Shaping the Future of HIV Self-Testing in Sub-Saharan Africa: Leveraging Predictive Modeling to Overcome Barriers and Enhance Targeted Interventions

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Abstract

The use of predictive modeling in HIV prevention is gaining traction in Sub-Saharan Africa (SSA), particularly for enhancing HIV self-testing (HIVST) among underserved populations. Implementing predictive models to target HIVST interventions presents both opportunities and challenges, requiring culturally sensitive approaches and ethical considerations in data use. This Viewpoint explores the application of Random Forest (RF) and Classification and Regression Tree (CART) models to identify high-risk groups and optimize HIVST outreach. It highlights key considerations and lessons for practitioners in balancing technological innovation with community engagement and inclusivity to strengthen HIV response strategies across SSA.

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Viewpoint

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Abstract
The use of predictive modeling in HIV prevention is gaining traction in Sub-Saharan Africa (SSA), particularly for enhancing HIV self-testing (HIVST) among underserved populations. Implementing predictive models to target HIVST interventions presents both opportunities and challenges, requiring culturally sensitive approaches and ethical considerations in data use. This Viewpoint explores the application of Random Forest (RF) and Classification and Regression Tree (CART) models to identify high-risk groups and optimize HIVST outreach. It highlights key considerations and lessons for practitioners in balancing technological innovation with community engagement and inclusivity to strengthen HIV response strategies across SSA.

Keywords: Predictive modeling, HIV self-testing (HIVST), Public health intervention, Sub-Saharan Africa, Random Forest (RF), Classification and Regression Tree (CART)

Introduction
Sub-Saharan Africa (SSA) remains central to the global HIV epidemic, bearing a substantial portion of cases worldwide.[1] HIV self-testing (HIVST) offers a transformative approach for expanding access to testing, offering privacy and convenience that encourages uptake among at-risk populations, including men who have sex with men (MSM), female sex workers (FSWs), adolescents, and economically disadvantaged groups.[2,3] However, HIVST uptake in SSA is challenged by persistent logistical and socio-cultural barriers, including stigma, limited post-test support, and economic constraints.[4–6]
Predictive modeling, especially through Classification and Regression Trees (CART) and Random Forest (RF) models, offers a novel, data-driven means to overcome these barriers by identifying and predicting patterns in HIVST uptake across diverse communities. By pinpointing population-specific factors, predictive models enable public health practitioners to tailor HIVST outreach and

resources, thus potentially revolutionizing HIV testing strategies in SSA. Nonetheless, for this approach to succeed, ethical considerations, including the prevention of model bias and active community engagement, are paramount.

Leveraging Predictive Modeling to Enhance HIVST Outreach

Predictive models such as CART and RF are adept at revealing intricate patterns in data, particularly in complex, varied settings like SSA.[7,8] For example, by analyzing historical HIV testing data combined with demographic and behavioral factors, RF models can identify high-risk subpopulations with low testing rates, thus informing where HIVST kits could be most impactful. In practice, these models might prioritize distribution in urban informal settlements where stigma is high and healthcare infrastructure is limited, thus maximizing HIVST's reach where traditional testing is less feasible.

Moreover, predictive modeling allows for dynamic response to real-time data, which could be transformative in SSA's resource-limited settings.[9] For instance, predictive insights could support adaptive HIVST distribution models, whereby local clinics or pharmacies are resupplied based on anticipated demand. Such targeted supply chains could reduce logistical costs and optimize kit availability, ensuring that high-risk populations consistently have access to HIVST.

Ethical Considerations: Ensuring Fairness and Inclusivity

While predictive modeling offers immense potential, it also risks reinforcing health inequities if not carefully implemented. A key ethical concern is data bias, as models trained on incomplete or skewed datasets could exclude or misrepresent vulnerable groups.[10,11] For example, predictive models based primarily on urban data may not account for unique barriers in rural communities, where access to HIVST is further complicated by transport limitations and socio-cultural stigma.

