Proposals for enhanced health risk assessment and stratification in an integrated care scenario

(ON-LINE SUPPLEMENTARY MATERIAL)

Dueñas I et al

Part I of the document *(pages 2-24)* provides a detailed description of the characteristics of the survey (Opimec®) carried out to assess the population-based health risk prediction tools in each of the five ACT regions.

A second section of the document *(Part II, Table 1S, pages 25-26)* describes the list of main domains and specific indicators for regional population-based risk assessment. Comparability among regions requires standardization of calculations for indicators, including aggregated data.

The third section *(Part III, Tables 2S and 3S, Figures 1S-3S, pages 27-33)* describes the basic characteristics and clinical validation of the Catalan population-based risk assessment tool based on the GMA morbidity grouper. Further questions or information regarding the GMA risk assessment tool should be addressed to David Monterde (dmonterde@gencat.cat). Institut Català de la Salut, Gran Via de les Corts Catalanes, 587-589. 08007-Barcelona. Phone: 34-934824246.

Finally, the last section of the document *(Part IV, Table 4S page 34)* provides complementary material that should facilitate regional site deployment of health-risk assessment strategies.

DG SANCO

Contract Nr : HEALTH-20121209

Directorate-General for Health & Consumers

Advancing Care Coordination and Telehealth Deployment

ACT Programme

Annex B to Deliverable 7

Opimec survey

Due date of deliverable: Month 27
Actual submission date: 1st June 2015

DOCUMENT INFO

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Documents history

Document version #	Date	Change
V0.1	30-04-2015	Starting version, template
V0.2	14-05-2015	Final version
V1.0	21-05-2015	Final version for submission

Document data

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Delivery date	1st June 2015

Keywords

Keywords	Chronic Care; Health Risk Prediction; Integrated Care; Patient Stratification; Population Health

Table of Contents

1 OPIMEC survey

1.1 Risk Stratification Survey

1.1.1 Email letter and Survey Cover page

This survey collects information on key features of risk stratification models

Dear ACT partner:

Welcome to this survey about characteristics and implementation of predictive models for risk stratification applied to people with chronic diseases.

We ask your cooperation in completing this survey because you have developed and / or implemented a risk stratification model. If you know any other person able to provide information, please provide his/her contact details to andres.cabrera.easp@juntadeandalucia.es.

The information will be analysed by members of the Area Risk Stratification Action group B3 of the EIP on AHA and members of ACT EU project. The results will be used to assess the different models that are being developed in Europe.

Please complete the survey before **Friday 28th of February**. If you identify any error or substantial improvement area in the survey, we would greatly appreciate your feedback.

Thank you in advance for your interest and support!

There are 57 questions in this survey

1.1.2 Introduction

Please specify below the predictive model implemented in you work setting, entering the reference model, showing longer user range or best results.

If you have developed more models we would really appreciate that you fulfill another survey, once you finalize this one, directly from the same email in which you received the first invitation.

*** Please select at least 3 answers**

	Predictive Model
Name of the model	
Brief description (90 words max.)	
Reference Organization/s	

Which part of the model are you describing? *

Please choose **all** that apply:

☐ Statistical model

☐ Tool (calculator, scale,...)

☐ Platform web app

☐ Desktop app

☐ Other:

Scope of the model? *

Please choose **all** that apply:

☐ GP's office

☐ Hospital

☐ Area, district

☐ Region

☐ Country, state

☐ Other:

[]Type of model *

Please choose **all** that apply:

☐ Individual stratification

☐ Population stratification

☐

Other:

Please select only one answer

[]

Please introduce name, surname and email of people participating in the development of the model/tool/platform.

(Apart from identifying the working teams on risk stratification models, we intend to share with them the results of this survey).

Name and surname
Person 1
Person 2
Person 3
Person 4

[]

Is the working team in risk stratification model development the same as the team working in the implementation of the model?

