Building Continents of Knowledge in Oceans of Data: The Future of Co-Created eHealth
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A Personalized Risk Stratification Platform for Population Lifetime Healthcare

Ali DAOWD [a], Samina Raza ABIDI[b], Ashraf ABUSHAREKH[a] and Syed Sibte Raza ABIDI[a]
[a]*NICHE Research Group, Faculty of Computer Science, Dalhousie University, Canada*
[b]*Dept. of Community Health & Epidemiology, Dalhousie University, Canada*

Abstract. Chronic diseases are the leading cause of death worldwide. It is well understood that if modifiable risk factors are targeted, most chronic diseases can be prevented. Lifetime health is an emerging health paradigm that aims to assist individuals to achieve desired health targets, and avoid harmful lifecycle choices to mitigate the risk of chronic diseases. Early risk identification is central to lifetime health. In this paper, we present a digital health-based platform (PRISM) that leverages artificial intelligence, data visualization and mobile health technologies to empower citizens to self-assess, self-monitor and self-manage their overall risk of major chronic diseases and pursue personalized chronic disease prevention programs. PRISM offers risk assessment tools for 5 chronic conditions, 2 psychiatric disorders and 8 different cancers.

Keywords. Personalized Healthcare, Lifetime Health, Chronic Disease Risk Assessment and Prevention, Citizen Empowerment, Population Health

1. Introduction

Chronic non-communicable diseases, such as cardiovascular disease, diabetes and cancers are causing 70% of all deaths worldwide [1]. Generally, chronic diseases are regarded as lifestyle-related diseases, because the incidence of a disease is strongly influenced by the manner a person lives. It is well understood that if risky lifestyle behaviours are avoided, most major chronic diseases can be prevented. Lifetime health is an emerging health paradigm that aims to assist individuals to achieve long-term health targets, and avoid harmful lifecycle choices to mitigate the risk of chronic diseases. Early risk assessment at the population level is central to lifetime health.

Public Health Agency of Canada's strategic directions indicate the urgent need for innovative citizen-engagement and empowerment strategies to preemptively detect and effectively prevent the onset of chronic diseases. This can be achieved by targeting modifiable risk factors through digital health based personalized risk assessment, monitoring, lifestyle change and behaviour modification programs [2, 3].

Chronic disease risk factors can be classified as *modifiable* risk factors such as diet and lifestyle, whereas others are *non-modifiable* risk factors such as age, genetics and family history. Over 90% of diabetes, 80% of cardiovascular diseases, 70% of stroke and colon cancer are potentially preventable by combining few lifestyle modifications: non-smoking, moderate physical activity, moderate alcohol consumption, healthy diet, and maintaining a healthy weight [4]. A systematic review has demonstrated the positive impact of communicating personalized risk scores towards motivating at-risk

individuals to modify their risk factors—overall 45% of participants who received personalized risk information made informed choices, compared to 20% of participants who received generalized risk information [5].

Our objective is to provide informative and interactive tools for individuals to assess their cumulative chronic disease risk, and in response to the noted risks present personalized behavioral interventions targeting lifestyle changes to mitigate the risk of chronic diseases. In this paper, we present the functional design of our digital health based *Personalized Risk Investigation, Stratification and Mitigation (PRISM)* platform that leverages artificial intelligence, data visualization and mobile health technologies to empower citizens to self-assess, self-monitor and self-manage their overall risk of major chronic diseases and pursue personalized disease prevention programs. At present, PRISM has digitized risk assessment tools for 5 chronic conditions (Cardiovascular disease, Diabetes, Hypertension, Stroke and COPD), 2 psychiatric disorders (Anxiety and Depression), and 8 different cancers. The significance of PRISM lies in empowering individuals to pursue lifetime health to impact on quality of life, health care costs, chronic disease reduction and mortality.

2. Methods

Our risk assessment and mitigation approach posits that chronic disease risk assessment should be (a) pursed from a holistic multimorbid perspective, as it has been shown that major risk factors are additive in predictive power, where their co-occurrence leads to greater risk for chronic disease; and (b) personalized to an individual's health status. In this regard, we take a Healthcare Knowledge Management [6] approach to (a) model and computerize a range of validated chronic disease risk assessment tools as a chronic disease risk knowledge model; (b) establish interactions between risk factors across multiple diseases; (c) provide person-centered risk assessment, as opposed to disease-centric risk assessments; and (c) employ interactive data visualizations to display chronic disease risks based on live health data.

