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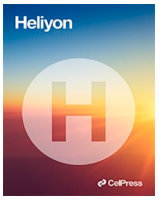

Research article

An empirical approach for life expectancy estimation based on survival analysis among a post-acute myocardial infarction population

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ABSTRACT

Background: Practical communication of prognosis is pertinent in the clinical setting. Survival analysis techniques are standardly used in cohort studies; however, their results are not straightforward for interpretation as compared to the graspable notion of life expectancy (LE). The present study empirically examines the relationship between Cox regression coefficients (HRs), which reflect the relative risk of the investigated risk factors for mortality, and years of potential life lost (YPLL) values after acute myocardial infarction (AMI).

Methods: This retrospective population-based study included patients aged 40–80 years, who survived AMI hospitalization from January 1, 2002, to October 25, 2017. A survival analysis approach assessed relationships between variables and the risk for all-cause mortality in an up to 21-year follow-up period. The total score was calculated for each patient as the summation of the Cox regression coefficients (AdjHRs) values. Individual LE and YPLL were calculated. YPLL was assessed as a function of the total score.

Results: The cohort (n = 6316, age 63.0 ± 10.5 years, 73.4 % males) was randomly split into training (n = 4243) and validation (n = 2073) datasets. Sixteen main clinical risk factors for mortality were explored (total score of 0–14.2 points). After adjustment for age, sex and nationality, a one-point increase in the total score was associated with YPLL of ~one year. A goodness-of-fit of the prediction model found 0.624 and 0.585 for the training and validation datasets respectively.

Conclusions: This functional derivation for converting coefficients of survival analysis into the comprehensible form of YPLL/LE allows for practical prognostic calculation and communication.

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Key messages

- **What is already known on this topic** –translation of survival analysis models into life expectancy format is complex and not straightforward for interpretation.
- **What this study adds** – it is possible to express the coefficients of survival analysis in the form of years of potential life lost in post-acute myocardial infarction patients; one-unit increase of the total score, calculated as a sum of adjusted Hazard Ratios shortens life expectancy by ~ one year.
- **How this study might affect research, practice or policy** – a useful derivation for expressing the coefficients of survival analysis in the comprehensible converted structure of life expectancy allows for practical communication and maintains a simplistic technique for calculation.

1. Introduction

In disease diagnoses and progression, practical and clear depiction of prognosis is fundamental for clinician-patient communication [1]. There is a varying spectrum of recognized measures for prognosis presentation involving an array of approaches for calculation [2]. Among these metrics are: standardized mortality ratio, comparative mortality figure and life expectancy (LE) [3].

LE refers to the average number of years a given population may be expected to survive based on their mortality rates as distinctive to their age [4]. This concept can be visually elucidated as equal to the domain beneath a mortality curve, irrelevant of its shape [4]. LE is unique in that it is a cohort mortality measure and, in turn, allows for cross-populational comparison; this is particularly of relevance in a time where disparities and inequality in healthcare are a focal point. Furthermore, LE is a more graspable concept than alternative prognostic metrics for both the patient and clinician alike [5]. A related term is years of potential life lost (YPLL), indicating the estimated mean in years an individual may have lived had they not demised earlier [6]. However, the calculation of LE and YPLL are intricate and complex [7–9], complicating the accessibility of these notions for physicians, researchers, and statisticians.

Contrastingly, survival approaches, such as Kaplan-Meier method and Cox Proportional Hazards regression, are acceptable in research, and results are simplistically obtainable using popular statistical programming. However, their values are not straightforward for interpretation. Given the barrier underpinning LE attainability, we postulated examining translation of survival analysis models (e.g., hazard ratios [HRs]) into LE format. Several studies have explored such derivations [5,10]. However, the formulas applied were notably elaborate.

According to data from the Global Burden of Disease Study, ischemic heart disease ranks among the leading causes of morbidity and mortality worldwide, imposing substantial YPLL burdens [11]. In this regard, reports show that reduction of cardiovascular disease-related deaths/adherence to cardiovascular health may markedly increase LE [12]. Thus, comprehensive approaches addressing the challenges posed by ischemic heart disease in public health are necessary [13].Acute myocardial infarction (AMI) is one of the most severe presentations of coronary artery obstruction [14]. Lifetime prediction models following AMI demonstrate appreciably higher mortality than among the general population [15]. Moreover, stratification of post-AMI patients by sex, age, and ethnic group, among other variables, impacts their predictive mortality outcomes [15].

This study aims to empirically examine the possibility of expressing the coefficients of the investigated risk factors for mortality calculated using Cox regression model (HR), in the form of YPLL values spanning a long-term follow-up period for patients who sustained AMI.

2. Materials and methods

2.1. Study population

This retrospective population-based study included patients who survived an AMI event and were discharged following hospitalization at Soroka University Medical Center (SUMC), Israel, during January 1, 2002, to October 25, 2017. SUMC is a tertiary referral center (~1200 beds), singly serving the metropolitan area of Beer-Sheva, Southern Israel (more than 500,000 residents).

AMI patients, aged 40–80 years old with Israeli citizenship, who were discharged (alive) from hospitalization were included. The first hospitalization was regarded for analyses among patients with multiple hospitalizations during this period.

The study was approved by the SUMC ethical review board, which was performed in accordance with the Helsinki declaration (approval number SOR-0319-16). Informed consent was waived since this was a retrospective observational study.

2.2. Data sources and classifications

Data were obtained from the electronic medical files of SUMC (baseline characteristics) and the Ministry of the Interior Population Registry (mortality data). The following baseline data were included regarding patients' index events: demographic and clinical characteristics, laboratory, echocardiographic and angiographic findings and AMI management, as previously reported for the Soroka Acute Myocardial Infarction (SAMI) project [16,17].

Diagnostic variables were mostly determined by the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) discharge codes. The ICD-9-CM codes of ST-elevation MI (STEMI): 410.0*- 410.6* and non-ST elevation MI (NSTEMI): 410.7*- 410.9* were utilized to classify AMI diagnosis. In addition to ICD-9-CM codes: *i)* anemia diagnosis was applied to low blood hemoglobin levels in accordance with the World Health Organization guidelines [18], *ii)* renal diseases referred to estimated

glomerular filtration rate (eGFR) < 60 mL/min/1.73 m^2, aligning with the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) formula [19], *iii)* diabetes mellitus diagnosis was given when hemoglobin A1C levels ≥6.5 %, based on the American Diabetes Association [20] and *iv)* dyslipidemia was classified when low-density lipoprotein levels were ≥100 mg/dL, determined by the American Heart Association diagnostic criteria [21].

