Measuring population health using health expectancy estimates from morbidity and mortality data

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Abstract

Background

National health plans frequently rely on health expectancies, which are systematically calculated in the EU countries using the Sullivan method. The Sullivan health expectancy index combines age-specific mortality rates and age-specific prevalence of healthy life. The main limitation of the Sullivan method is that prevalence data depends on expensive national health surveys. The objective of this work is to investigate an equivalent estimation, considering multiple health states, but using available information on morbidity and mortality.

Methods

Mortality and morbidity information, corresponding to years 2016 and 2017, was obtained for the population of the county of Baix Empordà (Catalonia), N = 91,130. The set of anonymized individual information on diagnoses, procedures and pharmacy consumption contained in the individual clinical record (ICD and ATC codes), were classified into health states according to the 3M-Clinical Risk Groups. The information analysed included acute inpatient care, acute outpatient care, primary care, pharmacy prescriptions, diagnostic tests, emergencies and long-term residential care services. Based on the health transitions observed between 2016 and 2017, life expectancies by health state were obtained from a multistate microsimulation model.

Results

Healthy life expectancies at birth and 65 years for females and males were respectively $HLE_0^{female} = 39.94$, $HLE_0^{male} = 42.87$, $HLE_{65}^{female} = 2.43$, $HLE_{65}^{male} = 2.17$. Point estimates for global life expectancies at birth and 65 years of age: $LE_0^{female} = 85.82$, $LE_0^{male} = 80.58$, $LE_{65}^{female} = 22.31$, $LE_{65}^{male} = 18.86$. Life expectancies were consistent with the government estimates for 2017. Healthy life expectancies substantially differed from the government estimates based on self-reported health surveys and the calculation method of prevalence.

Conclusions

Health expectancies can be efficiently obtained from multistate models based on mortality and morbidity information and can be useful for monitoring the population according to their health status, in the context of health planning. The results obtained were not comparable with those calculated with the standard Sullivan method.

Background

The progressive incorporation of quality of life indicators in health planning responds to the necessity of evaluation of health services. The interest in measuring not only the number of years lived but also the quality is growing, adding concepts such as chronic disease burden or self-perceived health status. However, despite the fact that life expectancy is an accurate measure of the number of years expected to live on average by a specific population, the measurement of quality of life remains a more complex issue [1–8].

Different types of Health expectancies (HE), are obtained as mixed indicators, combining Life Expectancy and a certain approach to the concept of health. For example, Healthy Life Expectancy (HLE) is defined as the average number of years a person can expect to live with a subjective perception of good health. In general, health expectations are usually calculated based on the Sullivan method, I.e. by combining a given prevalence rate and the age-specific mortality rate [9, 10]. This method, is a standard for comparison between different populations and also for comparison over time for the same population [7].

The critical element in the calculation of HE is the measurement of the concept of health, which can be approached from different dimensions, such as the individual self-perceived health, occurrence of chronic diseases or disability. For example, HLE uses the subjective perception of health obtained from population surveys [9, 12, 13]. The measure of self-perceived health is inferred from one or more simple questions, in which the respondent answers according to his own or her assessment. There is a European agreement on the use of common questions for the purpose of standardisation [13].

Despite the consensus on the definition of indicators such as the HLE, an important limitation is the dependence on the availability of health surveys, usually conducted only on a limited basis, with relatively small but representative population samples, for certain periods and population areas, and implying considerable economic costs. For this reason, an important question that emerges is whether the enormous amount of clinical-administrative information stored by health systems can be used to obtain equivalent HE indicators. An affirmative answer to the question would imply that HE can be produced more efficiently.

This idea is based upon two considerations. First, demographic and clinical information can be easily transformed into categories equivalent to health states [14–17], i.e. adjustment or classification systems for the clinical management of patients. For example, 3M Clinical Risk Groups (CRG) software approximates the health status of individuals in a population, described from a clinical point of view (chronic disease burden), from the set of diagnostic and consumption codes of pharmacies registered during a given period [14]. Second, individual lifetime trajectories and global expectations can be obtained by integrating demographic, clinical and mortality information into micro simulation models [18–21].