Please choose **only one** of the following:

- Yes
- No
- Model not implemented yet

Please select only one answer

1.1.3 Information on the VARIABLES of the model

Next we are asking some information related to the model identified as the **reference model**

If you use more than one risk prediction model we kindly ask you to fulfill another survey, once you finalize this one, directly from the same email in which you received the first invitation.

Select below which events or variables and terms are used as dependent or result variables to classify people with chronic conditions with increased risk of:

Please select at least one answer

- [ ] Unplanned hospital admission

Unplanned hospital readmission ☐

Unplanned hospital days ☐

Death ☐

Functional decline ☐

Cognitive decline ☐

Pharmacy expenditure ☐

Expenditure on additional tests ☐

Transportation expenditure ☐

Health costs ☐

Health resource consumption ☐

Social resource cost ☐

Other events or variables ☐

Please specify other events or variables

Please write your answer here:

Now select which variables you are using in the model as explanatory or independent variables:

Please select at least 2 answers

Please choose **all** that apply:

☐ Age

☐ Sex

☐ Location

☐ Diagnostics

☐ Stage of the disease

☐

Visits annual average

☐

Urgent visits

☐

Dispensing drugs after diagnosis

☐

Annual average hospital stay

☐

Days stays (not planned)

☐

Number of hospitalizations

☐

Number of outpatient visits

☐

Rates of cognitive impairment (Barthel, ...)

☐

Comorbidity (Charlson, Elixhauser, ACG, GRGs, ICC, ...)

☐

Polypharmacy

☐

Previous costs

☐

Other:

Which statistical models are used?

(Please select at least 1 answer)

Please select at least one answer

Please choose **all** that apply:

☐

Linear Regression.

☐

Logistic Regression.

☐

Poisson regression.

☐

Cox Regression.

☐

Other:

The aim of the model is:

Please select at least one answer

Please choose **all** that apply:

☐

Holistic (social and heatlh)

☐

Health-care oriented

☐

Social-care oriented

☐

Other:

1.1.4 Characteristics of the model

Next we will ask about some of the characteristics of the reference model that you implemented

What sample size did you use to build up the model?

Please write your answer here:

Only numbers can be entered in this field

How big is the population targeted by the model?

Please write your answer here:

Only numbers can be entered in this field

What criteria are considered for Inclusion of an individual to the study population?

Check any of these:

Please choose **all** that apply:

☐ Age

☐ Previous admission.

☐ Diagnosis.

☐ Individual assigned to a primary care team.

☐ Result of the stratification.

☐ Other:

Check any of these:

Which are the exclusion criteria from the target population?

Please write your answer here:

What statistical results are used in the predictive model? Please select at least one answer:

Please select at least one answer

Please choose **all** that apply:

☐ Odds Ratio (OR)

☐ Relative Risk.

☐ Probability / percentage.

☐ Other:

What other statistical parameters are obtained from the

predictive model? Check any of these:

Please choose **all** that apply:

☐ Confidence intervals (CI).

☐ R squared.

☐ Positive Predictive Value (PPV).

☐ Negative Predictive Value (NPV).

☐ Sensitivity.

☐ Specificity.

☐ Area under the curve (AUC).

☐ Other:

1.1.5 Information Exploitation

Has a software been developed for the use of the tool? *

Please choose **only one** of the following:

○ Yes

○ No

○ In development

Please specify the name of the Software below *

Only answer this question if the following conditions are met:

Answer was NOT 'No' at question '19 [p9_sw]' (Has a software been developed for the use of the tool?)

Please write your answer here:

Is this software linked to a data exploitation Platform? *

Please choose **only one** of the following:

- ○ Yes
- ○ No
- ○ In development

Please specify the name of the Platform below

Only answer this question if the following conditions are met:

Answer was NOT 'No' at question '21 [p9_swlinked]' (Is this software linked to a data exploitation Platform?)

Please write your answer here:

Is the software free?

Please choose **only one** of the following:

- ○ Yes
- ○ No

Is there any license?