2.3. Follow-up and outcome

The primary outcome was all-cause mortality. The individual follow-up period was defined as the timespan from the patient's

Table 1
Baseline characteristics of patients included in the training and the validation data sets.

Characteristic	Training data set (n = 4243)	Validation data set (n = 2073)	p
Demographics			
Age, Years - Mean (SD)	67.86 (9.25)	68.05 (8.94)	0.441
Sex, Males	2789 (65.7)	1390 (67.1)	0.298
Nationality, Arabs [Minorities]	515 (12.1)	274 (13.2)	0.223
Cardiac diseases			
Cardiomegaly	453 (10.7)	211 (10.2)	0.545
Supraventricular arrhythmias	848 (20.0)	399 (19.2)	0.489
CHF	969 (22.8)	432 (20.8)	0.073
Pulmonary heart disease	472 (11.1)	220 (10.6)	0.541
CIHD	3320 (78.2)	1663 (80.2)	0.071
AV block	187 (4.4)	89 (4.3)	0.835
Cardiovascular risk factors			
Renal diseases	628 (14.8)	280 (13.5)	0.169
Diabetes mellitus	2235 (52.7)	1087 (52.4)	0.858
Dyslipidemia	3367 (79.4)	1696 (81.8)	0.021
Hypertension	2439 (57.5)	1182 (57.0)	0.726
Obesity	1008 (23.8)	466 (22.5)	0.260
Smoking	1565 (36.9)	729 (35.2)	0.183
PVD	759 (17.9)	360 (17.4)	0.610
Other disorders			
COPD	532 (12.5)	240 (11.6)	0.274
Neurological disorders	897 (21.1)	423 (20.4)	0.50
Malignancy	256 (6.0)	101 (4.9)	0.061
Anemia	2316 (54.6)	1128 (54.4)	0.899
GI bleeding	119 (2.8)	48 (2.3)	0.255
Schizophrenia/Psychosis	95 (2.2)	44 (2.1)	0.767
Alcohol/Drug addiction	135 (3.2)	62 (3.0)	0.682
Characteristics of AMI			
Year of AMI event:			
2002–2004	1259 (29.7)	622 (30.0)	0.988
2005–2009	1596 (37.6)	781 (37.7)	
2010–2014	1022 (24.1)	495 (23.9)	
2015–2017	366 (8.6)	175 (8.4)	
Type of AMI, STEMI	1744 (41.1)	885 (42.7)	0.229
Results of echocardiography			
Echocardiography performance	3310 (78.0)	1639 (79.1)	0.340
Severe LV dysfunction	526 (15.9)	228 (13.9)	0.068
LV hypertrophy	244 (7.4)	89 (5.4)	0.010
Mitral regurgitation	295 (8.9)	115 (7.0)	0.023
Tricuspid regurgitation	165 (5.0)	72 (4.4)	0.359
Pulmonary hypertension	373 (11.3)	154 (9.4)	0.044
Results of angiography			
Angiography performance	2782 (65.6)	1385 (66.8)	0.327
Measure of CAD:			
No/non-significant	137 (4.9)	54 (3.9)	0.369
One vessel	580 (20.8)	288 (20.8)	
Two vessels	684 (24.6)	363 (26.2)	
Three vessels/LM	1381 (49.6)	680 (49.1)	
Type of treatment:			
Noninvasive	1339 (31.6)	624 (30.1)	0.426
PCI	2330 (54.9)	1152 (55.6)	
CABG	574 (13.5)	297 (14.3)	

AMI - acute myocardial infarction; AV - atrioventricular (block); CABG - coronary artery bypass graft; CAD - coronary arteries disease; CHF - congestive heart failure; CIHD – chronic ischemic heart disease; COPD – chronic obstructive pulmonary disease; GI – gastrointestinal; IHD - ischemic heart disease; LM - left main (coronary artery); LV - left ventricular; PCI - percutaneous coronary intervention; PVD - peripheral vascular disease; SD – standard deviation; STEMI – ST-elevation myocardial infarction.
*The data are presented as n (%) unless otherwise stated.

hospital discharge and extended either until his/her death or to the last documented update, which was July 31, 2023.

2.4. Study variables

For each patient, personal LE value was calculated, based on the corresponding general population, according to the year of hospitalization, patient age on the day of hospitalization, sex, and nationality (Jewish or Arab). Referenced data was extracted from the Central Bureau of Statistics [22]. In addition, YPLL was calculated as the difference between LE and the duration of individual follow-up.

2.5. Training and validation data sets

The study cohort was randomly divided into training and validation data sets. The training set (~70 % of the cohort) was used to build a predictive model. All those allocated to the training set demised at the end of the follow-up period. The validation set (~30 % of the cohort) was used to predict the responses for the observations based on the results of the predictive model. Patients who died during the follow-up period, as well as those who survived were included in the validation set. However, patients alive on the last data extraction date and whose follow-up period was shorter than calculated personal LE were excluded from analyses.

2.6. Statistical analysis

Data analysis was performed using IBM SPSS Statistics 29 software. Patient characteristics were presented as mean and standard

Table 2
Relative risk (adjusted hazard ratios - AdjHRs) for long-term post-discharge mortality in accordance to the investigated parameters (columns "Survival analysis"); relationships between the investigated parameters and years of potential life lost (YPLL) (columns "Prediction of YPLL") – multivariable analyses.