The development of new efficient HLE methodologies is important because HLE is considered an essential indicator of the overall performance of any healthcare system. The previous affirmation is evidenced by the fact that HLE indicators are well established in the EU statistics and are present in most European countries health plans.

In line with the above arguments, the main goal of this study is to obtain an equivalent estimation of HLE inferred from demographic, morbidity and mortality data available for a specific population. In addition, we compare the results with the standard Sullivan's estimates [10], conducted by the Catalan government for the same population. Methodological and conceptual differences related to HLE constructions (data versus self perception based) will be discussed in the further sections of the article.

Methods

Population Data

Individual data of the population of the county of Baix Empordà (Catalonia), N = 91,130, was collected ex-post for the consecutive years 2016 and 2017. The set of anonymized individual information included demographic, morbidity and mortality data. The particular subset of morbidity data included exhaustive individual information on diagnoses, procedures and pharmacy consumption contained in the individual clinical record, according to the International Classification of Diseases (ICD) and Anatomical Therapeutic Chemical Classification system (ATC) codes [22, 23].

The dataset was made possible thanks to the support of Serveis de Salut Integrats Baix Empordà (SSIBE), an integrated healthcare services organisation responsible for the global public provision of health services for the population living in the county of Baix Empordà (Catalonia). The services provided included acute inpatient care, acute outpatient care, primary care, pharmacy prescriptions, diagnostic tests, emergencies and long-term residential care services. The framework of organization and delivery of healthcare services described above is equivalent to a Healthcare Maintenance Organisation (HMO).

For clinical management purposes the Baix Empordà population was individually classified into health states according to the 3M Clinical Risk Groups (CRG). Individuals were classified into mutually exclusive categories according to their clinical data and demographic characteristics. The original CRG health status classification aggregates individuals into nine categories: 1. Healthy, 2. History of significant acute disease, 3. Single minor chronic disease, 4. Minor chronic disease in multiple organ systems, 5. Single dominant or moderate chronic disease, 6. Significant chronic disease in multiple organ system, 7. Dominant chronic disease in three or more organ systems, 8. Dominant and metastatic malignancies and 9. Catastrophic conditions.

Throughout this article, we used the CRG classification as a proxy of the health status of the population. However, with the objective of minimizing the number of groups with a reduced number of individuals, we aggregated individual morbidity histories into six health status: 1. Healthy, 2. Significant acute disease, 3. Minor chronic disease, 4. Significant chronic disease in one or two organ systems, 5. Significant chronic disease in three or more organ systems - Catastrophic conditions, 6. Dominant and metastatic malignancies.

ICD codes on diagnostics and procedures and ATC drug codes related to the 91,130 individuals included in the study were collected between 1/1/2016 and 31/12/2017. A number of 758 deaths corresponding to individuals in the study population were reported during the year 2017.

The demographic characteristics and the CRG status of the population at 31/12/2016 are shown in the Fig. 1.

The Fig. 2 shows how the individual data (individual ICD and ATC codes), coming from different clinical sources, were transformed into CRG categories equivalent to health status.

Healthy Life Expectancy by Sullivan's method (HLE-Sullivan)

Considering the county of Baix Empordà as a specific geographical area in Catalonia, HLE estimates of the study population can be obtained from government official reports. In particular, within the period of study, the Catalan Health Department (Departament de Salut) calculated global HLE estimates, for the general Catalan population. HLE estimates were periodically calculated by sex, at different ages of interest, using mortality and self-perception of health information. Mortality data was systematically obtained from the Catalan Register of Mortality (RMC) and the information on self perception of health from the Catalan Health Survey (ESCA) [11, 12]. Moreover, the self perception of health question in the survey included the standard answers: 1. Very good (VGOOD), 2. Good (GOOD), 3. Fair (FAIR), 4. Bad (BAD), 5. Very bad (VBAD), according to the European Health Interview Survey (EHIS) and the definition of dimensions of the EU statistics on income and living conditions (EU-SILC) methodology [12]. Since, question and answers were exactly the same, the HLE indicators obtained from the Catalan government health department are comparable to the equivalent European standards from the European Health and Life Expectancy Information System (EHLEIS) [7, 13].

