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Evidence on the validity of a comprehensive health risk index and implications for ambulatory care and population health management

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Abstract

A novel, comprehensive health risk index for adults has been validated and is now ready for use to improve health for individuals and populations. This health risk index provides an estimate of the avoidable risk of death for adults age 30 years or older. It includes 12 evidence-based clinical and behavioral risk factors and was validated on *discrimination* and *calibration* using the NHANES and the Framingham Heart Study cohorts. The results from both cohorts were consistent and similar. Discrimination was good and calibration was acceptable but tended to over-predict mortality risk for females in the higher risk deciles.

“An ounce of prevention is worth a pound of cure.”

Benjamin Franklin

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Appendices (Supplemental Digital Content)

- A. Health Risk Survey
- B. Pseudo Code for Calculating Health Risk Index

INTRODUCTION

Most people would agree that it is better to prevent disease than to treat disease. But to know if prevention efforts are effective – if an ounce invested early saves a pound spent later -- one needs to have a valid and useful measure of health risk that reflects the major known risk factors that contribute to the development of disease, disability and premature death. As society moves towards care that is both patient-centered with respect to achieving outcomes that matter to individuals, and population based with respect to holding healthcare providers accountable for the health of a population, it will require measures of health risk that are accurate and useful for guiding and evaluating both patient-level and population-level prevention programs.

To be sure, there are many validated measures of health risk but most tend to focus on specific types of risk factors. Some are based on biometrics such as body mass index, blood pressure level, and blood glucose level, while others focus on behavioral risks such as smoking, exercise, alcohol intake, and eating patterns.¹ A few risk measures, the most well-known being the Framingham Index,² take a more comprehensive approach to estimating risk by creating a composite risk index based on both biometric and behavioral risks.³⁻⁶

Recognizing the need for a comprehensive measure of health risk that is based on available epidemiologic and health sciences research, a team from Boston (the Framingham Heart Study Group), the University of Washington (Institute for Health Metrics and Evaluation), and Dartmouth (The Dartmouth Institute for Health Policy and Clinical Practice) worked collaboratively to develop and validate a health risk index that estimates the avoidable risk of death for both individuals and populations. The index includes the leading biological risks as well as behavioral risks. Consequently the new, predictive health risk index is comprehensive – includes both biometrics and health behaviors -- and is based on current research about factors that contribute to avoidable mortality. The index was first validated based on national (NHANES) data,⁷ and has been re-validated based on Framingham Heart Study (FHS) data.

The purpose of this paper is to briefly summarize both sets of validation results – from the already published NHANES results as well as the new Framingham results – and to suggest how this comprehensive health risk index could be used for ambulatory patient care, ambulatory population health management, and value based payment programs.

METHODS

Overview of Methods

The risk index estimates an individual's total risk of mortality over the next 10 years based on exposure to 12 risk factors for adults aged 30 years or older. Risk factors were included based on reviews of the scientific literature and represent the most substantial, modifiable risk factors that contribute to mortality.⁸ All risk factors selected had to be: (a) actionable: subject to modification by clinical or behavioral interventions; (b) substantial: contribute at least 0.20 years to mortality risk; and (c) evidence-based: supported by recent meta-

analyses.⁹ A full description of the risk index calculation and validation methods have been published previously⁷ and are briefly summarized below.

Risk Index Calculation

Overall mortality risk—An individual's risk of mortality is determined by first calculating, for each cause of death, the individual's overall relative risk of mortality compared to no exposure to the 12 risk factors. The index takes into account risk factor correlation (individuals having higher/lower exposure to multiple risk factors due to common socioeconomic or behavioral determinants), and risk mediation (risk associated with factors such as obesity may be mediated through other risk factors such as blood pressure). An individual's relative risk of mortality by cause is multiplied by the annual background mortality risk by cause to estimate an individual's overall mortality risk.

Avoidable mortality risk—An individual's avoidable mortality risk -- the mortality risk that could be avoided by reducing exposure to the 12 risk factors to an optimal level -- is calculated as the individual's overall mortality risk less the individual's background mortality risk based on age and sex. The background mortality risk is an estimate of the risk of mortality over the next ten years for an individual of the same age and sex who is not exposed to any of the 12 risk factors. We use the currently observed age-and sex-specific background mortality risk to predict an individual's future background risk of mortality following standard life-table methodology.^{10,11} An individual's overall risk of mortality from all causes over the next ten years and their remaining life expectancy are calculated using the standard competing risk model.¹²

Background mortality risk by cause—To determine the background mortality risk by cause for the current period we combined information on: (a) the current distribution of exposure to the 12 risks by age and sex using national NHANES and Behavioral Risk Factor Surveillance System (BRFSS) databases; (b) age-, sex-, and cause-specific mortality rates in 2010 from the Global Burden of Disease Study 2010;¹³ and (c) relative risks by age, sex, and cause associated with exposure to the 12 risk factors from systematic reviews.

