Go With the Flow: Understanding the Temporal Dynamics of the HIV Continuum of Care or the HIV Treatment Cascade

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Background

Despite the availability of antiretroviral therapy (ART) for HIV infection, only about a quarter of infected individuals in the US on treatment and have undetectable viral loads indicating successful viral suppression (Figure 1). In order to maximize clinical outcomes for patients and reduce HIV transmission, a greater proportion of people living with HIV (PLWHIV) in the United States (US) need to be diagnosed, linked to care, start ART and successfully adhere to their medication regimens over time (the "treatment cascade").

Research Objective

The major aim of this study is to conduct an integrated evaluation of the role of the public health and health care delivery systems in the US and determine the optimal allocation of resources that would optimize the net impact on the AIDS epidemic. We did this by developing a mathematical model of the steps in the continuum of HIV care (displayed graphically in Figure 2). The results from the model will offer a way to optimizing total expenditures across different stages of the "treatment cascade" to obtain the maximum number of people successfully virally suppressed on ART.

Data Sets and Sources

We utilized epidemiological information on HIV collected by state health departments in the US and compiled by the Centers for Disease Control and Prevention (CDC) as well as data from the US studies that are part of the North American AIDS Cohort Collaboration on Research and Design (NA-ACCORD).

Study Design

Using queueing theory, we used annual data on the number of people newly tested for HIV; those tested who are subsequently linked to care; those linked who are started on ART and; those on ART successfully virally suppressed, to model how patients flow from one stage of the treatment cascade to the next, including: 1) the transition time from stage-to-stage; 2) the time spent in a given stage: 3) the percent of individuals progressing from stage-to-stage and; 4) the percent dropping out of the cascade in a given stage. Using this model, we propose a method for assessing optimal strategies for intervening in the continuum of care, in order to maximize the number of people who make it through the cascade and onto successful sustained treatment.

Analysis

We fit the data from CDC and NA-ACCORD with likelihood functions using exponential, Weibull and hyper-exponential distributions predicting month-to-month transitions from diagnosis to first CD4 or viral load test; first CD4 or viral load test to second CD4 or viral load test, and second CD4 or viral load test to viral suppression, as proxies, respectively, for linkage to care, retention in care and establishment of successful suppression of viral load on antiretroviral therapy. We assessed goodness-of-fit via maximum log likelihood values. Using the parameter values from these analyses, we constructed a cross-sectional version of the continuum of care for the first three stages of the cascade.

Figure 1. HIV Continuum of Care or the HIV Treatment Cascade, National Cross-Sectional Data, 2012 (Source: CDC)

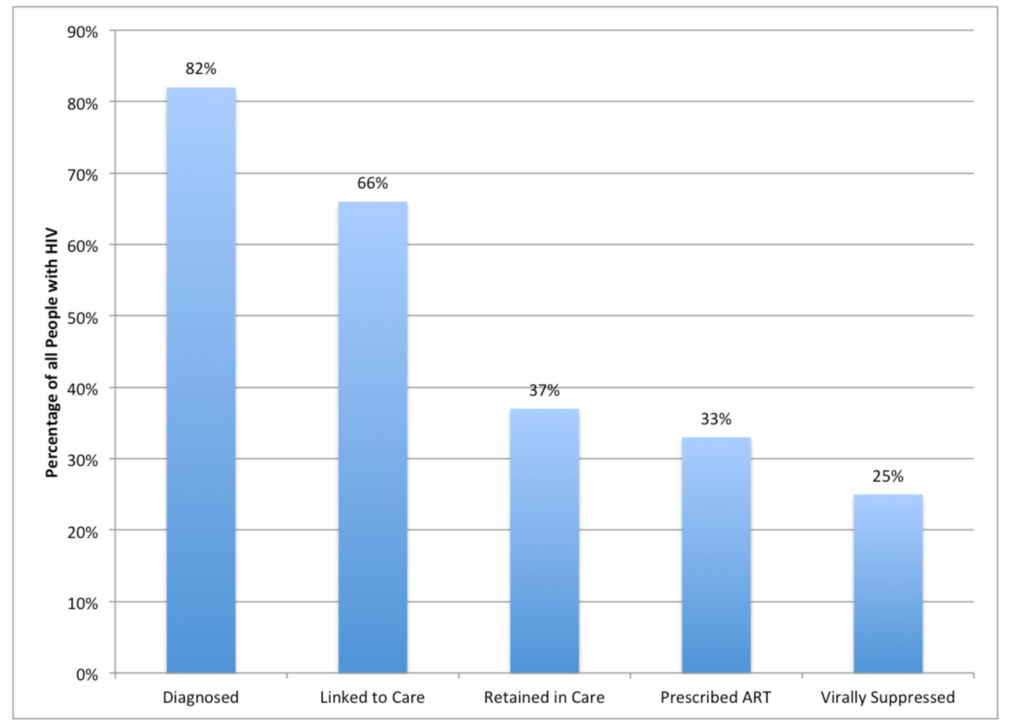

Figure 3. HIV Continuum of Care or the HIV Treatment Cascade, Model Results from Subset of Data Supplied by CDC, 2014