Throughout the study we used the global Catalan HLE estimates calculated for 2017 as a HLE proxy for the Baix Empordà population for the period 2016–2017.

Healthy Life Expectancy by multistate micro simulation (HLE-MMS)

Based on the individual health status transitions observed between 2016 and 2017, life expectancies by health state, were obtained from a multistate Markov chain microsimulation model.

According to the fundamental Markov chain assumptions, time in the process takes discrete values $t = 1,2, \ldots, n$ (natural years), as well as the space of states $X_{t,1}, X_{t,2}, \ldots, X_{t,m}$. Consequently, the health status of an individual for a specific year was assumed depending only on the health status observed in the previous year. In other words, the last observed status summarized the health history of the individual [18–21].

$$P\left(X_t = x_t | X_{t-1} = x_{t-1}, \ldots, X_2 = x_2, X_1 = x_1\right) = P\left(X_t = x_t | X_{t-1} = x_{t-1}\right),$$

The transition probabilities required in the model were assumed stationary - i.e. constant over time - and were estimated from the individual health status transitions observed for the couple of years 2016–2017. Following the previous definitions we considered six health states plus death as a final absorbing state. Moreover, we considered gender and ten age groups: < 1 year of age, 1–14 years of age, 15–24, 25–34, 35–44, 45–54, 55–64, 65–74, 75–84,>= 85. The health transition model is described in the Fig. 3.

The maximum likelihood estimator of the stationary transition probabilities were simply obtained as counts or frequencies:

$$p'_{\mathrm{ij}}\left(age, t\right) = s_{\mathrm{ij}}\left(age, t\right) / s_{\mathrm{i}}\left(age, t-1\right),$$

were $t = 1, 2, \ldots, T$ are the times of observation, $i, j = 1, 2, \ldots, m$ are the states of the process and S_{ij} are the number of individuals having state j at time t, having state i at time t-1.

The result was an initial set of 20 transition matrices, corresponding to the defined age groups, 10 for men and 10 for women [see Additional file 1]. According to the design of the experiment, these probabilities were age-group centered. Then, with the exception of the first age group (< 1 year of age), we interpolated the yearly transition probabilities using cubic splines. The result was a set of 182 matrices describing the yearly transitions, 91 matrices for men and 91 for women (0 to > = 90 years of age) [see Additional file 2].

In the next step, we generated a sample of random lifetime trajectories according to the observed transition probabilities, N_1 = 10,000 females and N_2 = 10,000 males. The algorithm started assigning an initial health status for a standard individual. Such initial assignation reproduced the composition of the population group < 1 year of age. Hereinafter, for each individual, the model generated a sequence of cycles from birth until death (final absorbing state). A new cycle in the simulation represented an additional year of life. According to the Monte Carlo simulation scheme, changes in the health status were obtained generating pseudo-random numbers and comparing them to the transition probabilities [24]. The final result was a random sample from which we can calculate Health Expectancies according to the standard demographic formula:

$$e_{x,j} = \frac{\sum_{y \geq x} L_{y,j}}{l_x} \quad j = 1,2,\ldots k$$

were *j = 1, 2, …, 7* were the defined states of the process, $L_{y,j}$ the number of person years lived at age *y* in the state *j* and l_x the number of survivors at age *X*.

The healthy life expectancy metrics from this model (HLE-MMS) corresponds to the CRG status “1. Healthy”.

Graphics, data management and statistical calculations were conducted using the Microsoft Office Suite and the Office Visual Basic for Applications (VBA) programming libraries [25].

Results

HLE-Sullivan: Combining mortality and standard health survey information

Since specific indicators of HLE-Sullivan for the population of the area of Baix Empordà were no available, in accordance with the methodology, we used the Catalan government estimates on mortality, demographic and health indicators, published for the year 2017. According to the official Catalan report [11] the values of Healthy life expectancies are shown in the Table 1. HLE- S point estimates at birth and 65 years for females and males were respectively HLE_0^{female} = 66.08, HLE_0^{male} = 66.62, HLE_{65}^{female} = 10.68, HLE_{65}^{male} = 11.43.