Characteristic	Survival analysis		Prediction of YPLL	
	AdjHR	95 % CI	B	95 % CI
Reference group[a]	1		20.953[d]	20.004–21.902
Age, Years:				
46–50	0.924	0.707–1.209	−4.457[d]	(-5.582) - (−3.333)
51–55	1.111	0.876–1.408	−8.645[d]	(-9.641) - (−7.648)
56–60	0.954	0.759–1.199	−13.279[d]	(-14.241) - (−12.317)
61–65	1.080	0.862–1.351	−16.842[d]	(-17.786) - (−15.898)
66–70	1.272[b]	1.019–1.588	−19.888[d]	(-20.818) - (−18.957)
71–75	1.432[c]	1.148–1.785	−22.848[d]	(-23.775) - (−21.921)
76–80	1.651[d]	1.323–2.060	−25.362[d]	(-26.291) - (−24.433)
Sex, Female	1.032	0.963–1.105	1.598[d]	1.312–1.885
Nationality, Arab	0.975	0.887–1.072	1.793[d]	1.392–2.194
Supraventricular arrhythmias	1.197[d]	1.107–1.295	0.841[d]	0.512–1.169
CHF	1.179[d]	1.090–1.275	0.783[d]	0.460–1.106
Pulmonary heart disease	1.163[c]	1.047–1.293	0.556[b]	0.122–0.989
Renal diseases	1.493[d]	1.364–1.634	1.392[d]	1.016–1.768
Diabetes mellitus	1.246[d]	1.168–1.328	0.941[d]	0.672–1.210
PVD	1.183[d]	1.090–1.284	0.908[d]	0.564–1.252
COPD	1.427[d]	1.300–1.568	1.603[d]	1.208–1.997
Neurological disorders	1.304[d]	1.208–1.409	1.053[d]	0.731–1.374
Malignancy	1.597[d]	1.404–1.817	2.011[d]	1.468–2.554
Anemia	1.164[d]	1.090–1.242	0.868[d]	0.596–1.140
Schizophrenia/Psychosis	1.361[c]	1.109–1.671	1.396[c]	0.534–2.259
Alcohol/Drug addiction	1.367[d]	1.147–1.630	1.544[d]	0.805–2.283
Year of AMI event:				
2005–2009	1.507[d]	1.392–1.631	1.928[d]	1.611–2.245
2010–2014	2.229[d]	2.031–2.446	3.921[d]	3.564–4.278
2015–2017	3.436[d]	3.024–3.903	5.540[d]	5.038–6.043
Severe LV dysfunction	1.318[d]	1.194–1.456	1.251[d]	0.840–1.662
LV hypertrophy	1.247[c]	1.093–1.423	0.798[c]	0.245–1.351
Tricuspid regurgitation	1.299[c]	1.097–1.538	0.965[c]	0.268–1.662
Treatment, Noninvasive	1.661[d]	1.545–1.785	2.028[d]	1.717–2.340

AdjHR – adjusted hazard ratio; AMI – acute myocardial infarction; B – linear regression coefficient; CHF - congestive heart failure; CI – confidence interval; COPD – chronic obstructive pulmonary disease; LV - left ventricular; PVD - peripheral vascular disease; YPLL - years of potential life lost.

[a] Reference group: males, Jews, 40–45 years old, acute myocardial infarction (AMI) event in 2002–2004, with no investigated risk factors and invasive treatment for AMI. P-values.

[b] <0.05.

[c] <0.01.

[d] <0.001.

deviation (SD) for continuous variables and as n and percent for categorical data. Univariable analysis included Student's t-test and Chi-Squared test for continuous and categorical variables respectively.

Cox regression survival multivariable model assessed the relationships between the study variables and the outcome. The study parameters presented in the model were based on a demographic and clinical data, as well as relevant mortality data as established in the literature [11,13,23], as available to us. Among those, we investigated parameters that demonstrated a preliminary univariable significance level of p-value<0.1. The results of the model were presented as adjusted HRs (AdjHR) with 95 % confidence intervals (CI).

The relationship between the baseline characteristics and YPLL were investigated using multivariable linear regression. Results were presented as regression coefficients (B) and standard errors (SE). Association between AdjHRs derived from the survival model and the linear regression coefficients was estimated using Pearson correlation. For validation of our model we applied the bootstrapping procedure (BP) 1000 BP sample on the linear prediction model of the training dataset.

Total score was subsequently calculated for each patient based on the results of Cox regression model as the summation of AdjHR values.

A P-value of <0.05 (two-tailed) for each test was considered statistically significant.

3. Results

3.1. Study population; training and validation data sets

Throughout the timeframe of extraction 13,117 AMI patients, aged 40–80 years were found. Of them, 768 (5.9 %) died during hospitalization. The remaining patients (n = 12,349) were randomly split into training (n = 8618, 69.8 %) and validation (n = 3731, 30.2 %) data sets. After randomization, 6218 (50.4 %) patients from the training set survived the follow-up period and were excluded from analysis. Additionally, 1658 out of 3731 subjects (44.4 %) were excluded from the validation set, given that they were alive on the last date of mortality data extraction and their follow-up period was shorter than calculated personal LE. Therefore, based on these criteria, the study population was classified as: 4243 patients in the training set and 2073 patients in the validation data set (see the study flow chart in Supplementary figure 1).

The average age of the study population before randomization (n = 12,349) was 62.97 (SD = 10.53) years, 9064 (73.4 %) were male and 1617 (13.1 %) were Arabs. Among the study population, 6039 (48.9 %) endured STEMI, 10,394 (84.2 %) had a diagnosis of chronic ischemic heart disease (CIHD) and 10,258 (83.1 %) dyslipidemia; 9963 (80.7 %) underwent invasive intervention (percutaneous coronary intervention [PCI] or coronary artery bypass graft surgery [CABG]) during hospitalization.

The baseline demographic and clinical characteristics of the training and validation data sets are depicted in Table 1. No statistically significant differences in prevalence of most investigated parameters between the patients from the data sets were found, except for higher prevalence of left ventricular (LV) hypertrophy, mitral regurgitation and pulmonary hypertension, among patients included in the training set.