To address this, ethical predictive modeling requires inclusive data collection that accurately reflects SSA's diverse populations. This might involve incorporating data from both formal healthcare providers and community health networks to capture a broader spectrum of health behaviors. Furthermore, engaging local communities in model development and validation could help ensure that predictive insights are sensitive to local needs and socio-cultural contexts.[12] Integrating qualitative research, such as community feedback or focus group discussions, with quantitative model training could further safeguard against potential biases and enhance model relevance.

Public Health Implications and Transformative Potential

Table 1 summarizes specific applications of predictive modeling techniques in HIVST interventions, detailing how these models can enhance targeted outreach and resource allocation across Sub-Saharan Africa.

Table 1. Predictive Modeling Applications for HIVST in Sub-Saharan Africa

Application Area	Predictive Model Used	Description	Public Health Implications
Targeted Kit Distribution	RF	Identifies regions with low HIVST uptake and high HIV prevalence, guiding where	Efficient resource allocation to high-need areas

		kits should be allocated	
Real-Time Demand Prediction	CART	Predicts areas with fluctuating HIVST demand, helping manage and replenish stock	Reduces stockouts and optimizes supply chains
Demographic Risk Profiling	CART and RF	Analyzes socio-demographic data to categorize individuals by the likelihood of HIVST uptake	Personalized outreach and tailored educational interventions
Outreach Optimization	Mixed Methods Approach	Integrates predictive insights with qualitative feedback to identify stigma barriers and customize outreach	Improves trust, engagement, and accuracy of targeted public health messaging

Legend: CART - Classification and Regression Tree; RF - Random Forest

The insights generated from predictive models can transition HIVST strategies from broad, generalized approaches to highly specific, evidence-based interventions (as shown in **Table 1**). In SSA, where resources are often limited, this could be pivotal. Predictive models, for instance, can help pinpoint regions with high rates of undiagnosed HIV and low HIVST uptake. Community-based interventions, such as mobile health units or local pharmacy distribution in these areas, can then be deployed with confidence in their necessity and impact.

Early trials of predictive modeling applied to HIV prevention in Nigeria and South Africa underscore this potential, showing that targeted outreach can significantly improve HIVST engagement among underserved groups.[13,14] Additionally, recent evidence from Kenya demonstrates how coupling predictive insights with SMS reminders led to higher engagement rates among youth populations, a critical demographic in HIV prevention.[15]

Transforming Predictive Insights into Actionable Strategies

Figure 1 illustrates the process of integrating predictive modeling with HIVST interventions, demonstrating how data insights translate into targeted actions and improved health outcomes.

