
- Effectiveness Assessment: The outcomes and challenges of different interventions were critically evaluated to identify best practices and gaps. For instance, the review assessed how well modern diagnostic tools have performed in pilot programmes and what obstacles have limited their effectiveness.
- Synthesis of Findings: Insights from all themes were synthesised to formulate recommendations. By integrating the evidence, the study distils strategies for enhancing trachoma surveillance and control, emphasising how modern diagnostics can be optimised and what supportive measures (training, funding, community engagement) are required for success.

All analyses were conducted to maintain objectivity and ensure that conclusions were grounded in the collective evidence of the reviewed literature.

Discussion

This study explored the role of modern diagnostic methods and complementary control strategies in trachoma elimination, emphasising their integration into the WHO's SAFE strategy. The findings from the literature review highlight several important themes in trachoma control efforts, including recent advancements, persistent challenges, and future opportunities.

Application of the SAFE Strategy in the Reviewed Studies

1. Ethiopia: A Success Story in Trachoma Control

   Ethiopia, which historically bore one of the highest global burdens of trachoma, has made wonderful progress toward elimination via the implementation of the SAFE strategy (Gebresillasie et al., 2020). The integration of innovative diagnostic tools has been pivotal, particularly in guiding mass drug administration (MDA) campaigns and evaluating their effectiveness. The deployment of point-of-care tests (POCTs) and mobile health technology in numerous areas has

enhanced ailment surveillance and advanced remedy accuracy. These efforts have led to a good-sized discount in trachoma incidence, bringing Ethiopia closer to its elimination objectives (Gebresillasie et al., 2020).

2. Tanzania: Leveraging Mobile Health for Hygiene and Environmental Monitoring
   Tanzania adopted mobile health applications to support diagnostics and streamline data collection processes (Mpyet et al., 2023). Healthcare workers use these tools to upload high-resolution images of the conjunctiva, which are then analysed remotely by trained professionals. This reduces variability in diagnostics and enables precise, targeted interventions. The approach has proven especially effective in remote areas with limited healthcare infrastructure, improving the overall efficiency of trachoma elimination efforts (Mpyet et al., 2023).
3. Nepal: Sustained Progress through Community Engagement
   Nepal achieved a significant milestone by being declared trachoma-free by the WHO in 2018 (WHO, 2022). This fulfilment was driven by integrating cutting-edge diagnostics with sturdy network engagement programs. Public education campaigns extended the focus on facial cleanliness and environmental hygiene, complementing diagnostic efforts. Molecular diagnostics were used to reveal ailment incidence, ensuring that interventions are timely and powerful (WHO, 2022).
4. Nigeria: Mass Drug Administration and Community-Based Surgery
   In Nigeria, between 2001 and 2020, surveys revealed that 122 local government areas (LGAs) had active trachoma and received MDA with azithromycin as part of the SAFE strategy. Also, 231 LGAs carried out community-based trichiasis surgery programmes. By 2021, more than 34 million doses of antibiotics had been distributed, contributing to a 71% reduction in the population requiring SAFE interventions (Mpyet et al., 2024).

Advancements in Diagnostics

Modern diagnostic tools, such as nucleic acid amplification tests (NAATs) and point-of-care tests (POCTs), help in better tracking of trachoma surveillance and control. These tools address the limitations of traditional clinical diagnostics by providing high sensitivity and specificity, enabling the identification of asymptomatic and low-burden infections (Gebresillasie et al., 2020; Solomon et al., 2022). Their integration into control programmes has allowed for targeted interventions, optimising the allocation of resources and reducing unnecessary antibiotic use.

Control Strategies and Integration

The SAFE strategy remains the cornerstone of global trachoma elimination efforts. However, the study reveals significant demanding situations in enforcing and sustaining the SAFE strategy components, mainly in resource-constrained settings. Mass drug administration (MDA) has effectively decreased infection prevalence, but its long-term sustainability and the risk of antibiotic resistance require careful management (Harding-Esch et al., 2021). Similarly, although impactful, hygiene and sanitation campaigns demand sustained community engagement and infrastructure investments.