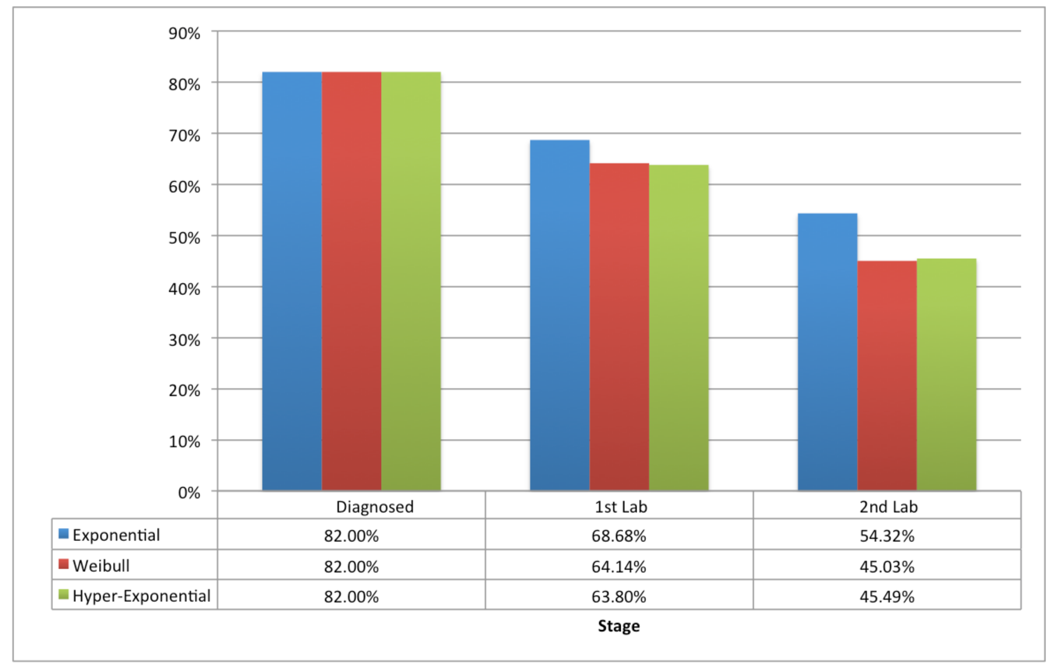

Figure 2. Queueing Model of the HIV Treatment Cascade

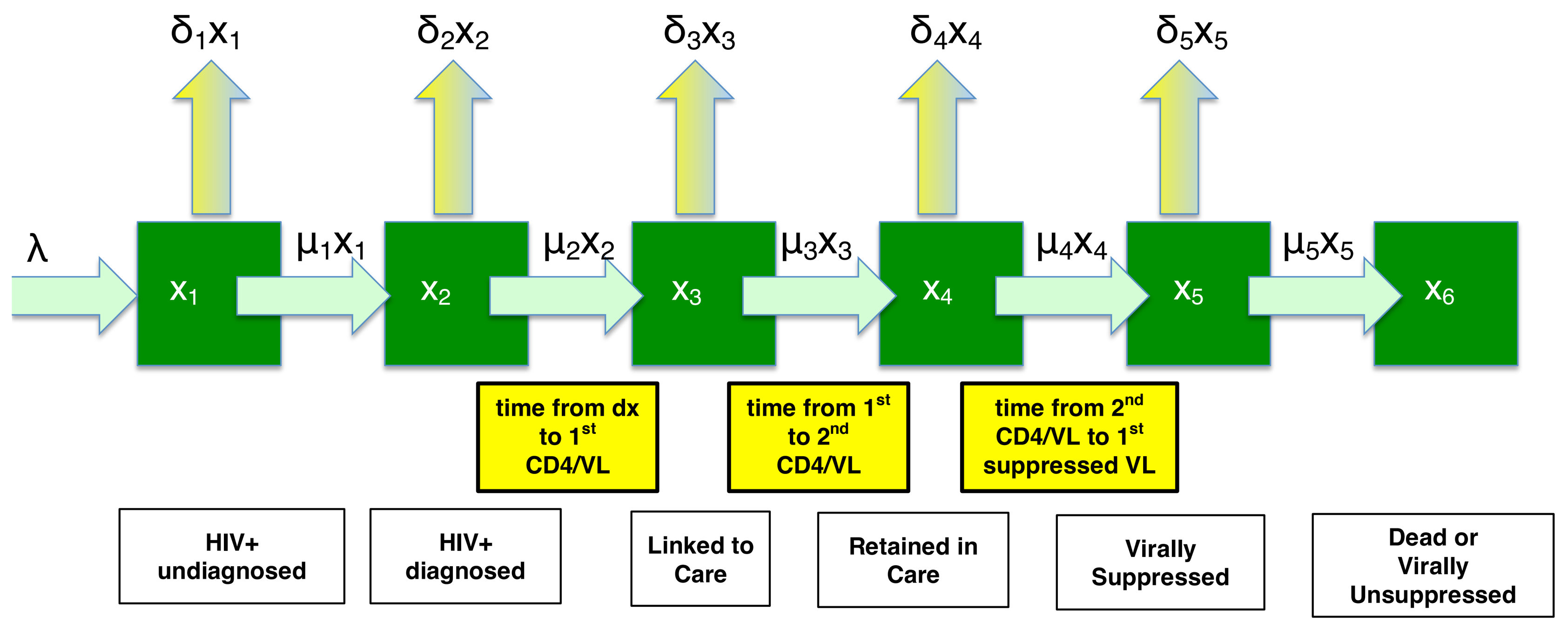

Table 1. Fitting Model Parameters	Model		
	Exponential	**Weibull**	**Hyper-exponential**
Diagnosed -> 1st lab (linked to care)			
Time in stage (diagnosed) in months before progressing to next stage (linked to care)	3.13	3.11	4.84
Dropout fraction (from diagnosed stage)	0.0826	0.0785	0.0668
Log Likelihoods	-31077.48	-27267.24	-26409.78
1st lab -> 2nd lab (retained in care)			
Time in stage (linked to care) in months before progressing the next stage (retained in care)	3.65	3.64	5.22
Dropout fraction (from linked stage)	0.0578	0.0561	0.0374
Log Likelihoods	-29634.68	-28856.88	-28368.74
2nd lab -> viral suppression (undetectable viral load on ART)			
Time in stage (retained in care) in months until progressing to next stage (viral suppression on ART)	9.13	14.59	13.47
Dropout fraction (from retained in care)	0.1709	0.0938	0.1087
Log Likelihoods	-33747.35	-33077.58	-33240.37

red text indicates distribution with maximum log likelihood value

Preliminary Findings and Conclusions

Based on the data from the CDC alone (analysis of NA-ACCORD data is not finished), the hyper-exponential distribution best represents the transitions from diagnosis to first CD4 or viral load test and; from first CD4 or viral load test to second CD4 or viral load test, while the Weibull distribution best fit the transition from and second viral load test to viral suppression. The transition times from diagnosis to first CD4 or viral load test; from first CD4 or viral load test to second CD4 or viral load test, and; from second CD4 or viral load test to viral suppression are represented in Table 1, as are the associated dropout fractions for each stage. Using the parameter estimates for each distribution in the model of the continuum of care and starting with the assumption that 82% of people living with HIV know their serostatus, the percentages of individuals linked to care (1st lab) and retained in care (2nd lab), can be easily derived and are displayed in Figure 3. We conclude that state-level epidemiological data can be used to understand the temporal dynamics of the HIV continuum of care.

