Health risk assessment and stratification in an integrated care scenario

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Word count: 3.419 words, 21 pages, 3 Tables; 3 Figures
Abstract

Background – Health risk assessment and stratification have proven highly relevant for large-scale implementation of integrated care by facilitating services design and case identification.

Aims – The principal objective was to analyse five health-risk assessment strategies used in the five regions participating in the Advancing Care Coordination and TeleHealth Deployment (ACT) program (www.act-programme.eu): Scotland (UK), Basque Country (ES), Catalonia (ES), Lombardy (I) and Groningen (NL). A second aim was to explore the potential of population-based health risk predictive tools to contribute to risk prediction in the clinical setting.

Method – We characterized and compared risk assessment strategies among ACT regions by analysing operational risk predictive modelling tools for population-based stratification, as well as available health indicators. The risk assessment tool deployed in Catalonia (GMA, Adjusted Morbidity Groups) was used as an example to explore how population-based analysis can contribute to clinical risk prediction.

Results – There was consensus on the need for a population health approach to generate risk predictive modelling. However, this strategy was fully in place only in two ACT regions: Basque Country and Catalonia. We found marked differences among regions in both risk predictive modelling tools and health indicators. Key factors constraining comparability of population-based risk predictive tools were identified. The research proposes the use of population-based risk prediction for enhanced clinical risk assessment.

Conclusions - Further efforts should be devoted to improve both comparability and flexibility of current population-based health risk predictive modelling approaches. The novel strategy for enhanced clinical risk assessment requires prospective evaluation.

Key words: Case finding; Clinical decision making; Chronic care; Health risk assessment; Patient stratification; Risk strata population distribution.

Word count: 239
Introduction

Large scale deployment and adoption of integrated care services in Europe is seeking health efficiencies with simultaneous reduction of outcome variability within and among regions [1–4]. It is well recognized that health risk assessment is relevant for regional adoption of integrated care [5,6]. Therefore, not surprisingly, the on-going deployment processes of integrated care are generating novel requirements, and exciting opportunities, in both population-based health risk assessment and clinical risk prediction with potential impact on the design of healthcare services and clinical management of chronic patients [6], respectively.

The current study aimed to meet the challenges generated by large-scale deployment of integrated care services in the area of health risk prediction. That is, to fulfil the need for comprehensive risk assessment, both at the population level and the clinical scenario. In the latter, health risk assessment is needed to support adaptive case management strategies [7,8] aiming to cover the evolving requirements of chronic patients over time.

The research was carried out within the frame of the Advancing Care Coordination and TeleHealth program (http://www.act-programme.eu/) [8] involving five leading EU regions in terms of scaling up integrated care: Basque Country (ES), Scotland (UK), Lombardy (I), Groningen (NL) and Catalonia (ES).

In the healthcare services domain, population-based risk predictive modelling facilitates the elaboration of stratification maps characterizing risk strata distribution of the entire population in a given geographic location. It allows identification of subsets of citizens with similar healthcare requirements facilitating both case finding and screening. The former, case finding, identifies highly vulnerable patients, allocated at the tip of the risk pyramid who are prone to major deleterious health events such as unplanned hospital admissions/re-admissions, fast functional decline and/or death [9]. It is acknowledged that case finding fosters cost-effective preventive interventions despite compromised strength of prediction. Likewise, screening looks for discovery of cases with non-manifest illnesses that may benefit from early diagnosis and cost-effective preventive interventions [6].

In the clinical management domain, risk prediction of well-defined medical problems (i.e. prediction of survival in acute exacerbations of COPD) [10] can support health professionals in the decision making process. Moreover, clinical risk prediction may contribute to patient classification in the optimal healthcare tier, helping to define shared care arrangements between primary care and specialists. However, it is acknowledged that modelling tools addressing specific clinical issues with a high predictive power may present limitations for their general application outside the source population [11].
In the current research, it is hypothesized that clinical prediction for any given specific medical purpose could be significantly improved by including the allocation of the individual in the population risk pyramid into the modelling approach.

The study addressed two specific aims. Firstly, to analyse population-based health risk assessment strategies, including assessment tools and health indicators, in the five European regions in order to identify current barriers and to elaborate recommendations for large scale deployment of integrated care at European level. The second purpose was to propose strategies toward enhanced health risk predictive modelling in the clinical scenario.

**Method**

The general characteristics of the population and healthcare organization of these five regions have been reported in detail [8]. The analysis of population-based health risk assessment and stratification strategies in place in the five ACT regions was done focusing on two specific components: i) analysis of health risk predictive modelling tools; and, ii) comparison of reported health indicators.

*Population-based health risk predictive modelling*

We performed a two-phase survey approximately eight months apart (Summer 2014 and Spring 2015) addressing the person(s) responsible for the development/maintenance of the risk predictive modelling tools at regional level.

In the first survey, systematic responses to a standardized questionnaire elaborated for this purpose by Opimec® [12] were collected. Participants answered the questionnaire by mail and subsequently underwent an interview. We captured information on several key dimensions characterizing the risk predictive modelling tools, namely: (i) modelling approach, (ii) source sample, (iii) main and summary statistics, (iv) outcome (dependent) variables and covariates, (v) update periodicity, (vi) target population; and, (vii) maturity of clinical implementation. This facilitated the elaboration of an initial map of regional practices.