2.1. Computerization of Risk Assessment Tools

To computerize the risk assessment tools, we have developed an integrated, agile and evidence-informed knowledge model—i.e., Chronic Disease Risk Ontology (CDRO)—to logically represent synergistic associations between risk factors, risk ratios, health determinants (physiological, pathological, genetic, psychosocial, etc.), risk assessment tools and multimorbid diseases. CDRO represents the following concepts:

1. *Risk Determinants* that denote all health determinants and risk factors influencing the risk of chronic diseases. Given that the onset of a disease can influence the risk of other associated chronic diseases, the concept includes diseases, disorders and medical conditions contributing to the risk of chronic diseases, in addition to the conventional risk factors, such as demographic and lifestyle risk factors.
2. *Observables* represent an individual's measureable health attribute which can be used to quantify the exposure to a specific risk factor.
3. *Risk Association* describes and maps the mutual associations between source of risk (i.e. risk factors) and outcome of risk (i.e. chronic diseases). To determine the risk association, we state a specific observable that provides a measure of

the source of risk, and the specific condition under which the association becomes true. The associations and conditions are defined according to the hazard ratios and/or odds ratio presented in the risk assessment models.

The CDRO (shown in Figure 1) serve as an evidence-based knowledge resource to (a) assess multiple chronic disease risks; (b) integrate these risks with the individual's health determinants to calculate the "My Health Asset"; and (d) design risk prevention and behaviour modification plans based on personal health profile [3, 7, 8].

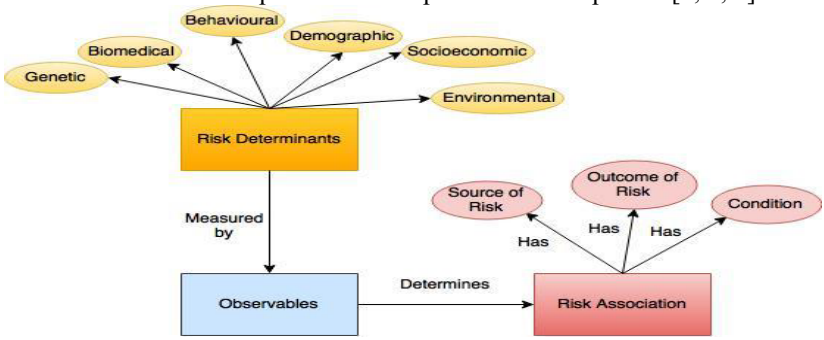

Figure 1. Chronic Disease Knowledge Model

2.2. Health-Centered Risk Assessment:

Most existing chronic disease risk assessment tools are disease-centered, as opposed to being centered on an individual's health. Given the presence of many-to-many relationships between risk factors and chronic diseases [4], we argue that pursuing a disease-centric view is not effective in determining the overall 'health' status of an individual. Therefore, from a personalized lifetime healthcare perspective, we have developed a singular, objective health status measure–termed as the *Health Asset Score (HAS)*—that represents an individual's overall multimorbid chronic disease risk. HAS has been derived through an aggregation of multiple impactful health determinants and major chronic disease risk factors. Given that some risk factors have stronger associations with chronic diseases than others, we weighted differentially the risk factors according to their contribution to the total burden of disease in Canada. The development and validation of HAS is discussed in separate publications.

2.3. PRISM Platform: Functional Architecture

The PRISM platform is developed as a *web- and mobile app* that serves as the digital health interface for individuals to assess their personalized chronic disease risks and pursue personalized behavior modification plans to mitigate the risks for chronic diseases. Using a user-centered design approach, we developed the PRISM dashboard that provides chronic disease risk assessments and related risk mitigation information in an intuitive and interactive format. PRISM entails advance visual analytics methods, based on Angular and D3 visualization libraries, to implement health-lines to illustrate the evolution of health profiles over time; node-diagrams to show risk factor influence on multimorbidity risk; pictograms for comparisons with similar populations; H-graphs to illustrate the health score and impact of related chronic disease risks; and chord diagrams to illustrate effect of influencing modifiable risk factors. PRISM dashboard allows citizens to interact with any visualization, such as zooming-in for more detailed

information, and modulating risk factors to learn how changing a risk factor will influence their HAS. The PRISM app is developed for iOS and Android platforms.