Please choose **only one** of the following:

- ○ Yes
- ○ No

Do you provide the license to interested users?

Only answer this question if the following conditions are met:

Answer was 'Yes' at question '24 [p9_license]' (Is there any license?)

Please choose **only one** of the following:

- ○

Yes

○

No

Do you provide training to other organizations wanting to use the tool?

Please choose **only one** of the following:

○

Yes

○

No

Is this platform integrated with the Databases of the Organization?

Please choose **only one** of the following:

○

Yes

○

No

○

In development

Please select the sources of information used for the construction of the model and where appropriate, please state why certain sources are not used

Please select at least one answer	USED in the model
Unified Medical Record	☐
Primary Care Medical Record	☐
Specialized Care Medical Record	☐
Pharmacy (prescription registry)	☐
Minimum basic data set (MBDS)	☐

Health Surveys ☐

Please specify other source/s of information the model might be using

Please write your answer(s) here:

1

2

3

How many suppliers are providing the information?

Please choose **only one** of the following:

○ One

○ Two

○ Three or more

Barriers to implementation

Please choose **all** that apply:

☐ Legal

☐ Economic

☐ Human resources

☐ Time

☐ Others (e.g.: difficulty moving from research to hospitals, from pilot to scale)

Is the data for risk stratification analysis available in the Health System?

Please choose **only one** of the following:

○ Yes

○ No

1.1.6 Change management

Please check below for answers that refer to the 'reference model'.

Check any that apply:

Please choose **all** that apply:

☐ Leaders of the health centers are involved and participate in the model.

☐ Leaders are identified with this model

☐ Clinicians (doctors and nurses) are involved and understand how it works (e.g, if you ask doctors what the intervention is, are they able to describe and explicitly support?).

☐ There have been briefings / training in the centers and for clinicians about the potential of the tool.

☐ We have defined a system to collect information at the clinical level to detect areas for improvement

☐ Stratification is integrated into the patient's medical history and therefore is displayed in single or shared clinical history.

☐ The visualization of stratification is shared by the different levels of care

☐ We have developed an application or platform to publish the results.

☐ Stakeholders (end users) are interconnected

☐

Data for end users in available, such as process-relevant data or data stream.

☐

There is the possibility to generate lists of people with certain levels of risk.

☐

The population included in the model is stable over time

☐

Pathways are defined for recruiting stratified patients.

☐

It is possible to monitor and analyze coverage, monitoring of patients selected by stratification (it has established a monitoring and evaluation plan).

☐

A system has been established to collect incidents by end users (healthcare, managers, etc...) in the model implementation.

How is the recruitment of the patients done?

Please choose **all** that apply:

☐

Telephone

☐

Regular mail

☐

Email

☐

Other:

What agents are responsible for the recruitment?

Only answer this question if the following conditions are met:

Answer was 'The population included in the model is stable over time' at question '33 [copia P13]' (Please check below for answers that refer to the 'reference model'. Check any that apply:)

Please select at least one answer

Please choose **all** that apply:

☐

Primary Care Doctor/General Practitioner

☐

Primary Care Nurse

☐

Secondary Care Doctor

☐

Enfermero/a de Atención Especializada

☐

Other:

1.1.7 Patient recruiment

Which periodicity of update has been defined for stratification?

Please choose **all** that apply:

☐

None

☐

Daily

☐

Weekly

☐

Monthly

☐

Quarterly

☐

Semiannual

☐

Anual

☐

Other:

Please select only one answer.

Which utility is being given to the stratification? (please add information in case of Other)

Please select at least one answer

Please choose **all** that apply:

☐ Currently none

☐ Informative

☐ Selection of the intervention population

☐ Other:

What variables are used for the selection of target populations?

Check any that apply:

Only answer this question if the following conditions are met:

Answer was at question '37 [P15]' (Which utility is being given to the stratification? (please add information in case of Other))

Please choose **all** that apply:

☐ Diagnosis

☐ Age

☐ Stratification results

☐ Previous admission

☐ Other:

Is the clinician able to identify in the computer system the patients selected for a given program by stratification?