The second survey had a twofold purpose: (i) to fill specific information gaps; and, (ii) to ask additional questions inquiring on existing plans for evolving the risk predictive modelling tool in place. Also, we assessed the potential for transferability across regions at EU level. To this end, four main items were analyzed: (i) openness of algorithms; ii) flexibility for adjustments to other populations; (iii) licence costs associated with the use of the case finding tool; and, (iv) licence agreements binding its applicability to specific territories.
The comparative analysis of health risk assessment tools among ACT regions was carried out taking into account a clear distinction regarding the characteristics of the source population. That is, health risk assessment tools generated from modelling the entire population of a given region (or geographical area) with a holistic approach were considered to follow a population health approach, as proposed by Kindig D et al. in 2003 [13]. On the other hand, health risk assessment derived from modelling patient populations were regarded as following a population medicine approach [14].

Because of our interest on case finding analysis, the current study focused on healthcare forecasting [15] that implies predicting an individual's healthcare utilization for interventional purposes with either preventive or therapeutic goals. Comprehensive descriptions of the characteristics of health risk predictive modelling and the logistics required for deployment are reported elsewhere [16–18]. It is of note that other analyses like risk adjustment [19–21] or actuarial approaches [22] were not considered in the current research.

Health indicators

A semi-structured questionnaire including indicators to evaluate health status at population level was sent via email to the ACT coordinator in each of the five regions. The indicators were shared by the five ACT regions and had been previously defined and agreed within the consortium in order to facilitate comparability of the effects of integrated care interventions over time within and across regions.

The study aimed to identify a common set of indicators useful for evaluating the impact of health interventions at population level in order to facilitate comparability of the effects of integrated care services within and across regions.

Elaboration of a proposal for enhanced clinical risk assessment

We analysed the potential of population-based health risk assessment to contribute to enhance clinical risk predictive modelling. To this end, we assessed the flexibility of the different health risk predictive modelling tools to contribute to clinical risk estimation.

Results

Population-based health risk assessment tools

The main characteristics of the health risk prediction modelling tools in place in four out the five ACT regions are depicted in Table 1. Groningen (NL) is not represented because the site does not use any population-based health risk prediction modelling for the two integrated
care programs currently deployed [8]. Instead, Groningen prioritized individual health risk characterization based on information collected in the electronic health records.

The four regions (Table 1) perform periodic updates of their respective population-based stratification. The table indicates that a population health approach [13] is currently only adopted in the Basque Country [23–26] and in Catalonia. Since 2010, Scotland [27] is clearly evolving in this direction. The source population of the current health risk predictive modelling tool already covers 63 per cent of the entire Scottish population. Strategically, it is moving from a strong focus on use of hospital-related resources (e.g., emergency department consultations, unplanned hospital admissions and/or early re-admissions) toward integration of needs for frail patients, including social support and long-term care.

In contrast, Lombardy [28] has a population medicine approach consisting of a classification system based on stratification by health costs. It serves the coordinated care program for chronic patients, especially those with conditions such as chronic obstructive pulmonary disease (COPD), cardiovascular disorders and diabetes mellitus types I and II.

The analysis of the risk-strata distributions resulting from the different regions showed poor comparability (Table 2). This is explained by differences among risk predictive modelling tools, and by the diverse classification criteria used to define risk groups.

We identified significant constraints for transferability across regions due to three main factors, namely: i) lack of openness of algorithms, ii) rigidities due to inclusion of expert-based criteria in the morbidity groupers; and, iii) license bindings constraining applicability of health risk assessment tools to other EU regions. It is of note that only Catalonia and Scotland (Table 2) have white-box tools owned by the regions, which, in principle, implies high potential to properly deal with the limitations for transferability described above.

The four regions indicated in Table 1 provide information on case finding for primary care doctors. We identified a consensus on the need for transferring information on high-risk patients to practicing clinicians in order to trigger preventive interventions and to support clinical decision-making processes. However, we observed different degrees of maturity in the interactions with clinicians, from only providing a list of high-risk candidates for interventions to the display of simple clinical decision support systems in the clinical workstation of primary care physicians.

The two surveys carried out during the project lifetime did not indicate relevant conceptual differences among regions in terms of the basic aspects that should be covered in an ideal health-risk assessment strategy. Accordingly, a high acceptability of the population health approach [13] for elaboration of health risk predictive models was confirmed. Table 3 indicates the characteristics recommended for an ideal population-health risk assessment tool showing transferability among regions and potential to generate synergies with clinical
risk predictive models. The practicalities for deployment of health risk assessment tools at regional level are summarized in Table 3S (on-line supplementary material). Because the survey showed agreement among all regions on the need for using predictive models, showing statistics indicating sensitivity/specificity of the predictions was selected as a recommendation for good practice of population-based health risk assessment (Table 3). Both Basque Country and Scotland risk predictive modelling tools provide information on sensitivity and specificity; by contrast, Catalonia and Lombardy classify individuals into specific percentiles of the risk-strata pyramid thereby neglecting the metrics assessing robustness of predictions.

Health indicators

The list of indicators identified by the consortium is included in Table 4S. We found that despite availability of most of the data at the regional level, two main limiting factors precluded comparisons among the regions, namely: (i) insufficient data harmonization (e.g. different versions of International Classification of Diseases (ICD) coding) [29]; and, (ii) differences on data reporting (i.e. different levels of data aggregation and/or differences in calculation of complex indices).

Enhanced clinical risk predictive modelling

We propose to incorporate the classification of the individual in the risk stratification pyramid as one of the covariates of the clinical predictive models. Among the different population-based risk assessment tools evaluated in ACT (Table 1), only the population-based risk assessment tool deployed in Catalonia (GMA, Adjusted Morbidity Groups) [30,31], fully complied with the characteristics recommended in Table 3. The current GMA version covers four key requirements: i) a population health approach using the entire source population of 7.5 million inhabitants of the region, with a bi-annual update of the risk pyramid distribution; ii) publicly owned without licensing constraints; iii) open source computational algorithms; and, iv) the GMA morbidity grouper relies only on statistical criteria, without expert-based criteria, thus facilitating quick adaptation to different territories. Accordingly, it was selected as a use case for the analysis carried out in this section (see the on-line supplementary material for detailed information on the GMA tool).