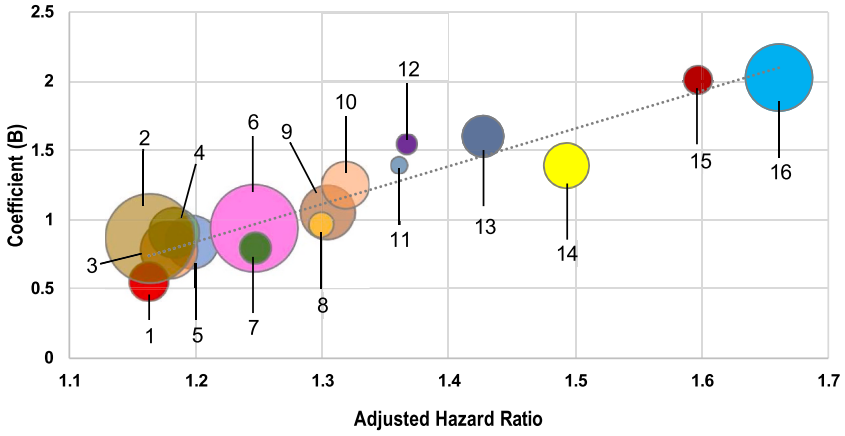

Fig. 1. The figure illustrates the results of the models described in Table 2. Adjusted hazard ratios (AdjHRs) are the results of multivariable Cox regression analysis assessing the relationship between the investigated risk factors and the risk of mortality. "B" represents the results of multivariable linear regression analysis, examining the relationship between the investigated risk factors (the same risk factors as in the Cox regression analysis) and years of potential life lost (YPLL).

* Adjusted for age, sex, nationality and year of acute myocardial infarction (AMI) event; scaled by prevalence.

1 – pulmonary heart disease, 2- anemia; 3 - congestive heart failure (CHF); 4 - peripheral vascular disease (PVD); 5 - supraventricular arrhythmias; 6 - diabetes mellitus; 7 - left ventricular (LV) hypertrophy; 8 - tricuspid regurgitation; 9 - neurological disorders; 10 - severe left ventricular (LV) dysfunction; 11 – schizophrenia/psychosis; 12 – alcohol/drug addiction; 13 - chronic obstructive pulmonary disease (COPD); 14 - renal diseases; 15 – malignancy; 16 - noninvasive treatment.

Dashed line - linear trend. The size of a bubble represents prevalence.

3.2. Training data set; survival analysis

The post-discharge follow-up period ranged between two days and 20.9 years; the median was 5.5 years and interquartile range (IQR) 2.0–9.7 years. In accordance with the inclusion criteria, all patients from the training data set died during the follow-up.

The results of the Cox survival multivariable regression are summarized in Table 2 (columns "Survival analysis"). Based on the results of the applied model, a higher risk of long-term all-cause mortality related to older age (above 65 years), later calendric year of AMI event, non-invasive (vs invasive) treatment of AMI and the investigated cardiovascular and non-cardiovascular comorbidities. No statistically significant relationships between sex and nationality and the risk for mortality were found.

3.3. Training data set; life expectancy (LE) and years of potential life lost (YPLL)

The distribution of LE values among the patients of the training data set ranged between 7.8 and 39.8 years, average 15.84 (SD = 6.81) and median of 14.1 years. Consistently, YPLL ranged between (−11.7) and 37.9 years, with a mean of 9.47 (SD = 7.44) and a median of 8.7 years. For 3874 patients, (91.3 %) death preceded LE (YPLL >0) (see histogram presenting the distribution of YPLL values in Supplementary figure 2).

The results of linear multivariable regression for prediction of YPLL are presented in Table 2 (columns "Prediction of YPLL"). Older age was associated with lower YPLL. However, a later calendric year of AMI event, female sex, Arab (vs Jew), non-invasive (vs. invasive) treatment for AMI and the investigated comorbidities were associated with higher YPLL values. The parameters of goodness of fit for this model were as follows: R = 0.825, R-Squared = 0.681 and adjusted R-Squared = 0.679.

The values of AdjHRs of Cox regression model and the regression coefficients (Bs) of the linear model highly correlated. After adjustment for age, sex, nationality and the year of AMI event, positive correlation was found for the variables of clinical characteristics: weighted by prevalence of these variables, greater values of AdjHR were associated with increased YPLL (r = 0.968), see Fig. 1.

3.4. Training data set; total score and prediction of YPLL

Based on the results of the Cox multivariable model, the total score value for each patient was calculated, as the sum of AdjHR values of 16 clinical parameters, as presented in Fig. 1. The total score values ranged between 0 and 14.2, mean 4.07 (SD = 2.51) and median 3.85. The total score for 316 (7.4 %) of the patients was 0; the subsequent total score value (>0) was 1.16.

The results of the multivariable linear regression for prediction of YPLL using the total score variables are presented in Table 3 (columns "Training data set"). The results show that the predicted YPLL of the reference group post-AMI (males, Jews, 40–45 years old, with no investigated comorbidities) is ~23 years. Thus, the designating LE of this group is roughly 38 years, with these patients expected to live about 15 years following hospital discharge. In addition, the results of the model demonstrated that older age was associated with lesser YPLL; female sex and Arab nationality (compared to Jewish) were associated with greater YPLL. Moreover, an increase of one point of the total score corresponded with 0.9 years (~11 months) of YPLL. For example, predicted YPLL of an "average" post-AMI patient in our cohort (male, Jew, 65–70 years old, with the clinical total score value of 4 [~three investigated comorbidities]) is ~four years. Thereby the given LE of this group is about 15 years, with patients expected to live about 5.2 years after hospital discharge. Supplementary Table 1 presents fictitious patient examples for practical calculability of the model.

The model exhibited a high goodness of fit: R = 0.791, R-Squared = 0.625 and adjusted R-squared = 0.624. Adding the total score variable into the model with the demographic characteristics led to an 8.9 % improvement of R-squared (p-for-change <0.001). The scatter plots of correlation between predicted and calculated YPLL for the training data set is presented in Fig. 2A. The results of the BP

Table 3
Multivariable model for predicting years of potential life lost (YPLL), using total score variable – training and validation data sets.