Please choose **only one** of the following:

○ Yes

○ No

Who is able to identify these patients?

Only answer this question if the following conditions are met:

Answer was 'No' at question '39 [p15_pob_ident]' (* Is the clinician able to identify in the computer system the patients selected for a given program by stratification?)

Please write your answer here:

Does the clinician have the possibility to assess and validate the patients selected by stratification?

Please choose **only one** of the following:

○ Yes

○ No

Validation of patients by clinicians is reflected in the patient's medical history.

Only answer this question if the following conditions are met:

Answer was 'Yes' at question '41 [p15_pob_validar]' (Does the clinician have the possibility to assess and validate the patients selected by stratification?)

Please choose **only one** of the following:

○ Yes

○ No

All levels of care can see the same information related to patient stratification and participation in a program

Please choose **only one** of the following:

○ Yes

○ No

How do you assess the applicability in a given patient?

Please select at least one answer

Please choose **all** that apply:

☐ Identification criteria (misdiagnosis, patient death, bugs ...)

☐ Clinical criteria of the end user

☐ Other:

Please select at least one answer.

Is the population included in a program stable over time?

Please choose **only one** of the following:

○ Yes

○ No

Are there admissions and discharges on the programs?

Please choose **only one** of the following:

○ Yes

○ No

Who does this task?

Only answer this question if the following conditions are met:

Answer was 'Yes' at question '46 [p15_pob_nuevas]' (Are there admissions and discharges on the programs?)

Please write your answer here:

Have you launched a program to improve care for patients at risk as a result of the use of a predictive model?

Please choose **only one** of the following:

- ○ Yes
- ○ No

1.1.8 Implementation

Advantages of implementing this model:

Please write your answer here:

Disadvantages, limitations or suggested improvements:

Please write your answer here:

Which are the barriers to implement the model?

Please choose **all** that apply:

- ☐ Legal
- ☐

Economic

☐

Human resources

☐

Time

☐

Organizational / Institutional

☐

Other:

Check any of these:

Please enclose files related to the model (description, plan monitoring / evaluation, results ...):

Kindly attach the aforementioned documents along with the survey

Please indicate others who have implemented any other risk stratification model different from what you have described in this survey (so we can contact them to collect and disseminate information from other models and programs).

Full name

1.

2.

3.

[]

1.1.9 Additional information about the survey

Finally, if you wish, please add any additional information appropriate on matters relating to the scope of this survey.

Please write your answer here:

Before submitting the survey, **if you want to change some of the previous answers**, you can go back by clicking **"Previous"** button at the bottom center.

You can also **save the survey and continue it at another time** by clicking **"Resume later"** button at the bottom left and following the instructions.

If you have finished please click the **"Submit"** button.

Improvement areas of the Survey

Please, answer the following questions. They will be very useful to assess and improve this survey.

Please rate from 1 to 4:

Please choose the appropriate response for each item:

	Not at all
Utility: do you consider that the survey is useful for the purpose of ACT?	○
Usability: do you think it is user friendly?	○
Readability: do you understand questions and concepts?	○

Other questions you would include:

Please write your answer here:

Other answers (choices) you would include:

Please write your answer here:

Thank you for your interest and support!

Sincerely,

Andres Cabrera-Leon

Observatory of Innovative Practices for Complex Chronic Disease Management (www.OPIMEC.org)

Andalusian School of Public Health (www.easp.es)

email: andres.cabrera.easp@juntadeandalucia.es; acabreraleon@gmail.com

Phones: +34958027400 , +34697958289

Profile: www.opimec.org/personas/andrescabrera/ and es.linkedin.com/in/acabreraleon

LimeSurvey Manager

Submit your survey.

Thank you for completing this survey.