Overall, the GMA approach shows flexibility and transferability, as demonstrated by its recent adoption by thirteen out of the seventeen regional healthcare systems in Spain, covering 92% of the overall Spanish population. Figure 1 illustrates the contribution of the morbidity grouper GMA to explain the variance of four relevant outcomes, namely: mortality, hospital admissions, emergency department admissions and total healthcare expenses.
Statistical refinement of the computational modelling of the current GMA [32], in order to generate an enhanced GMA fulfilling all the requirements indicated in Table 3, is recommended as the first milestone to enhance clinical risk predictive modelling. In a second step, we propose to prospectively assess the benefit of using the predictions from the enhanced GMA as an additional covariate into clinical risk predictive modelling. Both conceptual grounds and statistical feasibility support the proposal. However, its implementation will require further work beyond the scope of the current research.

**Toward personalized medicine**

The study also explored a systems approach [33] considering all dimensions influencing patient health as potential covariates to be taken into account for elaboration of a roadmap toward personalized medicine for chronic patients.

Three categories of covariates have been identified to show potential for inclusion into clinical risk predictive modelling, as displayed in Figure 2: (i) input from enhanced case finding tools; that is, population-based health risk predictive models, as mentioned above; (ii) individual clinical, physiological and biological information relevant to the medical problem being assessed; and (iii) individual informal care data including lifestyle, adherence profile, socioeconomic status, requirements in terms of social support and environmental factors. It is hypothesized that inclusion of all dimensions influencing patient health will markedly increase the accuracy and predictive power of the individual risk predictive modelling for clinical decision-making.

The three categories of covariates, as alluded to above, shall be dynamically captured from different sources, respectively: (i) population-based health risk predictive models; (ii) articulated healthcare and biomedical research knowledge (integration of clinical, physiological and biological/molecular information); and, (iii) in-place personal health folders (lifestyle, adherence profile, socioeconomic status, social support and environmental factors).

The implementation of a Digital Health Framework, conceptually formulated in [34], should have the potential to articulate the three categories of variables potentially allowing for dynamic assessment of health risk both for population-based purposes, but also for specific clinical problems. Nowadays, a Digital Health Framework, as depicted in Figure 3, is only a conceptual formulation, but it contains the seeds to foster the concept of the “exposome”, as defined by Coughlin SS [33], which provides the basis for personalized medicine for chronic cases. There is no doubt that the implementation of the Digital Health Framework constitutes an ambitious endeavour requiring an stepwise approach to effectively overcome major challenges involved in the transitional process to make it operational.
Discussion

Summary of main findings

The results of the two surveys indicated a high degree of conceptual agreement among the five ACT regions on the relevant role of population-based health risk assessment for regional deployment of integrated care. Its usefulness for service commission, case finding and screening was shared by the entire ACT consortium. There was also consensus on the use of a population health approach [13] as the optimal strategy for population-based risk assessment.

However, the health risk predictive modelling tools in place showed marked heterogeneities that precluded comparability of the risk pyramid distributions across regions. Moreover, we identified a clear need for evolving toward risk predictive modelling tools allowing proper quantification of the estimations (Table 3) [35]. Likewise, different well-identified problems mostly associated to data reporting precluded appropriate comparisons of the recommended health indicators described in Table 4S.

The current study identified transferability across regions and potential for evolving, that is flexibility, as two key requirements for any population-based health risk assessment tool. Factors such as: i) license binding constraints, ii) insufficient public availability; iii) lack of availability for inspection; and/or, iv) rigidity of some computational algorithms (i.e. due to inclusion of expert-based criteria in some morbidity groupers) are currently limiting transferability. These factors might also preclude adaptation of the current risk prediction tools toward evolving requirements such as: i) integration between healthcare and social services; and, ii) implementation of synergies between population-based and clinically oriented risk predictive modelling, as described in the study.

We acknowledge some intrinsic limitations of population-based predictive modelling in terms of strength of estimations. However, their potential for allocation of individuals into the risk stratification pyramid facilitates both design and implementation of preventive strategies that have shown high potential to generate healthcare value. For example, for those individuals in the tip of the pyramid (~5%) accounting for high use of healthcare resources (~ 36% total healthcare costs, as assessed for Catalonia in 2014, Figure 2S).

The study reports on the conceptual steps required for development of innovative strategies for clinical risk predictive modelling with potential to enhance its supporting role for decision making in the clinical scenario. We acknowledge, however, that further studies evaluating feasibility, benefits and applicability of the proposals for enhanced clinical risk prediction are needed.
Toward an European strategy for population-based health risk prediction

While the ACT project has confirmed the role initially ascribed to population-based health risk assessment in regional deployment and adoption of integrated care services, the core lesson learnt from the current study is that a common European strategy is needed and it constitutes a priority for any region planning adoption of integrated care.

Two basic pillars for a future European strategy should be: i) the characteristics of the risk predictive modelling tools, as displayed in Table 3; and, ii) the ability to report on the list of basic indicators depicted in Table 4S. The current heterogeneities among regions clearly indicate that adjustment of the current settings to the recommended good practice will require site-specific transitional strategies whose common goals and basic principles are described in the current study. Key operational steps needed for practical implementation of a regional strategy for population-based health risk predictive modelling are summarized in Table 3S.