Characteristic	Training data set			Validation data set		
	B	95 % CI	p	B	95 % CI	p
Reference group[a]	23.097	22.099–24.095	<0.001	21.138	19.277–22.998	<0.001
Total score, 1-point increase	0.918	0.861–0.974	<0.001	1.108	1.020–1.196	<0.001
Age, Years:						
46–50	−4.494	(-5.710) - (−3.278)	<0.001	−2.823	(-5.027) - (−0.619)	0.012
51–55	−8.769	(-9.846) - (−7.693)	<0.001	−7.025	(-9.016) - (−5.035)	<0.001
56–60	−13.073	(-14.111) - (−12.036)	<0.001	−11.854	(-13.790) - (−9.917)	<0.001
61–65	−16.704	(-17.721) - (−15.687)	<0.001	−16.456	(-18.343) - (−14.569)	<0.001
66–70	−19.918	(-20.917) - (−18.919)	<0.001	−19.808	(-21.679) - (−17.937)	<0.001
71–75	−22.711	(-23.705) - (−21.716)	<0.001	−22.312	(-24.172) - (−20.452)	<0.001
76–80	−25.033	(-26.028) - (−24.039)	<0.001	−24.624	(-26.490) - (−22.758)	<0.001
Sex, Female	1.490	1.193–1.787	<0.001	1.476	0.989–1.962	<0.001
Nationality, Arab	1.339	0.915–1.763	<0.001	1.190	0.523–1.857	<0.001

B – linear regression coefficient; CI – confidence interval.

[a] Reference group: males, Jews, 40–45 years old, acute myocardial infarction (AMI) event in 2002–2004, with no investigated risk factors and invasive treatment for AMI.

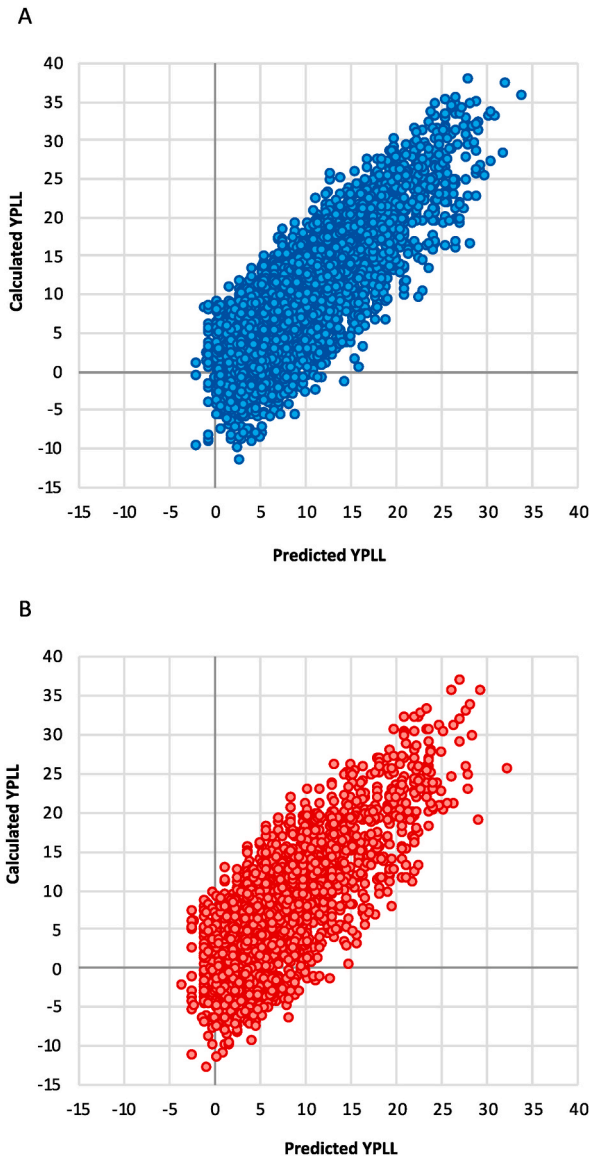

Fig. 2. Scatter plot - correlation between predicted and calculated years of potential life lost (YPLL): A - training data set; B - validation data set. Predicted YPLL summarizes points for age, sex, nationality, and comorbidities from the multivariable model (Table 3). Calculated YPLL is the difference between life expectancy (LE) and follow-up duration. LE was estimated based on age, sex, nationality, and admission year data. Follow-up extended from discharge to death or last update (July 31, 2023). This comparison assesses predicted versus actual potential life lost accuracy. LE - life expectancy; YPLL - years of potential life lost.

resampling are delineated in Supplementary Table 2 yielding low bias values, thus indicating strong validity of the model.

3.5. Validation data set

The baseline characteristics of the patients included in the validation data set are presented in Table 1 (right column). Out of 2073 patients included in the validation data set, 1888 (91.1 %) died during the follow-up period within 21.6 (median = 6.2, IQR 2.3–11.5) years (cumulative mortality = 0.964).

The values of personal total score in the validation data set ranged from 0 to 14.7, mean 3.87 (SD = 2.61) and median 3.66; the total score for 189 (9.1 %) of the patients was 0. The results of the multivariable linear regression for prediction of YPLL for this group are presented in Table 3 (columns "Validation data set"). An increase of one point of the total score related to 1.1 years (~13 months) of YPLL. The goodness of fit of this model was as follows: R = 0.766, R-Squared = 0.587 and adjusted R-squared = 0.585. Adding the total score variable into the model with the demographic characteristics led to a 12.1 % improvement of R-squared (p-for-change <0.001). Correlation between predicted and calculated YPLL among the validation data set is presented in Fig. 2B.

4. Discussion

The present study empirically examined the possibility of expressing the coefficients of survival analysis (AdjHR of Cox regression model) in the form of YPLL in patients following AMI. Our findings demonstrate that: 1) YPLL may be predicted by considering "classic" demographic and clinical parameters, including age, sex, nationality, chronic diseases and characteristics of AMI event; 2) analyzation of the cohort of post-AMI patients with an extended follow-up period through estimates of Cox regression model (AdjHRs) highly correlated with the predictors of YPLL; 3) an "average" (male, Jew, 65–70 years old, with ~three comorbidities) post-AMI patients' life is reduced by roughly four years when matched with the general population; and 4) the presence of risk factors shortens LE. For instance, a one-unit increase of the total score, calculated as a sum of AdjHRs (for example, 2 to 3, 4.5 to 5.5, etc.) shortens LE by ~ one year.