Part II – Health indicators

Table 1S - 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 hospitalization
	The prognosis (in years) on life expectancy	Average expected number of years remaining i n 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 age ≤75 years	(Number of persons between ≥65 years and ≤75 years old/total population)*100	%
	Population size (in %) age >75 years	(Number of persons ≥75 years old/total population)*100	%
Socioeconomic status[b]	The regional derived deprivation index	The regional derived deprivation index	%
	The education level for disease Xi	The education level for disease Xi	%
	The accessibility to healthcare	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	No.
	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 and <15 drugs (per 1000), last 12 months, due to any cause	(The number of patients using ≥10 and <15 drugs in the last 12 months, due to any cause/total population)*1000	No.
	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	No.

[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.*

Part III - 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 modelling 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.

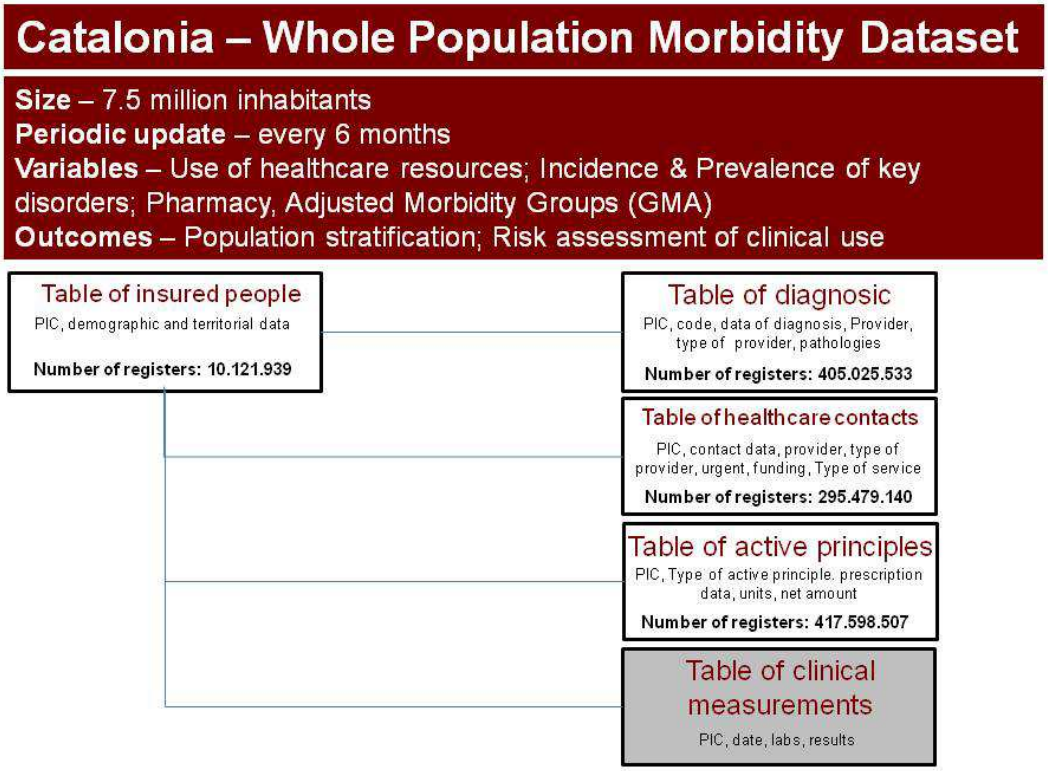


Figure 1S – Scheme of articulated datasets included in the whole population morbidity dataset in Catalonia used for population-based health risk assessment. The articulation of the Table of clinical measurements (grey background) is not operational. GMA: Adjusted Morbidity Groups, PIC: Personal identification 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 2S** 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 combine two dimensions: (i) Morbidity, including a total of seven morbidity groups, and, (ii) Case Complexity, as depicted in **Table 2S.**

Table 3S – The GMA grouper classifies each case in five levels of complexity

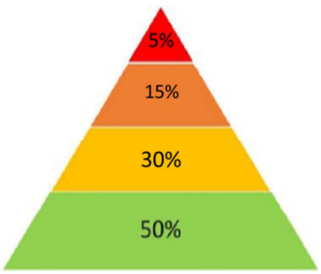
	Group of morbidity	**Complexity Level**				
Multi-morbidity	Patients with active neoplasms	1	2	3	4	5
	Patients with a chronic disease in 4 or more systems	1	2	3	4	5
	Patients with a chronic disease in 2 or 3 systems	1	2	3	4	5
	Patients with a chronic disease in 1 system	1	2	3	4	5
	Patients with an acute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

The GMA classification (**Table 3S**) 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.



