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A Framework to Study the Emergence of Non-Communicable Diseases

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Abstract

Objective: To design a framework for creating computational models that support the understanding of emergent mechanisms for non-communicable diseases.

Scope: The national and global burden of Non-Communicable Diseases (NCDs) represent a major public health challenge that undermines the social and economic development in countries with limited resources. For instance, Cardiovascular Diseases (CVDs) accounted for four out of five deaths in Jamaica and it was the most significant contributor to non-communicable diseases. CVDs are caused by a cluster of comorbidities and lifestyle behaviors that interact to promote a vascular risk. However, their combined effect on CVDs have not been established because of interdependency, nonlinearity and feedback loops. In this research, we developed a computational model based on the Overview, Design concepts, and Details (OOD) protocol to understand the emergence of CVDs in the population. The pattern of this behavior is determined by the interaction of causal relationships among the risk factors. This work has inspired a framework that can be used to model the emergence of non-communicable diseases as complex systems.

Results: Understanding the behavior of the Jamaican system provided insights to the creation of a novel framework for NCD emergent patterns. The framework could potentially reduce development cost and time of NCD management systems, since it supports an iterative modeling paradigm. The framework is dynamic enough to be applied in different populations, health states, and various NCDs.

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Keywords: Emergence; system behavior; modeling; complex systems; non-communicable diseases; cardiovascular diseases; comorbidities; lifestyle behaviors; framework; OOD protocol

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1. Introduction

Non-communicable diseases (NCDs), are by far the leading cause of death in the world, representing 63% of all annual deaths [1]. The four main types of non-communicable diseases are cardiovascular diseases (CVDs), cancer, chronic respiratory diseases and diabetes [1], [2]. According to the Ministry of Health [2], NCDs in Jamaica have emerged as the number one cause of morbidity and mortality. The World Economic Forum estimates the economic burden of life lost due to the four major NCDs was $22.8 trillion in 2010 and is expected to increase to $43.3 trillion in 2030 [2]. NCDs undermine productivity and result in the reduction of capital and economic growth. CVDs are the major contributors of NCDs, therefore, prevention and management are paramount [1], [2]. Furthermore, a chronic disease such as CVDs may develop over a long time period and may involve many comorbidities. For example, diabetes is a major risk factor for developing CVDs [1], [2]. Furthermore, persons who develop CVDs are usually diabetic as well [1], [2]. Most NCDs are caused by the same modifiable risk factors and thus largely preventable [1].

According to the WHO in 2012, an estimated 17.5 million people died from CVDs, representing 31% of all global deaths [1]. An estimated 7.4 million were due to coronary heart disease while 6.7 million was due to stroke [1]. In 2008, CVD was the leading cause of death in Jamaica with an estimated crude mortality rate from ischemic heart disease and stroke of 110 per 100,000 [3]. The incidence of CVD is expected to increase because of the high prevalence of risk factors within the population such as obesity (25.2%) and hypertension (25.2%) [4]. Cardiovascular diseases (CVDs) are a group of disorders of the heart and blood vessels. They include: coronary heart diseases, strokes, and peripheral arterial disease [5].

Risk factors for developing CVD are classified into behavioral and physiological attributes [5], [6]. Behavioral attributes include diet, physical activity, and smoking. In contrast, physiological attributes include blood glucose, blood pressure, cholesterol, weight, age, and sex. Most cardiovascular diseases can be prevented using population-wide strategies by addressing behavioral risk factors such as tobacco use, unhealthy diet, obesity, physical inactivity and dangerous use of alcohol [1], [5]. The effects of behavioral risk factors may show up in individuals as raised blood pressure, raised blood glucose, raised blood lipids, and overweight and obesity [1], [5]. For instance, the Institute of Medicine [6] stated that a reduction in smoking was responsible for between 6% and 56 % risk of CVDs.

In this study, Agent-Based Modeling (ABM) paradigm is used to evaluate the progression of CVD over time in the Jamaican population. We used the NetLogo [7] multi-agent toolkit to implement the CVD model following the ABM paradigm. ABM consist of multiple levels, various nonlinear interactions, and is able to explore emergent behaviors. According to Wilensky and Rand [8], ABM provides the flexibility to represent from very detailed models to highly abstract models. Moreover, it can be used to represent a heterogeneous population and capture the dynamics of each individual's risk factors [8], [9]. ABM is a bottom-up approach, therefore, it can be used to model the interrelated risk factors (Fig. 1) and observe the possible emergence of CVDs as system properties [8], [9]. Such a system has great benefits because it allows modeling complex dynamics based on simple rules with fewer restrictions.

Furthermore, longitudinal clinical trials to cover such long periods of time is difficult and expensive. However, diseases can be evaluated using modeling in real time. Modeling and simulation can be used to explore a "what-if" scenario planning in a virtual environment. E.g. to estimate the population-attributable portion of CVD arising from smoking. Therefore, the model is beneficial to epidemiologists, policy makers and health organizations.

The modeling of CVD, then inspired a framework that is based on a modular approach. It is comprised of three modules, namely population, disease and results that can be developed and validated separately. This approach, adopted from Miksch et al. [10] makes implementation more efficient and allows reusability of existing modules [10]. For instance, developing a model for a different population will only require changes to the population module. The framework is dynamic enough to be applied to different populations and various NCDs.

2. Related works

Computer simulation is widely used to study and predict behavior in complex systems [8], [9]. However, it remains underused to study non-communicable diseases. The most common complications studied were physical