We observed that patients who sustained AMI succumb to a lifespan lessened by roughly four years. These findings are generally similar to the literature. Liao et al. [24] found that AMI patients who underwent PCI therapy accounted for a protective association, wherein LE diminishment ranged from 3.6 (with PCI) to 5.2 (no PCI) years. In this context, following the results of our study, noninvasive therapy for AMI is related to a higher mortality risk (AdjHR = 1.66), and accordingly, shortens lifespan by ~1.5 years.

In the context of prevalence of risk factors on long-term mortality, our findings showed comorbid prevalence was markedly higher than that of previous studies [25]. We presumably attribute these differences to the undiversified geographic composition of our cohort, as well as the plausible difference in sample size between our study and the referenced work [25].

As addressed in the current study, the prognostic impact of an AMI event accompanied by additional risk factors/comorbidities on patient mortality is multifariously discussed in the literature. It has been observed that schizophrenia, obesity, and smoking, among others, contribute to reduced LE among AMI patients [26–28].

In comparing the goodness of fit of our work to other models described in the literature we found some fundamental parallels. Dorresteijn et al. [29] examined translation of clinical trial results into an LE prediction model, finding temporal validation to demonstrate alignment between predicted long-term survival probabilities and observed Kaplan-Meier survival data. An additional work [30] examining the notion of LE and its potential utility in public health contexts described the relationship between LE and relative risk to be influenced by both mortality levels and their age distribution, with lower LE populations experiencing greater impact from a given relative risk.

As seen in the cohort of the present study, a notable portion of the AMI patients endured multiple concomitant morbidities. The notion of multimorbidity is predominantly recognized as having two or more simultaneous health conditions [31], a phenomenon observed to be rampant among AMI patients [32]. Among the Israeli population, reports show prevalence of chronic disease as: 90 % to sustain one morbidity, 80 % with two and 65 % with three chronic illnesses [33]. Furthermore, it was seen that patients with multimorbidity accounted for a decreased LE of 2.9 years on average in contrast to patients who had less comorbidities. Particularly, the coexistence of AMI and chronic heart failure, cerebrovascular disease, and chronic renal failure independently ensued the highest mortality risk and greatest estimated YPLL [32]. In addition, our results demonstrated that greater YPLLs were associated with younger age, female sex, minorities and later calendric year of AMI occurrence; death among these groups cause more loss of life years, in similarity to postulations in the literature [6].

As stated, in the current study females exhibited a slightly elevated risk for mortality, indicating potentially shorter LE compared to males. These finding underscore the importance of considering sex-specific factors in risk assessment and management strategies for post-AMI patients. The importance of stratifying the contextualized outcomes by sex is consistent with findings emphasized in the literature, observing unfavorable outcomes to be associated with female sex [34,35].

The results of the current study contribute to the body of evidence exploring the correlative pathways between statistical techniques regularly applied to clinical medical research and mortality study metrics using various methodologies (Cox proportional hazards regression and exponential models, among others) [36–38]. While previous works determined significant correlations in analytical conversions, the process involved elaborate calculations that researchers and statisticians may find less accessible than the mathematical expression presented in the current study.

The implications of our study extend to both clinical practice and future research. Enhancement of prognostic discussions post-AMI by translating survival analysis coefficients into YPLL is imperative, as inconsistencies and inaccuracies in this regard have been reported [39–41]. Furthermore, the significance of population health management and the role of chronic diseases on health outcomes and inequalities may be addressed by optimizing patient education [42]. Predictive models converting survival analysis coefficients into interpretable metrics deem further investigation.

4.1. Limitations

Firstly, although this study included a relatively long-term follow-up period (up to 21 years), in the context of LE, this follow-up period may be perceived as limited. This conundrum often occurs in cohort studies spanning realistically executable timeframes [2]. A portion of the study cohort was still alive on the last date of mortality data collection. Therefore, their lifespan is unknown, and it is possible they may outlive their predicted LE. This conceivably may have resulted in an overestimation of YPLL in the present study. Additionally, the extrapolated LE data from the Central Bureau of Statistics of the general population refers to aggregated data from all regions of Israel, and is not distinctive to the Southern District, where the study cohort is located, potentially leading to incompatibility. However, it has been reported that LE among the residents of the Southern District is lower than in the rest of Israel [43]. Moreover, the precise health status of the referenced general population is not fully known; it is presumable that some of them have undergone AMIs. Additional characteristics which might be related to LE (such as socio-economic status, nutrition and lifestyle habits)

were not investigated. Lastly, there is an element of survival bias given that the patients with severe morbidity died upon arrival, or during hospitalization. The inclusion of these patients could have impacted outcomes. Nonetheless, this study aimed to examine AMI patients following discharge, and therefore excluded those who died imminently. Future studies should consider these drawbacks.

5. Conclusions

This study proposes a useful derivation for expressing the coefficients of survival analysis in the comprehensible converted structure of LE in patients following AMI, taking into consideration an extensive accumulation of parameters that serve as risk factors and predictors of mortality. This alternative and novel methodology allows for practical and interpretable prognostic communication, and simultaneously maintains a simplistic technique for calculation.

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Data availability statement

Data cannot be shared for ethical/privacy reasons.

CRediT authorship contribution statement

Batya Betesh-Abay: Writing – original draft, Methodology, Conceptualization. **Arthur Shiyovich:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Harel Gilutz:** Writing – review & editing, Supervision, Conceptualization. **Ygal Plakht:** Writing – review & editing, Supervision, Methodology, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e29968.