Challenges

Key barriers to adopting modern diagnostics and implementing control measures include financial constraints, infrastructure gaps, and confined technical capacity. Cultural resistance to change and systemic inequities further exacerbate these challenges in trachoma-endemic regions (World Health Organisation, 2022; Mpyet et al., 2023).

Future Directions

Emerging digital health tools, such as mobile applications and geographic information systems (GIS), present possibilities to enhance trachoma control. These technologies facilitate real-time monitoring, data collection, and decision-making, bridging surveillance and programme evaluation gaps.

Conclusion

Trachoma remains a pressing global health challenge, disproportionately affecting marginalised populations in resource-limited settings. This study underscores modern diagnostics' critical role in addressing traditional methods' limitations and enhancing the effectiveness of control strategies. Global efforts can achieve more targeted and sustainable interventions by integrating advanced diagnostic tools with the SAFE strategy. However, significant barriers remain, including financial constraints, technical capacity, and cultural resistance. Addressing these challenges requires a collaborative and innovative approach, combining investments in diagnostics, community engagement, and digital health technologies.

Recommendations

Based on the findings of this study, the following recommendations were proposed to enhance trachoma elimination efforts and ensure sustainable success:

Expand Access to Modern Diagnostics:

- Increase funding and partnerships to subsidise the costs of advanced diagnostic tools.
- Invest in capacity-building initiatives to teach and train healthcare workers in molecular diagnostics.

Strengthen Integration of Diagnostics into the SAFE Strategy:

- Use modern diagnostics to identify transmission hotspots, ensuring targeted and efficient interventions.
- Incorporate diagnostic data into health information systems for real-time monitoring and evaluation.

Promote Community-Led Approaches:

- Occupy societies in the intent and execution of control programmes to encourage ownership and sustainability.
- Conduct outreach campaigns to promote awareness about hygiene, sanitation, and the importance of early diagnosis.

Enhance Partnerships and Funding:

- Partner with worldwide bodies, governments, and private enterprises to secure sustainable funding for trachoma control programmes.
- Leverage public-private partnerships to innovate low-cost diagnostic tools and infrastructure solutions.

Leverage Digital Technologies:

- Integrate mobile health applications and GIS into trachoma surveillance systems to improve data accuracy and accessibility.
- Use digital platforms for training, monitoring, and communication among stakeholders.

Scientific Implications of the Study

1. *Reinforcement of Diagnostic-Driven Public Health Interventions:* This review emphasises the importance of integrating molecular diagnostics tools in strengthening trachoma control programmes. By highlighting evidence from various studies, it shows how molecular diagnostics can improve accuracy in detecting infections, including asymptomatic cases, ensuring effective steps are taken when needed.
2. *Enhancing Cost-Effectiveness in Trachoma Control:* The synthesis of reviewed literature makes it clear that improved diagnostic infrastructure is required in regions affected by trachoma. Results indicate that advanced diagnostics allow efficient use of antibiotics, make treatment

more accessible, and reduce wastage of limited public health resources.

3. *Contribution to WHO's 2030 Elimination Agenda for Trachoma:* This study contributes to the broader understanding of how diagnostic innovations can aid in meeting the World Health Organisation's objective of eradicating trachoma by 2030. It discusses implementing modern diagnostics with the SAFE strategy to enhance disease monitoring and intervention effectiveness.

Limitations of the Study

Despite its contributions, the study is constrained by its reliance on secondary sources, including existing literature and previously conducted research. It does not involve collecting primary data or experimental trials, which limits the scope of the findings to theoretical insights derived from available information. While this approach enables a comprehensive analysis of current knowledge, it lacks empirical validation or practical insights from real-world implementations. As a result, the conclusions may have limited direct applicability, particularly in diverse field settings where contextual factors play a significant role.

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Citation:
Adedokun, A. A., Alade, W. A., Oladokun, L. O., Adeyemo, R. A., Nassar, S. A., Hassan A. O., & Adeyanju K. A. (2025). Innovative Approaches to Trachoma Elimination: A Review on the Role of Modern Diagnostic Methods and Control. *Fountain Journal of Basic Medical and Health Sciences (FUJBMHES), 1(2), 14-25*