	% Pop.	Mortality	Admissions	Expenditure	% Expend.
GMA-4	5	11,2	58,4	7.070	35,8
GMA-3	15	1,1	6,6	2.124	32,3
GMA-2	30	0,1	2,4	777	23,6
GMA-1	50	0,0	0,5	164	8,3
Catalonia	100	0,8	4,9	987	100,0

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 colour (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 predict 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**, main text). 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) pseudo-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.

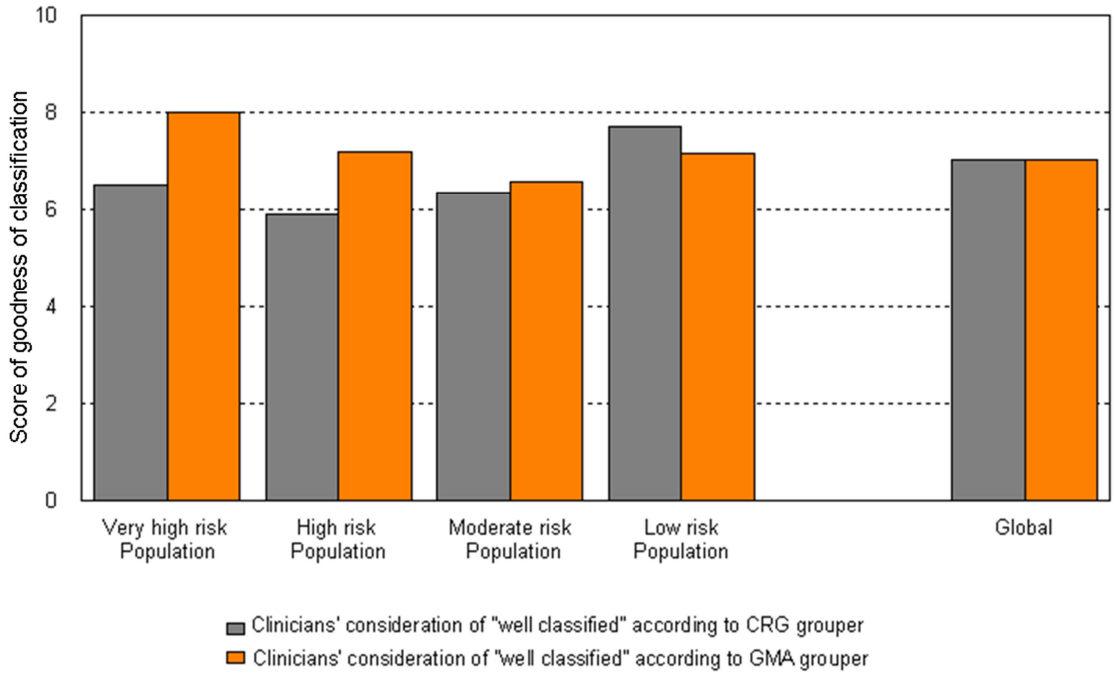


Figure 3S: Goodness of the classifications generated by the two morbidity groupers: CRG (grey) and GMA (orange) by level of complexity assigned by the general practitioner. The last column provides a summary analysis.

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 IV - Operational aspects for site deployment of health risk assessment strategies

This part includes (**Table 4S**) a brief systematic description of main recommendations for implementation and evaluation of a health risk assessment strategy at regional level.

Table 4S. 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 labour 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.

References of the supplementary material

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