Hle-mms: Combining Mortality And Available Data On Individual Morbidity

The output of the multistate micro simulation model is a random sample of individual lifetime trajectories. A numerical approach of the global Life Expectancy function can be obtained from the sample just applying the standard demographic formulas. Moreover, the individual health status changes, along the lifespan, were recorded in the simulation data. Consequently, specific Life Expectancy functions were also split according to the health status defined in the model: 1. Healthy, 2. Significant acute disease, 3. Minor chronic disease, 4. Significant chronic disease in one or two organ systems, 5. Significant chronic disease in three or more organ systems - Catastrophic conditions, 6. Dominant and metastatic malignancies. We assumed that the Life Expectancy function for the health status ‘1. Healthy’ is equivalent to the Healthy Life Expectancy indicator obtained from the for the multistate micro simulation model (HLE-MMS).

Full numerical approximations of the Life Expectancy function by health status are shown in the Fig. 4. HLE- MMS point estimates at birth and 65 years for females and males were respectively HLE_0^{female} = 39.94, HLE_0^{male} = 42.87, HLE_{65}^{female} = 2.43, HLE_{65}^{male} = 2.17. As can be appreciated, the values obtained for the HLE-MMS indicators differed considerably from those obtained in the previous section for the HLE-Sullivan equivalent, e.g. 8.25 years less for HLE_{65}^{female}, 9.26 less for HLE_{65}^{male} .

Finally, full Life Expectancies can also be obtained from the HLE-MMS model (considering all the area in the Fig. 4), with the following point estimates at birth and 65 years of age: LE_0^{female} = 85.82, LE_0^{male} = 80.58, LE_{65}^{female} = 22.31, LE_{65}^{male} = 18.86.

Life Expectancy Validation

Given that the two versions of the HLE indicators were considerably different, an interesting exercise consists in comparing full life expectancies obtained from the multistate micro simulation with those obtained from standard mortality model. For that purpose we compared the full Life Expectancy obtained from the HLE-MMS model with the official standard reports on mortality and Life Expectancy for Catalonia in 2017. We considered two sources of government data: 1. Catalan government reports [11] and 2. Spanish national institute of statistics (INE) reports [26], see Table 2. Although healthy life expectancies based on individual morbidity data substantially differed from the official estimates based on self-reported health surveys (previous sections), the global life expectancy indicators from both approaches were very close. According to the Catalan government data, the point estimates for Life expectancies at birth were: $LE_0^{female} = 86.16$, $LE_0^{male} = 80.71$. According to the INE data for Catalonia, the point estimates for Life expectancies at birth were: $LE_0^{female} = 85.73$, $LE_0^{male} = 80.37$. This similarity is maintained along all the range of ages with the exception of the elder groups (> = 90 years of age). For these groups, the HLE-MMS model tend to overestimate life expectancy in approximately 1,77 years. Therefore, setting aside the different conception of healthy life, and with the exception of elder individuals, both approaches converge on the same values for the LE estimates.

Discussion

We obtained two different approximations to the concept of HLE. A first aspect to discuss is the different concept of health embedded in the two approaches compared in the article. The significant difference in the results is simply a reflection of such different conception of health status. Beyond the World Health Organization's (WHO) definition of health from 1947 "… complete physical, mental and social wellbeing…", difficulty in establishing a common and uniform concept of health was reported in the literature. Recent approaches considered, heath care organisations, health care workers and patients as different actors with a non-uniform perspective over health [27]. Moreover, focusing on the patient context, the self-perception of health is a psychological and cultural convention susceptible to significant variability among individuals [28]. Other authors conclude that the inference of health status from clinical records on attended morbidity approximates to the subjective perception of health and vice versa. However, certain socio-demographic factors modulate the individual perception [29]. Different studies described only moderate or fair agreement comparing self-reported morbidity and pharmacy prescription. Individual factors such as age, gender, marital status, education, poor-delayed recall, depression and polypharmacy were significantly associated with discordance between morbidity measures [30, 31].