There is a lively debate regarding management modalities associated with generation and exploitation of population-based health risk predictive modelling. Should model generation and maintenance be publicly funded (i.e. Department of Health) or should there simply be policies promoting open market in terms of private suppliers of risk predictive tools [16,36]? The current study only stresses the need for openness, flexibility and transferability of risk predictive modelling in order to fulfil their core purposes. However, as stated below, we acknowledge the complexities of the issue, also involving ethical aspects. Doubtless, this issue will require proper regulation irrespective of the finally adopted business adoption.

Clinical health-risk assessment

The authors acknowledge that only a small proportion of the huge potential of risk predictive modelling is currently applied for health forecasting purposes in the clinical arena. A detailed description of the bottlenecks constraining the developments recommended for enhanced clinical risk predictive modelling, as proposed in the current study, are reported in [37]. Under the subheading, we are highlighting only a few key aspects that shall be addressed to accomplish successfully the roadmap proposed in the current study.

One key requirement of enhanced clinical risk predictive modelling is to set-up the concept of Digital Health Framework (DHF) (Figure 3) described in [34], as a measure to achieve a dynamic interplay among all dimensions influencing citizens’ health. An operational DHF should solve the insufficient communication across healthcare tiers and with social support and should unify digital access to all determinants of citizens’ health. Further development of knowledge management tools within the DHF will facilitate integration of multilevel, multi-scale and heterogeneous data regarding virtually any health determinants of a patient at any
levels of detail. However, we acknowledge that implementation of a DHF constitutes an ambitious task that requires a realistic stepwise strategy.

Enhanced applicability and integration of powerful data analytics, including risk predictive modelling, into clinical practice constitutes a central goal. In this regard, the development of novel clinical decision support systems, supported by advanced visual analytics, facilitating representation of patient information for effective clinical management of time-varying individualized data is a real yet unmet need to facilitate clinical judgement for decision-making.

Moreover, studies assessing the potential of different modalities of patient gateways, like the personal health folder, for patient self-management purposes and for collection of informal care variables, are urgently needed.

Finally, the novel healthcare scenario reveals new emerging needs regarding highly relevant non-solved ethical issues. These related to privacy, security of data transfer, as well as risks associated with healthcare decisions that rely on inadequate risk predictive models. The complexities involved in some of these aspects can only be addressed through a democratic debate; openness and transparency of the healthcare governance; as well as a timely and appropriate evolution of legal frames.

Conclusions

The implementation of current recommendations for population-health risk assessment, both in terms of risk predictive modelling and health indicators constitute a priority for the on-going processes of adoption of integrated care at European level. The current study proposes novel strategies for enhanced clinical risk assessment and stratification together with a roadmap for evaluation and future implementation of the novel approach.
Acknowledgments

We acknowledge the contributions from the ACT consortium; the B3 group from EIP-AHA; and, the ASSEHS (Activation of Stratification Strategies and Results of the interventions on frail patients of Healthcare Services) consortium. We would like to thank the input provided by the technical persons from the regions contributing to the two surveys carried out during the project lifetime: Jon Orueta Mendia from Osakidetza (Basque Country, ES), Anne Hendry from the Scottish Government-NHS24 (Scotland, UK); Wietse Weenstra from Scheper´s Hospital in collaboration with UMCG (Groningen, NL); and, Carlo Scire from Lombardia region in collaboration with Telbios. We are grateful to Andres Cabrera Andrés Cabrera, from Escuela Andaluza de Salud Pública, who created the Opimec questionnaire used in the current research. We are also indebted to Montse Bustins and Alex Guarga, from Servei Català de la Salut (Catalan Health Service), Francesc García Cuyàs from TicSalut foundation, Albert Ledesma from the Departament de Salut de la Generalitat de Catalunya (Catalan Health Department of the Government of Catalonia) and Marian López, Alfredo Martin, Carmen Arias and Paloma Casado, from the Ministerio de Sanidad Servicios Sociales e Igualdad (Ministry of Health, Social Services and Equity) for their support to the current study and for the support from their institutions in developing the GMA.

Supported by ACT – Advancing Care Coordination and TeleHealth Deployment program (UE Grant n° 20121209), PITES (FIS-PI12/01241) and Generalitat de Catalunya (2014SGR661).
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### Table 1 Risk predictive modeling tools in the ACT regions*

|                       | Basque                          | Catalonia                      | Lombardia                       | Scotland                       |
|-----------------------|---------------------------------|--------------------------------|---------------------------------|--------------------------------|
| **Model**             | Predictive (based in Adjusted Clinical Groups-Predictive Model ACG-PM®) | Explanatory (based in 3M Clinical Risk Groups, 3M-CRG®, and the self-development model GMA) | Classificatory (based in the Diagnosis Related Group, DRG, and a self-developed scheme CReG) | Predictive (Scottish Patients at Risk of Readmission and Admission, SPARRA-3) |
| **Source population** | 2.100.000                       | 7.500.000                      | 100.000                         | 3.400.000**                    |
| **Updates**           | Annual                          | Semester                       | Once                            | Monthly                        |
| **Scope of the use**  | Population-based risk assessment and stratification for health policy and service design, as well as use as case finding tool | Population-based risk assessment and stratification for health policy and service design, as well as use as case finding tool | Case finding tool and reimbursement model | Case finding tool |
| **Clinical application** | - All levels of care can see the same information. - Practicing physicians receive a risk score for each patient | - All levels of care can see the same information. - Practicing physicians receive a risk score for each patient | - All levels of care can see the same information. - Practicing physicians receive a risk score for each patient | - All levels of care can see the same information. - Practicing Physicians receive a risk score for each patient |
| **Outcomes (dependent variables)** | Mainly: Health costs | Mainly: Unscheduled hospital admissions at one year, re-admission at 180 days and risk of death at 12 months | Costs of pharmacy, outpatient and inpatient costs | Individual’s risk of emergency hospital inpatient admission over the next twelve months Risk of Institutionalization |
| **Covariates (independent variables)** | Demographic information Diagnosis Co-morbidity using a grouper Past health care consumption Aggregated socio-economic status | Demographic information Diagnosis Co-morbidity using a grouper Aggregated socio-economic status | The classification system uses diagnosis for grouping | Demographic information Diagnosis Co-morbidity using a grouper Past health care consumption |