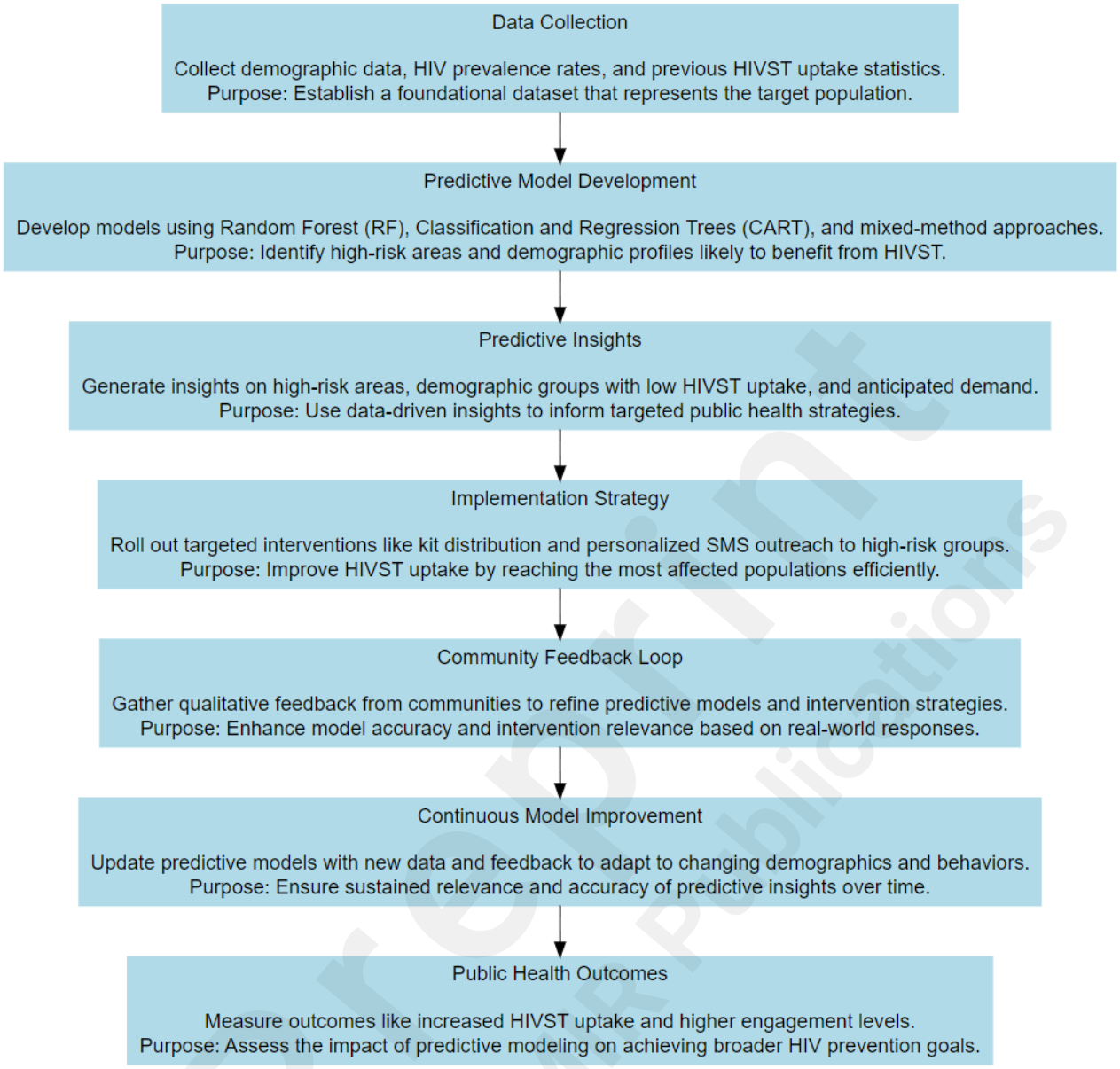

Figure 1: Integrating Predictive Modeling with HIVST Implementation in Sub-Saharan Africa

Effective implementation of predictive insights requires cross-disciplinary collaboration. Public health professionals, data scientists, and policymakers must work together to ensure predictive models are translated into practical, on-the-ground strategies. For example, integrating HIVST predictive modeling with community health worker programs could facilitate personalized outreach efforts in areas identified as high-risk by RF models. Community health workers, equipped with localized data insights, can encourage HIVST among individuals most likely to benefit, addressing stigma through face-to-face interaction within trusted networks.

Furthermore, the inclusion of digital supports—such as mobile applications or community-driven online platforms—could assist in real-time data collection, model refinement, and public health intervention adjustments. These tools would not only bolster model accuracy but also ensure that HIVST outreach remains adaptable to shifting demographics and health needs.

Conclusion

Predictive modeling represents a powerful tool for optimizing HIVST uptake across SSA by facilitating precision-targeted public health interventions. However, the path forward requires an ethically grounded, community-centered approach that respects local dynamics and values inclusivity. By prioritizing data fairness, stakeholder engagement, and interdisciplinary collaboration, predictive modeling can drive significant progress toward UNAIDS' 2030 goals for broad HIV testing access. Through responsible data science, SSA has the potential to lead in HIV prevention innovation, setting a model for leveraging technology in global health equity.

Competing Interests

The authors declare no competing interests.

Authors' Contributions

FEA, MNS, and OO conceptualized the manuscript. FEA drafted the original version of the manuscript, and OO and MNS critically contributed and reviewed it. All authors approved the final version for submission.FEA’s doctoral is being supervised by MNS and OO.

List of abbreviations

HIVST - HIV Self-Testing
SSA - Sub-Saharan Africa
RF - Random Forest
CART - Classification and Regression Trees
MSM - Men Who Have Sex with Men
FSW - Female Sex Workers
HIV - Human Immunodeficiency Virus

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Supplementary Files