Currently observed age-, sex-, and cause-specific mortality rates represent the rate at which individuals of that age and sex group will die from a cause in a given year. These rates reflect the current exposure to risk factors in the population and their hazardous effects on mortality. The fraction of mortality that is due to current exposure to the 12 risk factors can therefore be determined by calculating a population attributable fraction (PAF) by age, sex and cause.⁸ The PAF for each age, sex and cause is calculated as the sample weighted sum of the excess risk. The background mortality rate by cause is calculated as one minus the PAF multiplied by the current mortality rate. Mortality rates were converted to annual probabilities of dying using the standard life table calculation.^{10,11}

Risk Index Validation

Using established validation techniques, we performed two *out-of-sample* validation studies, one using an NHANES database and the second an FHS database.

NHANES Database—The first validation study was done using NHANES linked mortality data for respondents interviewed between 1988 and 1994 and between 1999 and 2004 through December 31, 2006. For each individual in the NHANES cohort we calculated the predicted risk of mortality over the available follow-up time period up to ten years.

Framingham Database—A complementary validation study was done using identical methods for risk score calculation but was performed using data from participants attending the FHS Offspring Examination 7 (1998–2001) and the Original Cohort Examination 20 (1986 – 1990) to further validate the 10-year mortality risk model. These cohorts were chosen because 11 of the 12 risk factors used in the risk index calculation model were also measured in these particular FHS cohorts. Seat belt use was not collected in the FHS cohort and this was handled by setting the assumption that everyone in the FHS answered “Yes” to the question about seat belt use. FHS participants aged 30 and older at the time of examination were included in the analyses.

Validation Tests—The NHANES and FHS validation studies assessed two characteristics of the health risk index. First, *discrimination*—the ability of the risk index to distinguish between those who die during the follow-up period and those that survive—by calculating the area under the curve (AUC);¹⁴ and, second, *calibration*—the ability of the risk index to predict the observed level of risk across deciles of the population—using the Hosmer-Lemeshow χ^2 statistic, calculated as follows: (1) order participants into deciles of predicted risk; (2) calculate within each decile the difference between mean predicted risk and the observed risk (proportion of participants with event); (3) square this difference and divide by the predicted risk; (4) sum the results across deciles. The resulting statistic has 8 degrees of freedom. The validation was performed for men and women and by age group.

RESULTS

The health risk index includes a total of 12 risk factors that make independent contributions to avoidable mortality: four clinical measures, (blood pressure, BMI, blood glucose, cholesterol), three behavioral measures (smoking, exercise, seat belt use), and four nutritional measures (vegetables, fruits, nuts, omega-3).

NHANES Cohort

The health risk index was validated on the NHANES database and then linked to mortality data.⁷ The results showed that the new health risk index performed well and was able to predict risk for both men and women across different levels of risk.

The health risk index was able to distinguish well between individuals who survived and those who died; results on the sensitivity and specificity of the health risk index as represented by the area under the curve (AUC) were very good: 0.84 for women and 0.84 for men (see Figure 1 - top panel). However, the new risk model slightly over predicted mortality risk for women in the higher risk deciles, ($\chi^2 = 22.8$ for females vs. 12.3 males). See Figure 2A.

Framingham Cohort

The second validation of the health risk index was conducted in the FHS population, which differed from the NHANES population in some respects, such as being somewhat older and having less racial and ethnic diversity. As described above, the FHS data were analyzed in the same way as the NHANES data.

The FHS results were remarkably similar to the NHANES results (see Figure 1 (bottom panel) and Figure 2B). Once again the new health risk index performed well at predicting who would survive and who would die: AUC of 0.73 for women and 0.74 for men. And, as with the NHANES sample, the new risk index had the same limitation of over predicting mortality rates for women in the higher risk deciles ($\chi^2 = 21.6$ females vs. 12.5 males).

DISCUSSION

Just as we need good measures of health outcomes (clinical outcomes as well as patient reported outcomes) to improve the quality and value of ambulatory care for individual patients and for ambulatory care populations, we need good measures of health risk to prevent avoidable death and disease. This new health risk index is novel, comprehensive, and evidence-based. It includes clinical, behavioral and nutritional risk factors, is based on recent available evidence regarding risk factors and their modification, and can be updated and improved as more research is published on risk factors contributing to premature death. Finally, the health survey and underlying algorithm for scoring and estimating health risk are available at no charge for anyone to use.

Use of Index for Personalizing Patient Care

The development of this new health risk index has important implications for customizing patient care. The risk index can be used by ambulatory care clinicians and health coaches to guide preventive care for individual patients. It can be used to estimate the patient's personal total health risk and then to work with the patient to determine which specific risk factors are most important to address and which risk factors the patient is ready and willing to work on. Then, the patient's efforts to reduce risk can be tracked over time to measure the success of both clinical and behavioral risk reduction efforts. The information in Table 1 provides answers to the basic question of which risk factors would have the most significant impact on health, thereby giving the patient and provider a place to begin negotiating which to act on.