* Groningen was not included in the Table because the integrated care programs are not using population-based health risk predictive modelling tools

** The total population of Scotland is 5,295,000 inhabitants
| Scope of the stratification strategy | Basque | Catalonia | Groningen | Lombardia | Scotland | Barriers for comparison |
|-------------------------------------|--------|-----------|-----------|-----------|----------|------------------------|
| Entire population (population health) | Population (population health) | Program (population medicine) | Program (population medicine) | 3.4 million people (toward population health) | Heterogeneous predictive modelling tools |
| Current predictive modelling tool | ACG-PM | GMA (owned by the region) | Not available | CReG, evolving toward a risk predictive modeling tool | SPARRA v3 (owned by the region) | Different statistics describing predictive power, different levels of flexibility |
| Number of categories | Four | Four | Four | Three | Four | Different criteria for risk categories leading to non-comparable population distributions |
| Characteristics of reporting on top indicators | Regional & Micro-systems | Regional & Four areas | Three programs | GReG cohorts | Sub-region | Heterogeneity of reporting allowed conceptual consensus but not comparability of results |

ACG-PM®= Adjusted Clinical Groups-Predictive Model  
CReG = Chronic Related Group  
SPARRA V3= Scottish Patients at Risk of Readmission and Admission- version 3
Table 3 Recommendations for good practice population-based health risk assessment

| Domain                              | Recommendations                                                                 |
|-------------------------------------|-------------------------------------------------------------------------------|
| **Type of risk stratification tool** | Predictive model using a population health approach                           |
| **Validation of the model**         | Longitudinal follow-up                                                        |
| **Predicted/explained Outcomes**    | Unplanned hospital-related events; risk of institutionalization; Death         |
| **Source sample**                   | Whole regional population                                                     |
| **Statistical model**               | Predictive modelling                                                          |
| **Statistical indices**             | Standardization on reporting performance (positive predictive value, PPV)[35]  |
| **Population usefulness**           | Risk adjustment; planning and commissioning health services                   |
|                                     | Support to novel reimbursement models                                          |
| **Clinical & social usefulness**    | Identification patients at high risk and cost-effective preventive clinical & social interventions |
| **Periodicity of updates**          | Semester                                                                      |
| **Clinical accessibility**          | Available into the professional workstation through clinical decision support systems |
| **Flexibility**                     | Open algorithms, open source, reduced or no licence binding, High transferability |
Figure 1 – Explained variability indicated by $R^2$ (expressed as a percentage) in the y-axis, for four main outcomes: mortality, hospital admissions, emergency department visits and total healthcare expenses obtained from the analysis of the Catalan population (7.5 million inhabitants) in 2014 using three different health risk assessment models built-up with different covariates: A+S+SE includes only age, sex and socioeconomic status as covariates; A+S+SE+CRG additionally includes Clinical Risk Groups as morbidity grouper [38]; and, A+S+SE+GMA includes information from Adjusted Morbidity Groups as morbidity grouper (see on-line supplementary material for further details).
Figure 2

Multi-level and multi-scale data | Heterogeneous sources of information
---|---
Socioeconomics | Adherence profiles
Environmental data | Life style risk factors
Biological data | Wellness
Genetic data | Social support

Informal Care

Clinical data

Functional data

Biological data

Patient self-management
Primary care
Specialized care

Health Care

Transcriptomics

Epigenetics

Metabolomics

Genetic data

Proteomics

Biomedical Research

Public Health
Systems Medicine
Clinical trials

Multi-level and multi-scale data Heterogeneous sources of information

Figure 2 – The interplay between outcomes from case finding tools (population-based risk assessment) and the dimensions of patient health indicated in the figure should enrich clinical risk predictive modelling. As a first step, we propose to include the outcome of the population-based risk assessment as a covariate in clinical risk predictive modelling. For future personalized care for chronic patients, enhanced dynamic communication among Informal Care, Health Care and Biomedical Research will allow inclusion of several dimensions into clinical risk predictive modelling. It will be done through multilevel/multi-scale heterogeneous data integration into a Digital Health Framework, as depicted in Figure 3.
Figure 3 – Scheme of the Digital Health Framework[34], a digital data normalization and knowledge management framework for knowledge generation and to embed novel Clinical Decision Support Systems (CDSS) into integrated care processes.
Health risk assessment and stratification in an integrated care scenario

(ON-LINE SUPPLEMENTARY MATERIAL)

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The document describes the basic characteristics and clinical validation of the Catalan population-based risk assessment tool based on the GMA morbidity grouper. Moreover, the document includes complementary material that should facilitate regional site deployment of health-risk assessment strategies.

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Part I - Population-based health risk assessment in Catalonia

CatSalut is the Catalan public agency acting as unique payer of regional healthcare services covering the entire population of approximately 7.5 million inhabitants. The Agency is commissioned by the Department of Health of the Catalan Government to generate a regional population health strategy for health risk assessment and stratification.