The research team considered to calculate the specific HLE-Sullivan estimate for the study population (instead of the global Catalan estimate), since it was feasible from the data available. Although, it would result in a more precise HLE estimate, since the focus of the study is the alternative multistate micro simulation method, the choice of the team was not to go further on the Sullivan estimates.

Throughout the study we proposed a new approach to the concept of healthy life based on available data. The same perspective can be also applicable to other Health Expectancies based on surveys, for example disability-free Life (less subjective and more related to legal or country system characteristics), without chronic morbidity or active life health expectancies.

Concerning the external validation of the results, the same model and data processing shown in the Figs. 2 and 3 can be transferred to different contexts of healthcare services provision or geographical areas. However, two aspects must be taken into account. First, there is no international consensus on patient classification systems from a global perspective. In this work we used the 3M Clinical Risk Groups (CRG) [14], but a well known study of the Society of Actuaries compared 12 different diagnosis and/or pharmacy based models [17]. A second concern is related to the quality of the data. Regardless of the particular system used, the accuracy of the patient classification depends on the richness and intensity of ICD and ATC codes. A poor level of patient-episode data will certainly result in a biased patient classification.

Limitation

Our work is focused on the production of health indicators using data, and some particular issues related to mortality estimation leave room for improvement. This orientation can be considered as a limitation of the work. That is the case of the general age-specific mortality estimation, field in which research is in constant development, but in particular at the extremes of life [32–34].

Finally, as a proposal for further research, a refined version of the model could be obtained by improving mortality and life expectancy forecasting via a Lee-Carter models, which would be practically equivalent to break the stationary assumption for the transition probabilities [35].

Conclusions

Our work introduces new insights on the use of available data for the calculation of health indicators. Healthy life expectancies can be efficiently obtained from multistate models based on mortality and morbidity information, without the use of health surveys. Moreover, healthy life expectancies obtained from data can be useful for monitoring the population according to their health status, in the context of health planning. The proposed methodology was empirically validated by comparing the life expectancy obtained from the model with the standard rate from government reports. However, our results using the multistate micro simulation version of Healthy Life Expectancy were not comparable with those calculated with the standard Sullivan method.

List Of Abbreviations

CRG
Clinical Risk Groups
HE
Health Expectancy
HLE
Healthy Life Expectancy
ICD
International Classification of Diseases
ATC
Anatomical Therapeutic Chemical Classification System
SSIBE
Serveis de Salut Integrats Baix Empordà
HMO
Healthcare Maintenance Organisation
ESCA
Catalan Health Survey
RCM
Catalan Register of Mortality
EHIS
European Health Interview Survey
EHLEIS
European Health and Life Expectancy Information System
HLE-Sullivan
Healthy Life Expectancy by Sullivan’s method
HLE-MMS
Healthy Life Expectancy by multistate micro simulation
INE
Spanish National Institute of Statistics
WHO
World Health Organization

Declarations

Ethics approval and consent to participate

This study is part of a research on population morbidity and healthcare expenditures and was carried out using individual anonymous data provided by SSIBE. The project was approved by the SSIBE Research Committee and by the Clinical Research Ethics Committee from Girona Universitary Hospital Dr. Josep Trueta. Informed consent was requested from study participants, with a commitment to guarantee confidentiality. The Research Committee of SSIBE authorized the study and the data transfer protocol. All methods were carried out in accordance with relevant guidelines and regulations

Consent for publication

Not Applicable.

Availability of data and materials

The dataset supporting the conclusions of this article is included within the article (and its additional files).

Competing interests

The authors declare no competing interests.

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Authors contributions

MC designed the research question, implemented the microsimulation model and drafted the initial manuscript, PI designed the research question, contributed to conceptualization and literature search, JMI managed population, mortality and morbidity data sets, conducted patient classification and statistical analysis. All authors contributed for data interpretation, critically reviewed and approved the manuscript.

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Tables

Table 1 and 2 are available in the Supplementary Files section.