Implications for Public Health Policy and Practice

When this queueing model of the treatment cascade is finalized, we will have the first full representation of the temporal dynamics of the continuum of HIV care. That is, for any given cohort, we will be able to estimate how fast or slow people living with HIV pass through various stages of the cascade, the time they reside in any given stage and the probability of their dropout from each stage.

We can then adapt this model of patient flow to assess optimal strategies for intervening in the continuum of care, in order to maximize the number of people who make it through the cascade and onto successful sustained treatment. This can be thought of as a constrained optimization problem in which costs are assigned to moving an individual from stage to stage and then keeping them virally suppressed on ART and the total costs associated with these transitions for all individuals in a cohort cannot exceed a fixed budget.

Though there have been a few attempts to understand how to optimize investments along the continuum of care, no analyses to date have examined the dynamics of patient flow as a function of costs. With the results of this type of model, decision-makers could make better-informed choices about how to invest resources to maximize the number of people virally suppressed on ART given their particular budget constraints.

Finally, this study provides a framework for using public health surveillance systems to improve healthcare outcomes and to elucidate how to most effectively use resources for HIV/AIDS care and treatment.

Acknowledgements

Irene Hall and Tian Tang (CDC), the staff of the NA-ACCORD study and the leadership of its constitutive cohorts for sharing data; the National Coordinating Center for Public Health Services Research and Systems Research, the Predoctoral and Postdoctoral Scholars in Public Health Delivery Awards Program, and the Robert Wood Johnson Foundation for their support.

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