Until very recently (early 2015), the risk predictive modeling in place was based on Clinical Risk Groups (CRG) [1]. However, CatSalut has developed its own system, the GMA (Adjusted Morbidity Groups), refined during the last years and fully implemented into the primary care clinicians workstation by May 2015. The reasons for moving from CRG to GMA were twofold: (i) to decrease costs, and, (ii) to increase flexibility of the risk predictive modeling tool allowing its adaptation to the evolving needs such as integration of social support. There has also been an active policy to foster transferability to other regions. As described in the main text, the GMA is being successfully implemented in thirteen out of the seventeen regional healthcare systems in Spain, which represents coverage of 92% of the Spanish population.
Regional source datasets

The current Catalan population-based risk assessment tool is updated every 6 months using the dataset depicted in Figure 1S that includes information from Primary Care, Hospital-related events, Pharmacy, Mental Health, and Socio-sanitary services. Analyses of use of healthcare resources, pharmacy consumption, prevalence of key disorders and calculation of adjusted morbidity groups, using the GMA morbidity grouper, constitute the basis for periodic updates of the regional health-risk strata pyramid.

**Catalonia – Whole Population Morbidity Dataset**

| Size – 7.5 million inhabitants |
| Periodic update – every 6 months |
| Variables – Use of healthcare resources; Incidence & Prevalence of key disorders; Pharmacy, Adjusted Morbidity Groups (GMA) |
| Outcomes – Population stratification; Risk assessment of clinical use |

**Table of insured people**
PIC, demographic and territorial data
Number of registers: 10,121,939

**Table of diagnostic**
PIC, code, data of diagnosis, Provider, type of provider, pathologies
Number of registers: 405,025,523

**Table of healthcare contacts**
PIC, contact data, provider, type of provider, urgent, funding, Type of service
Number of registers: 295,479,140

**Table of active principles**
PIC, Type of active principle, prescription data, units, net amount
Number of registers: 417,598,507

**Table of clinical measurements**
PIC, date, lab, result

**Figure 1S** – Scheme of articulated datasets included in the whole population morbidity dataset in Catalonia used for population-based health risk assessment. The articulation of the Table of clinical measurements (grey background) is not operational. GMA: Adjusted Morbidity Groups, PIC: Personal identification codes.

**The GMA health-risk assessment tool**

**General characteristics** – The health risk strata distribution of the entire Catalan population is useful for: (i) design of health services and resource distribution; (ii) case identification; and, (iii) estimation of health-related events of different types such as unplanned hospital-related events (hospitalizations, early re-admissions, emergency
room consultations), number of outpatient consultations, mortality, and, in general, health-related costs.

The multiple regression use as covariates: (i) age, (ii) sex, (iii) ZIP code location (as a proxy of socio-economic status using adjusted territorial income and health services accessibility), (iv) GMA morbidity grouper; and (v) use of healthcare resources. Interestingly, the GMA morbidity grouper is one of the components providing marked flexibility/transferability to the catalan health-risk assessment tool because it is not built on fixed expert knowledge, but it relies on population-based statistical information. Additional key features are algorithm openness and flexibility regarding licensing agreements. Table 1S indicates main advantages of the GMA compared with the CRG previously used in Catalonia.

Table 1S. Main differences between the previous risk predictive model (CRG) used in Catalonia and the current GMA model.

|                                           | CRG  | GMA  |
|-------------------------------------------|------|------|
| Adaptability                              | No   | Yes  |
| Validated                                 | Yes  | Yes  |
| Economic cost                             | High | Acceptable |
| Clinical specificity                      | Yes  | Yes  |
| Complexity/Individualized severity        | No   | Yes  |
| Complexity/Severity per groups            | Yes  | Yes  |

Risk classification using GMA - The GMA grouper is a new tool for assessing multi-morbidity, which classifies individuals into unique and mutually exclusive groups taking into account: (i) type of disease, (ii) occurrence of multi-morbidity; and, (iii) case complexity. Briefly, the risk classification criteria combines two dimensions: i) Morbidity, including a total of seven morbidity groups, and, ii) Case Complexity, as depicted in Table 2S.
**Table 2S** – The GMA grouper classifies each case in five levels of complexity

| Group of morbidity                                      | Complexity Level |
|---------------------------------------------------------|------------------|
| Patients with active neoplasms                         | 1 2 3 4 5        |
| Patients with a chronic disease in 4 or more systems   | 1 2 3 4 5        |
| Patients with a chronic disease in 2 or 3 systems      | 1 2 3 4 5        |
| Patients with a chronic disease in 1 system            | 1 2 3 4 5        |
| Patients with an acute diseases                        | 1 2 3 4 5        |
| Pregnancy and delivery                                 | 1 2 3 4 5        |
| Healthy population                                     | 1                |

The GMA classification (Table 2S) was elaborated using adapted versions of both the Clinical Classification Software for ICD9-CM [2] and the Chronic Condition Indicator (CCI) software for ICD9-CM [3]. These two clinical classifications allowed the grouping codes into disease categories and their classification in chronic or acute conditions. In the GMA grouper, the adjustment for disease complexity (classification from 1 to 5) is quantitatively determined through a joint analysis of mortality, hospital admissions, pharmaceutical expenses and visits to primary care. This statistically-based methodology should allow a relatively easy adaptation to different health systems and geographical scenarios as proven by the recent transferability of the GMA grouper to thirteen Spanish regions.

The main requirement to elaborate the GMA grouper is availability of all health diagnosis, events and use of pharmacy obtained from the registry of insured people, as displayed in **Figure 1S**. The core information is obtained from Primary Care datasets. Additional information from other healthcare tiers is useful to refine the GMA grouper but it is not strictly necessary.