Figures

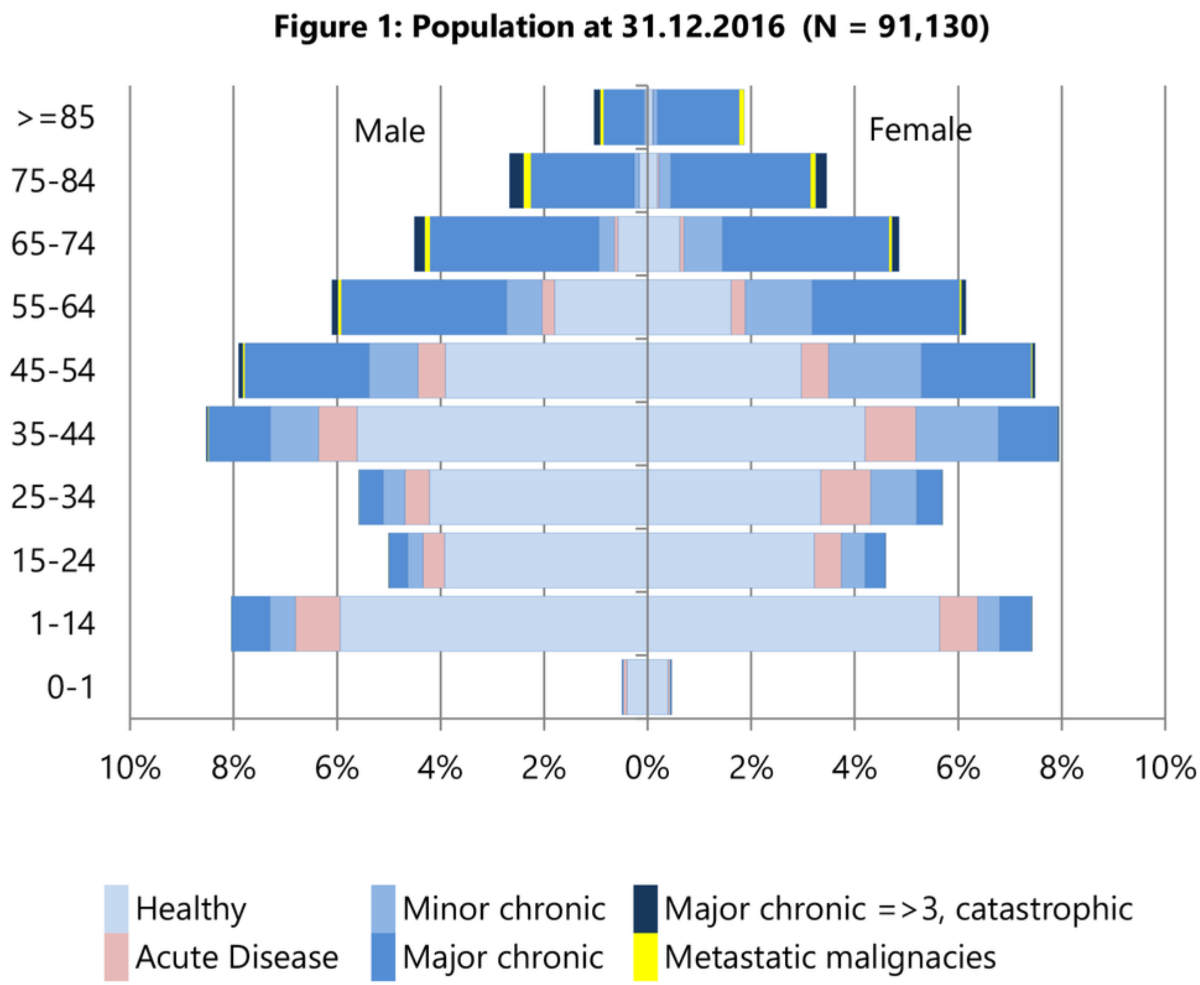


Figure 1

See image above for figure legend.