References

[1] T.J. Iwashyna, N.A. Christakis, Physicians, patients, and prognosis, West. J. Med. 320 (2001) 253–254, https://doi.org/10.1136/ewjm.174.4.253.
[2] M.J. Rutherford, T.M. Andersson, M. Björkholm, P.C. Lambert, Loss in life expectancy and gain in life years as measures of cancer impact, Cancer Epidemiology 60 (2019) 168–173, https://doi.org/10.1016/j.canep.2019.04.005.
[3] I. Kim, H.K. Lim, H.Y. Kang, Y.H. Khang, Comparison of three small-area mortality metrics according to urbanity in Korea: the standardized mortality ratio, comparative mortality figure, and life expectancy, Popul. Health Metrics 18 (2020) 3, https://doi.org/10.1186/s12963-020-00210-7.
[4] D. Naimark, Life Expectancy Measurements, 2016, pp. 419–431.
[5] P.B.S. Silcocks, D.A. Jenner, R. Reza, Life expectancy as a summary of mortality in a population: statistical considerations and suitability for use by health authorities, J. Epidemiol. Community Health 55 (2001) 38–93, https://doi.org/10.1136/jech.55.1.38.
[6] J. Gardner, J. Sanborn, Years of potential life lost (YPLL)—what does it measure? Epidemiology 1 (1990) 322–329, https://doi.org/10.1097/00001648-199007000-00012.
[7] L. Németh, T.I. Missov, Adequate life-expectancy reconstruction for adult human mortality data, PLoS One 13 (2018) e0198485, https://doi.org/10.1371/journal.pone.0198485.
[8] S.J. Olshansky, B.A. Carnes, Ever since gompertz, Demography 34 (1997) 1–15, https://doi.org/10.2307/2061656.
[9] B. Gompertz, On the nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies, in: In a Letter to Francis Baily, Esq. F. R. S. &c. By Benjamin Gompertz, Esq, F. R. S Proceedings of The Royal Society of London, 1833, pp. 252–253, https://doi.org/10.1098/rspl.1815.0271, 2.
[10] D.J. Sari, D. Lestari, S. Devila, Pricing life insurance premiums using Cox regression model, AIP Conf. Proc. 2168 (2019), https://doi.org/10.1063/1.5132461.
[11] G.A. Mensah, V. Fuster, C.J.L. Murray, G.A. Roth, Global burden of cardiovascular diseases and risks, 1990-2022, J. Am. Coll. Cardiol. 82 (2023) 2350–2473, https://doi.org/10.1016/j.jacc.2023.11.007.
[12] H. Ma, X. Wang, Q. Xue, X. Li, Z. Liang, Y. Heianza, O.H. Franco, L. Qi, Cardiovascular health and life expectancy among adults in the United States, Circulation 147 (2023) 1137–1146, https://doi.org/10.1161/CIRCULATIONAHA.122.062457.
[13] H. Dai, A.A. Much, E. Maor, E. Asher, A. Younis, Y. Xu, Y. Lu, X. Liu, J. Shu, N.L. Bragazzi, Global, regional, and national burden of ischaemic heart disease and its attributable risk factors, 1990–2017: results from the Global Burden of Disease Study 2017, European Heart Journal. Quality of Care & Clinical Outcomes 8 (2022) 50–60, https://doi.org/10.1093/ehjqcco/qcaa076.

[14] G.W. Reed, J.E. Rossi, C.P. Cannon, Acute myocardial infarction, Lancet (London, England) 389 (2016) 197–210, https://doi.org/10.1016/S0140-6736(16)30677-8.

[15] Y. Plakht, H. Gilutz, A. Shiyovich, Excess long-term mortality among hospital survivors of acute myocardial infarction. Soroka Acute Myocardial Infarction (Sami) project, Publ. Health 143 (2017) 25–36, https://doi.org/10.1016/j.puhe.2016.09.032.

[16] Y. Plakht, A. Shiyovich, S. Weitzman, D. Fraser, D. Zahger, H. Gilutz, A new risk score predicting 1- and 5-year mortality following acute myocardial infarction Soroka Acute Myocardial Infarction (SAMI) Project, Int. J. Cardiol. 154 (2012) 173–179, https://doi.org/10.1016/j.ijcard.2010.09.014.

[17] Y. Plakht, A. Shiyovich, S. Weitzman, D. Fraser, D. Zahger, H. Gilutz, Soroka Acute Myocardial Infarction (SAMI) score predicting 10-year mortality following acute myocardial infarction, Int. J. Cardiol. 167 (2013) 3068–3070, https://doi.org/10.1016/j.ijcard.2012.11.075.

[18] World Health Organization, Haemoglobin concentrations for the diagnosis of anaemia and assessment of severity, Available online: https://iris.who.int/handle/10665/85839, 2011.

[19] A.S. Levey, L.A. Stevens, C.H. Schmid, Y.L. Zhang, A.F.3rd Castro, H.I. Feldman, J.W. Kusek, P. Eggers, F. Van Lente, T. Greene, J. Coresh, A new equation to estimate glomerular filtration rate, Ann. Intern. Med. 150 (2009) 604–612, https://doi.org/10.7326/0003-4819-150-9-200905050-00006.

[20] American Diabetes Association, Classification and diagnosis of diabetes: standards of medical care in diabetes-2020, Diabetes Care 43 (Suppl1) (2020) S14–S31, https://doi.org/10.2337/DC20-S002.

[21] S.M. Grundy, N.J. Stone, A.L. Bailey, C. Beam, K.K. Birtcher, R.S. Blumenthal, L.T. Braun, S. de Ferranti, J. Faiella-Tommasino, D.E. Forman, R. Goldberg, P. A. Heidenreich, M.A. Hlatky, D.W. Jones, D. Lloyd-Jones, N. Lopez-Pajares, C.E. Ndumele, C.E. Orringer, C.A. Peralta, J.J. Saseen, J. Smith, C. Sidney, L. Sperling, S.S. Virani, J. Yeboah, AHA/ACC/AACVPR/AAPA/ABC/ACPM/ADA/AGS/APhA/ASPC/NLA/PCNA guideline on the management of blood cholesterol: a report of the American College of Cardiology/American Heart Association task force on clinical practice guidelines, J. Am. Coll. Cardiol. 73 (2018) e285–e350, https://doi.org/10.1016/J.JACC.2018.11.003, 2019.

[22] Central Bureau of Statistics. Available online: https://www.gov.il/en/departments/central_bureau_of_statistics/govil-landing-page (accessed on December 14, 2021).

[23] J.A. Dodson, A.M. Hajduk, M. Geda, H.M. Krumholz, T.E. Murphy, S. Tsang, M.E. Tinetti, M.G. Nanna, R. McNamara, T.M. Gill, S.I. Chaudhry, Predicting 6-month mortality for older adults hospitalized with acute myocardial infarction: a cohort study, Ann. Intern. Med. 172 (2020) 12–21, https://doi.org/10.7326/M19-0974.