The use of the GMA grouper provides allocation of each citizen into the risk stratification pyramid. A summary representation of the update carried out by the end of 2014 grouping the results in four main risk strata is depicted in **Figure 2S**. The four main strata are identified according to the criteria indicated below:

- **GMA-1 or low risk stratum**: it corresponds to 50% of the population, with a lower complexity level.
- **GMA-2 or moderate risk stratum**: it corresponds to 30% of the population, which has higher complexity than the previous risk stratum.
- **GMA-3 or high risk stratum**: it corresponds to 15% of the population, which has greater complexity than the risk stratum.
- **GMA-4 or very high-risk stratum**: it corresponds to 5% of the population, which has the highest complexity level.

**Figure 2S** - Stratification of the Catalan population (2014) using the GMA. The third and fourth columns depict rates of mortality and hospital admissions, respectively. The fifth column indicates the cost per inhabitant per year expressed in € and the last column refers the percentage of total healthcare expenditure by risk strata. It is of note that the closer the patient is to the tip of the pyramid, the higher are: mortality, risk of hospital admission and healthcare expenses. Green color (bottom) indicates healthy status whereas red (tip) corresponds to maximum risk of admissions and highest mortality risk.

**GMA evaluation protocol**

The GMA morbidity grouper was evaluated using two different approaches: i) Statistical evaluation using a comparative analysis of the contribution of different covariates to prediction a specific healthcare outcomes, namely: mortality, unplanned admissions, emergency department consultations and healthcare expenditure, as displayed in **Figure 1** (main text); and, ii) Clinical evaluation carried out by general practitioners.

**Statistical evaluation**

A set of models based on multiple linear regression analysis including different covariates were used to assess the performance of the GMA grouper for health risk assessment (**Figure 1**). The population of Catalonia in 2014 was taken as a reference for the analysis and the four healthcare outcomes indicated in **Figure 1** were the dependent variables. Two main statistics were used for comparison among the models obtained using different covariates: i) Akaike’s Information Criterion (AIC), as a
measure of the relative quality of statistical models for a given set of data; and, ii) R-square that should be interpreted as the proportion of uncertainty in the relevant outcome that has been explained by the model [4]. **Figure 1** shows that the explanatory power of the models increases with the introduction in the model of a morbidity grouper. Comparison of the CRG and GMA indicates a better explanatory power when using GMA.

**Clinical assessment**

A comparative clinical evaluation of GMA and CRG classifications was blindly undertaken by 40 general practitioners examining electronic heath records from 1000 cases (25 cases per general practitioner). An analysis of concordance among clinical evaluators was carried out. The analysis of the results was focused on identification of the discrepancies between the two morbidity groupers. The description of methodological aspects of the clinical validation, as well as a detailed report of the results can be found in [5]. Briefly, the results (**Figure 3S**) indicate that the two morbidity groupers (GMA and CRG) agreed with clinicians in the classification of the population by complexity, but GMA shows a better performance in the strata of greater complexity. Moreover, in most cases, clinical evaluators preferred GMA.
**Figure 3S:** Goodness of the classifications generated by the two morbidity groupers: CRG (grey) and GMA (orange) by level of complexity assigned by the general practitioner. The last column provides a summary analysis.

**Clinical workstation in Primary Care**

The outcome from the GMA for a given citizen/patient appears in the screen of the clinical workstation of all healthcare professionals to assist in the clinical decision making process. The current display showing the stratum of risk for the citizen/patient should evolve providing specific indicators showing the probability of death or unplanned hospital-related major events (admission, emergency department consultation). Moreover, each health risk stratum should associate plans of intervention in order to provide efficient and proactive care. As examples: i) GMA-1: Preventive measures and health promotion of healthy lifestyle; ii) GMA-2: Control and risk management; iii) GMA-3: Control and disease management; and, iv) GMA-4: Case management.
Part II - Operational aspects for site deployment of health risk assessment strategies

It includes a brief systematic description of main recommendations for implementation and evaluation of a health risk assessment strategy at regional level (Table 3S), as well as the list of main domains and specific indicators for regional population-based risk assessment (Table 4S).
Table 3S. Recommended operational steps toward implementation of a regional strategy for health risk assessment

| Recommended operational steps |
|-------------------------------|
| **1. Health risk predictive modelling implementation** - Use a population health risk assessment tool fulfilling the requirements indicated in Table 3 (main text), either by fostering the evolution of your own risk assessment tool or by adopting an existing risk assessment tool that fits your local needs, that can be used without any license bindings and supports an open market of suppliers. Screen your population on a regular and repeated basis. Be aware of the logistics required at regional level to develop operational health risk prediction strategies: i) identify and overcome the practical local hurdles and barriers for accessing and linking routine administrative and clinical data and, ii) estimate the cost of running a tool, software platform, data integration, as well as labor for operations. |
| **2. Define and activate specific functionalities** - Use population-health risk stratification to understand the needs and risks of your population to target and prioritize effective integrated care. Make the outcome to be predicted operational (risk type: unplanned hospital related event; functional decline/frailty; death, etc...) aiming at healthcare value generation by embedding risk assessment into healthcare delivery (i.e. setting cost-effective preventive interventions). Also, decide what risk strata you would like to address (i.e., risk pyramid with one top, two intermediate and one bottom layer). |
| **3. Engage professionals and customize the setting** - Engage and educate your healthcare professionals and clinical staff in the use, value and shortcomings of risk stratification in order to gradually obtain the buy-in of the clinical community. Use an iterative co-design process involving healthcare professionals to define clinical applicability of outcomes of population-based risk prediction. Also, involve them in designing the characteristics of the dashboard displaying information on risk outcomes in the clinical workstation. Likewise, cohorts and associated protocols designed to assess interventions on specific risk strata should be implemented in close collaboration with healthcare professionals who should be informed about usefulness and potential pitfalls associated with health risk prediction. Moreover, studies evaluating the potential of population-based risk assessment for enriching individual risk predictive models addressing specific clinical issues should be designed and conducted with clinical professionals. |
| **4. Generate recommended indicators with standardized reporting** - Population-based health indicators should follow the recommendations indicated in Table 4 (main text). Protocols for data harmonization and data reporting should be in place and shared at European level in order to ensure comparability across regions. |
Table 4S - Recommendations on indicators for population risk assessment and stratification^a