Figure 2: Transformation of individual morbidity and mortality data to health status

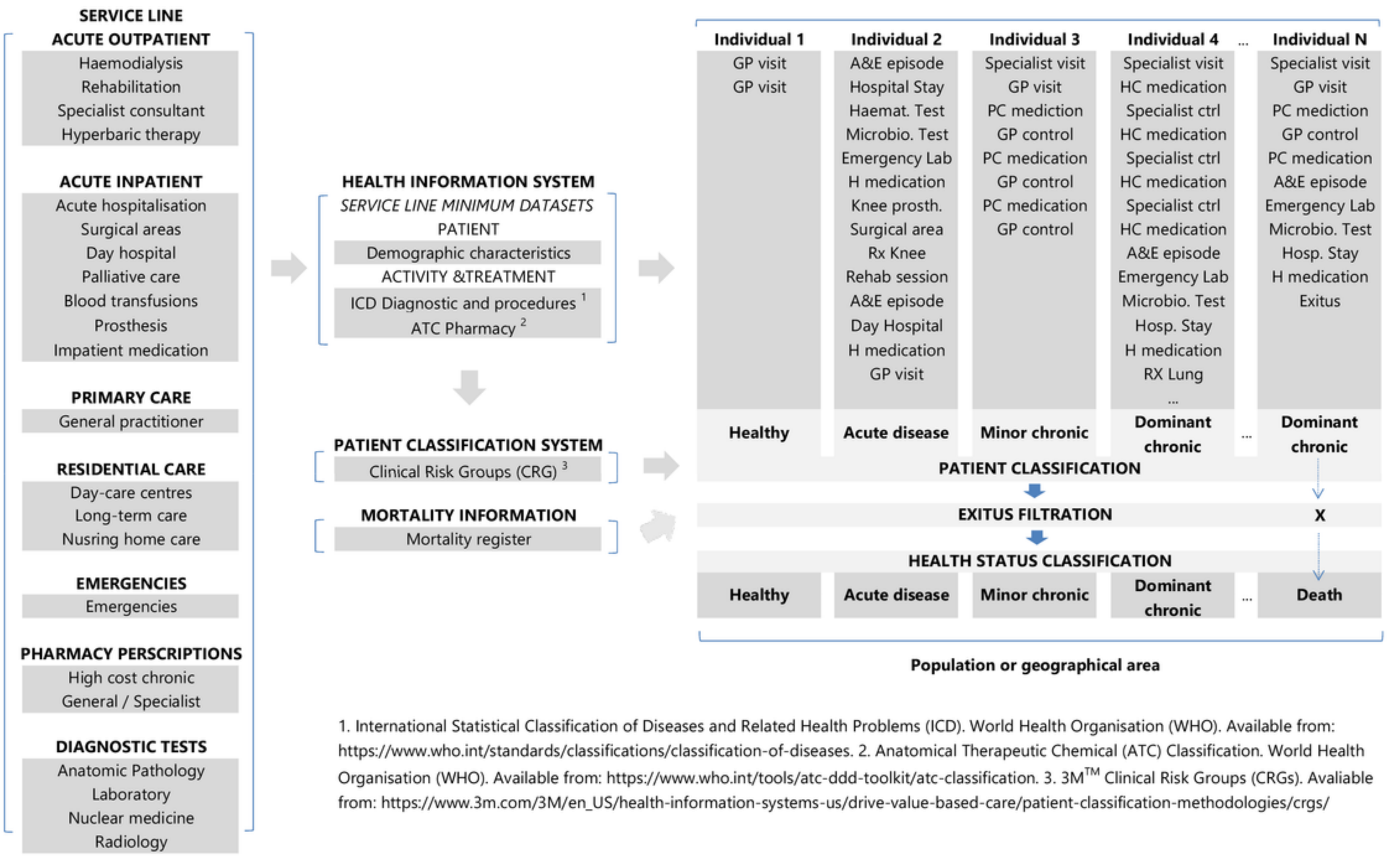
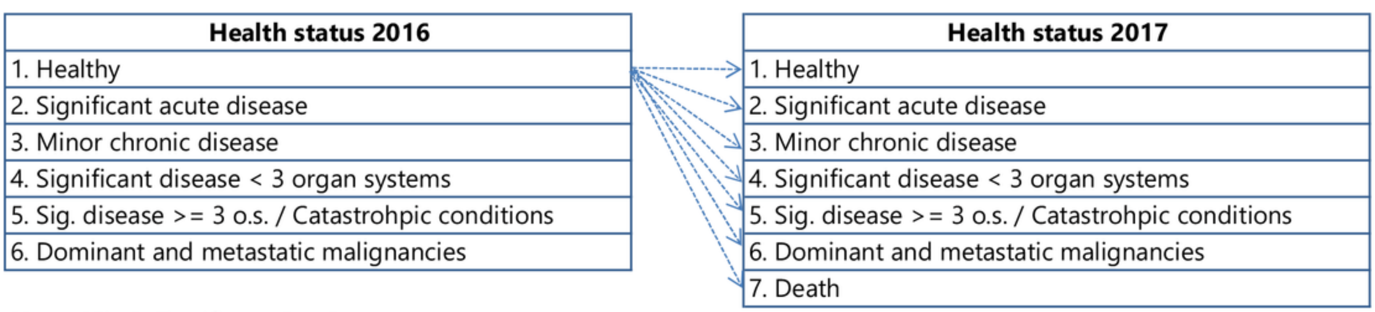