[24] C.T. Liao, T.H. Hsieh, C.Y. Shih, P.Y. Liu, J.D. Wang, Cost-effectiveness of percutaneous coronary intervention versus medical therapy in patients with acute myocardial infarction: real-world and lifetime-horizon data from Taiwan, Sci. Rep. 11 (2021) 5608, https://doi.org/10.1038/s41598-021-84853-y.

[25] M.E. Yadegarfar, C.P. Gale, T.B. Dondo, C.G. Wilkinson, M.R. Cowie, M. Hall, Association of treatments for acute myocardial infarction and survival for seven common comorbidity states: a nationwide cohort study, BMC Med. 18 (2020) 231, https://doi.org/10.1186/s12916-020-01689-5.

[26] R. Attar, A. Wester, S. Koul, S. Eggert, C. Polcwiartek, T. Jernberg, D. Erlinge, P. Andell, Higher risk of major adverse cardiac events after acute myocardial infarction in patients with schizophrenia, Open Heart 7 (2020) e001286, https://doi.org/10.1136/openhrt-2020-001286.

[27] E.M. Bucholz, A.L. Beckman, H.A. Krumholz, H.M. Krumholz, Excess weight and life expectancy after acute myocardial infarction: the obesity paradox reexamined, Am. Heart J. 172 (2015) 173–181, https://doi.org/10.1016/j.ahj.2015.10.024.

[28] E.M. Bucholz, A.L. Beckman, C.I. Kiefe, H.M. Krumholz, Smoking status and life expectancy after acute myocardial infarction in the elderly, Heart (British Cardiac Society) 102 (2016) 133–139, https://doi.org/10.1136/heartjnl-2015-308263.

[29] J.A. Dorresteijn, L. Kaasenbrood, N.R. Cook, R.C. van Kruijsdijk, Y. van der Graaf, F.L. Visseren, P.M. Ridker, How to translate clinical trial results into gain in healthy life expectancy for individual patients, BMJ (Clinical research ed.) 352 (2016) i1548, https://doi.org/10.1136/bmj.i1548.

[30] K. Modig, R. Rau, A. Ahlbom, Life expectancy: what does it measure? BMJ Open 10 (2020) e035932 https://doi.org/10.1136/bmjopen-2019-035932.

[31] M.C. Johnston, M. Crilly, C. Black, G.J. Prescott, S.W. Mercer, Defining and measuring multimorbidity: a systematic review of systematic reviews, Eur. J. Publ. Health 29 (2019) 182–189, https://doi.org/10.1093/eurpub/cky098.

[32] M. Hall, T.B. Dondo, A.T. Yan, M.A. Mamas, A.D. Timmis, J.E. Deanfield, T. Jernberg, H. Hemingway, K.A.A. Fox, C.P. Gale, Multimorbidity and survival for patients with acute myocardial infarction in England and Wales: latent class analysis of a nationwide population-based cohort, PLoS Med. 15 (2018) e1002501, https://doi.org/10.1371/journal.pmed.1002501.

[33] J.E. Arbelle, G. Chodick, A. Goldstein, A. Porath, Multiple chronic disorders - health care system's modern challenge in the Maccabi Health Care System, Isr. J. Health Pol. Res. 3 (2014) 29, https://doi.org/10.1186/2045-4015-3-29.

[34] R.P. Dreyer, V. Raparelli, S.W. Tsang, G. D'Onofrio, N. Lorenze, C.F. Xie, M. Geda, L. Pilote, T.E. Murphy, Development and validation of a risk prediction model for 1-year readmission among young adults hospitalized for Acute Myocardial Infarction 10 (2021) e021047, https://doi.org/10.1161/JAHA.121.021047. Available online: https://www.ncbi.nlm.nih.gov/pubmed/34514837.

[35] L. Kuehnemund, J. Koeppe, J. Feld, A. Wiederhold, J. Illner, L. Makowski, J. Gerß, H. Reinecke, E. Freisinger, Gender differences in acute myocardial infarction—a nationwide German real-life analysis from 2014 to 2017, J. Am. Heart Assoc. 44 (2021) 890–898, https://doi.org/10.1002/clc.23662.

[36] D. Lai, R.J. Hardy, S.P. Tsai, Statistical analysis of the standardized mortality ratio and life expectancy, Am. J. Epidemiol. 143 (1996) 832–840, https://doi.org/10.1093/oxfordjournals.aje.a008822.

[37] S.P. Tsai, R.J. Hardy, C.P. Wen, The Standardized mortality ratio and life expectancy, Am. J. Epidemiol. 135 (1992) 824–831, https://doi.org/10.1093/oxfordjournals.aje.a116369.

[38] E.M. Bucholz, S. Ma, S.T. Normand, H.M. Krumholz, Race, socioeconomic status, and life expectancy after Acute Myocardial Infarction, Circulation 132 (2015) 1338–1346, https://doi.org/10.1161/CIRCULATIONAHA.115.017009.

[39] M.G. Clarke, P. Ewings, T. Hanna, L. Dunn, T. Girling, A.L. Widdison, How accurate are doctors, nurses and medical students at predicting life expectancy? Eur. J. Intern. Med. 20 (2009) 640–644, https://doi.org/10.1016/j.ejim.2009.06.009.

[40] A. Griffin, Medical advances increase life expectancy but make people spend far more of their lives being ill, Available online: https://www.independent.co.uk/news/science/life-expectancy-average-healthy-the-lancet-diseases-when-will-i-die-a7349826.html, 2016. (Accessed 14 December 2021).

[41] J. Kagan, Life expectancy: it's more than just a number, Available online: https://www.investopedia.com/terms/l/lifeexpectancy.asp#:~:text=Life%20expectancy%20is%20a%20statistical%20prediction%20of%20how%20long%20a,to%20arrive%20at%20a%20figure, 2023. (Accessed 14 December 2023).

[42] L. Collins, L. Ross, M. Ugiagbe, Clinical practice review on population health management and promoting positive health outcomes, Journal of Hospital Management and Health Policy 7 (2023) 23, https://doi.org/10.21037/jhmhp-23-106.

[43] Israel Life Expectancy 1950-2024. Available online: https://www.macrotrends.net/global-metrics/countries/ISR/israel/life-expectancy (accessed on April 14, 2024).