| Domain                          | Indicator                                    | Definition of indicator                                                                 | Unit                        |
|---------------------------------|----------------------------------------------|----------------------------------------------------------------------------------------|-----------------------------|
| Population Health Status        | The education level                          | Number of students in tertiary education per 100,000 inhabitants                      | No./100,000 inhabitants    |
|                                 |                                              | Public current expenditure per student as % of gross national income (GNI) per capita  | %                           |
| Health care expenditures        |                                              | Per capita health care expenditures in the region                                      | currency & % GDP           |
| Disparities in access to health care |                                              | Percentage of (non-institutionalized) poor who did not receive or delayed receiving needed medical services, dental services, or prescription drugs during the previous year divided by the percentage of non-poor reporting the same barrier. | %                           |
| Insurance coverage              |                                              | Percentage of adults without health care coverage through insurance or entitlement      | %                           |
| Preventive services             |                                              | Percentage of adults who are up to date with age-appropriate screening services and influenza vaccination | %                           |
| Preventable hospitalizations (per 1000) | (Hospitalization rate for ambulatory-care-sensitive conditions/total population)*1000 | No. of hospitalizations     |
| The prognosis (in years) on life expectancy | Average expected number of years remaining in the life of the population | No. of years                  |
| The prognosis (in years) on healthy years | Average number of remaining years that population is expected to live without disability | No. of years                  |
| Co-morbidities                  | Number of co-morbidities in the population   | Average number of co-morbidities of the population                                    | No.                         |
|                                 | Charlson co-morbidity index in the population | Average Charlson index of the population                                               | No. of points in the score  |
|                                 | Comorbidity grouper                          | Usage of a comorbidity grouper in the stratification process.                          | Yes/No                      |
|                                 | Prevalence (in %) of disease Xi              | (Number of persons with disease Xi/Total population)* 100                              | %                           |
|                                 | Incidence (in %) of disease Xi               | (the number of new cases of disease Xi/ population initially at risk)* 100            | %                           |
| Age groups                      | Population size (in %) age <65 years          | (Number of persons <65 years old/total population)*100                                | %                           |
|                                 | Population size (in %) age ≥65 and ≤75 years old | (Number of persons between ≥65 years and ≤75 years old/total population)*100         | %                           |
| Years of Age | Formula                                                                 | Unit                  |
|-------------|-------------------------------------------------------------------------|-----------------------|
| age ≤75 years | (Number of persons ≥75 years old/total population)×100                 | %                     |
| Population size (in %) age >75 years | The regional derived deprivation index | %                     |
| Socioeconomic status | The education level for disease Xi | %                     |
| | The accessibility to healthcare | To be defined          |
| Past health care usage | Hospitalisation rate (per 1000), last 12 months | (Number of hospital admissions due to any cause except trauma/ total population)×1000 |
| | Average length of stay (days), last 12 months | Average regional length of stay (days) among those hospitalized due to any cause (except trauma) in the last 12 months | No. |
| | Number of ED consultations (per 1000), last 12 months | (Total number of ED consultations due to any cause except trauma in the last 12 months/total population)×1000 | No. |
| | Number of early 30-d readmissions (per 1000) in the last 12 months due to Xi disease | (Total number of hospital readmissions due to Xi disease in the last 12 months/total population)×1000 | No. |
| | Number of outpatient specialized visits (per 1000) | (Total number of outpatient visits in the last 12 months/total population)×1000 | No. |
| | Number of visits to primary care (per 1000) | (Total number of visits to primary care in the last 12 months/total population)×1000 | No. |
| | Number of home visits (per 1000) | (Total number of home visits in the last 12 months/total population)×1000 | No. |
| Drug consumption last 12 months | Total regional expenditure in drug consumption in the last 12 months | Currency & % total health expenditure |
| The number of patients using <5 drugs (per 1000), last 12 months, due to any cause | (The number of patients using <5 drugs in the last 12 months, due to any cause/total population)×1000 | No. |
| The number of patients using ≥5 and <10 drugs (per 1000), last 12 months, due to any cause | (The number of patients using ≥5 and <10 drugs in the last 12 months, due to any cause/total population)×1000 | No. |
| The number of patients using ≥10 drugs (per 1000), last 12 months, due to any cause | (The number of patients using ≥10 drugs in the last 12 months, due to any cause/total population)×1000 | No. |
| and <15 drugs (per 1000), last 12 months, due to any cause | cause/total population)*1000 |
|----------------------------------------------------------|-------------------------------|
| The number of patients using ≥15 drugs (per 1000), last 12 months, due to any cause | (The number of patients using ≥15 drugs in the last 12 months, due to any cause/total population)*1000 |

**a** The indicators are expressed over the population in a given year; some indicators could be specified for being applied to the population with specific diseases (Xi disease).

**b** In this domain, the deprivation index is calculated based on the next regional indicators domains: Barriers to Housing and Services Domain, Crime Domain, Education, Skills and Training Deprivation Domain, Employment Deprivation Domain, Health Deprivation and Disability Domain, Income Deprivation Domain, Living Environment Deprivation Domain. The Indices of Deprivation can be used for identifying areas with high levels of deprivation, looking at the proportion of the 10% most deprived areas.
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