The PRISM platform's architecture consists of 5 functional layers (Figure 2.):

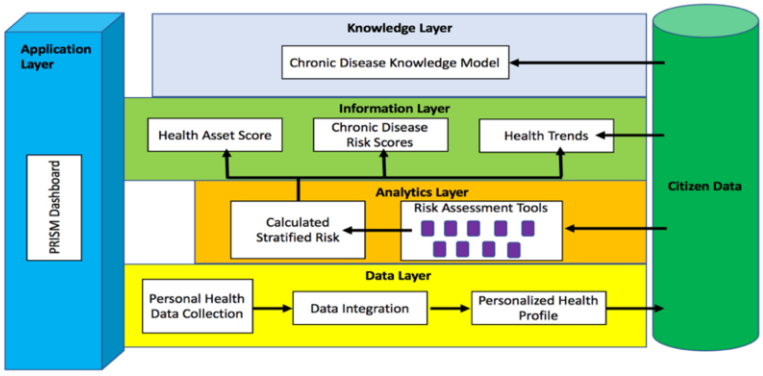

Figure 2. PRISM Functional Layers

1. **Application layer**: This layer hosts the front-end applications and serves as the interface for the end-user. This layer comprises the following applications: (a) PRISM dashboard offers a secure, interactive and personalized dashboard for individuals to (i) receive overall health and disease-specific risk scores via intuitive visualizations to effectively translate risk information, and (ii) receive alerts and reminders in response to changes in risk scores; (b) PRISM self-monitoring tool to facilitate tracking of risk information, personal health data and lifestyle data; and (c) PRISM health profile 'logbook' to provide users with a user-friendly interface that facilitates the input of personal health and lifestyle information.
2. **Data Layer**: This layer is responsible for the collection and integration of personal health data, collected from heterogeneous data sources to generate a holistic health profile that comprises person-reported health and psychosocial parameters and health data from wearable and mobile devices about lifestyle activities, socio-economic, environmental and demographics. The data collection interface is the PRISM mobile app that leverages existing health data collection kits (iOS and Android) to collect sensor data (heart rate, breathing, exercise, lifestyle, etc.) from wearable devices, health data from consumer health devices (such as blood pressure and glucometer, weight scale, etc.), and text- and voice activated questionnaires.
3. **Analytics Layer:** The analytics layer entails a range of data analytics methods to analyze the individual's health profile to generate both singular chronic disease risk scores and the cumulative HAS.
4. **Information Layer:** This layer provides a comprehensive overview of a person's health in terms of a personalized health score, individual chronic disease risks, health profile trend over time, and present risk factors and how they are influencing the risk for chronic diseases. The information layer uses state-of-the-art visual analytics techniques to create an interactive PRISM dashboard where individuals can visualize their chronic disease risks and recommended behaviour change strategies.
5. **Knowledge Layer:** The knowledge layer embodies the CDRO that contains the digitized chronic risk assessment tools. The knowledge layer uses the

health profile to generate personalized multimorbid risk trajectories. CDRO also generates personalized behaviour modification plans based on the individual's health profile. PRISM Evaluation Framework:

PRISM is currently undergoing evaluation, based on a cross-sectional study design, where we collect use a self-administered questionnaire to evaluate citizens' behavioural intention of using PRISM platform. From a theoretical perspective, PRISM's evaluation is based on a range of technology acceptance models [9]. According to the theories, perceived usefulness and attitude towards using can positively influence one's behavioural intention to use an application. Additionally, task-technology fit is being measured as it is an important factor that influences one's behavioural intention to use.

To measure citizens' behavioural intention towards PRISM, we designed a self-administered survey using standard questions, based on constructs from the abovementioned theoretical models. A sample size of 40 users allowed us to achieve a statistical power of 0.8 with a medium to large effect size (f^2=0.35). The evaluation results will be presented in detail in a follow-up publication.

3. Discussion:

Preventive and personalized health solutions are the right approach to reduce the health and economic burden of chronic diseases. The PRISM platform is an innovative population-based lifetime health eco-system designed to empower citizens to take personalized measures to prevent the onset of chronic diseases. The annual economic burden of chronic disease risks is estimated to be $50.3 billion in 2012—therefore if PRISM can help achieve a 1% annual relative reduction in the prevalence of chronic disease risk factors it will result in saving an estimated $8.5 billion annual by 2031 [10].

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