Figure 2

See image above for figure legend.

Figure 3: Health status transition model



Note. "Sig.": Significant; "o.s.": organ systems.

Figure 3

See image above for figure legend.

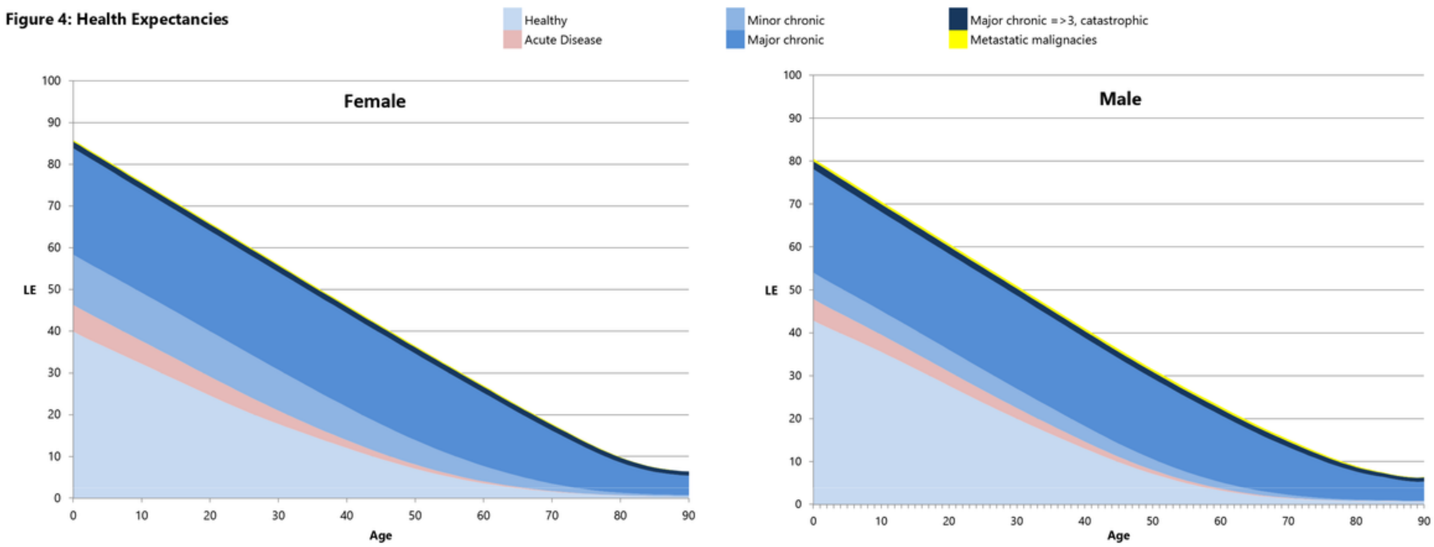


Figure 4

See image above for figure legend.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- BMCMRMTable1.pdf
- BMCMRMTable2.pdf
- BMCMRMAdditionalfile1.pdf
- BMCMRMAdditionalfile2.pdf