Use of Index for Population Health Management

The risk index can be used for both ambulatory population health programs as well as employee health promotion programs to proactively identify people at highest risk and then to track the results of risk reduction efforts for high-risk populations. Results show that mortality risk is highly concentrated. For example, in the NHANES cohort among those aged 30–44 years, approximately 5% of the male and 6% of the female population accounted for 25% of the risk of death. This suggests that it is possible to identify a small group of people with extremely high risk of death to target for prevention and health promotion interventions. And the success of these ambulatory population health

management initiatives can then be measured by assessing the change in the population's health risk over time.

Use of Index for Value Based Payments

As the nation moves towards value based payment programs and towards promoting a culture of health, we need a valid, comprehensive, practical method for measuring health risk (and the reduction in health risk), particularly for high-risk individuals and for subpopulations who suffer from health disparities. Just as it is important to include measures of health outcomes and patient experience in value based payment programs, including health risk measures would create truly patient-centered performance metrics.

Practical Implementation Issues and Challenges

Although the new risk index has the potential to bolster personal prevention and health promotion for patients and employees, to sharpen population health assessment and risk measurement, and to become a component of value based payment programs, there are several practical implementation issues that must be taken into consideration. Some key implementation issues are briefly addressed below.

Data collection: How might risk factor data be collected?—Primary care clinicians and employers could collect data on the 12 risk factors by establishing systems for periodically conducting a health assessment that includes the four biometric measurements (blood pressure, body weight, blood glucose, cholesterol) and a health habits survey to gather self-reports on the remaining risk factors. Many employers offer annual health assessments for their employees that include this type of information and primary care clinicians routinely collect this type of information as part of periodic health assessments. The value of this information could be enhanced by adopting the index for assessing overall risk, health coaching, and offering customized decision making on prevention.

Data accuracy: What factors might introduce reporting bias?—Some people respond to questions about health related behaviors such as alcohol intake, smoking, and seat belt use in a way that is biased towards giving a more socially acceptable answer. This may be particularly true when these questions are asked by an insurer, an employer or by a personal physician whom they trust and wish to please. It is likely, therefore, that some people will have estimated risks that are lower than actual risks due to biased self-reports on eight of the 12 risk factors. Reporting bias might be reduced by ensuring the individual that their answers will only be used for their benefit-- as part of a personal prevention program -- and will not be used for other purposes.

Taking action on the data: What matters most?—Once an individual learns of their overall results – i.e., receives information about the number of years of life that they might gain if they decreased their avoidable risks of death to optimal levels – then the questions become practical and tactical. For example, a person might ask questions such as: which risk factors matter most? How does decreasing my blood pressure compare to increasing exercise or eating more vegetables or reaching my ideal body weight? Table 1 provides answers to these important questions. It shows that the three risk factors that make the largest

independent contribution to avoidable risk of death (in years) are smoking, high blood pressure, and excess body weight, whereas the three risk factors that make the smallest independent contribution are low omega-3 intake, alcohol intake, and inadequate seat belt use. This kind of information could be used to determine where a person might best start their work to improve their chances of living longer.

Updating risk factor estimates: How can the index be refreshed?—The impact of different risk factors and combinations thereof may change over time due to behavioral, social, economic, and environmental trends and on the underlying science regarding the impact of these risk factors on longevity. Consequently, it will be important to provide periodic updates to the scoring algorithm for each subpopulation defined by gender and age. In fact, the team at the University of Washington now has the new data and evidence-base in hand to begin the first risk index update based on the latest available data used to produce the 2015 Global Burden of Disease report.

Conclusion

This new health risk index is valuable both for clinicians and individual patients working to reduce the individual's risk of death and disease as well as for ambulatory population health promotion and value-based payment programs. We believe that this health risk index could be used alongside other “triple aim” performance measures – such as health outcomes, patient experience, and per capita costs– to evaluate ambulatory care program success in promoting health and preventing premature death.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Performance of health risk index at predicting death: receiver operating characteristic (ROC) curves for males and females based on NHANES [reprinted from Lim et al Population Health Metrics (2015) 13:27] (top panel) and Framingham (bottom panel) cohort results

Age All, Males: Predicted Risk s. Actual Mortality NHANES Pooled, Complete Individuals (N=3903)

Age All, Females: Predicted Risk vs. Actual Mortality NHANES Pooled, Complete Individuals (N=4338)

Figure 2.

Predicted risk versus actual mortality for males and females across the gradient of health risk levels in NHANES cohort [reprinted from Lim et al Population Health Metrics (2015) 13:27] (2A) and Framingham cohort (2B)

Table 1

Life expectancy gains in the US population (in years) by removing risk factors

	Smoking	High Blood Pressure	Excess body weight	High blood glucose	High cholesterol	Low physical activity	Low nut intake	Low vegetable intake	Low fruit intake	Low omega-3 intake	Alcohol intake	Inadequate seat belt use	Joint Effects
Male	3.20	2.50	2.30	1.57	1.33	1.27	0.87	0.76	0.72	0.62	0.58	0.24	9.59
Female	2.39	2.92	2.21	1.38	0.92	1.39	0.72	0.70	0.61	0.54	0.40	0.23	8.98

Reprinted from Lim, et al. Population Health Metrics (2015) 13:27.