RESEARCH ARTICLE

Multimorbidity Patterns in Elderly Primary Health Care Patients in a South Mediterranean European Region: A Cluster Analysis

Quintí Foguet-Boreu1,2*, Concepción Violán1, Teresa Rodriguez-Blanco1, Albert Roso-Llorach1, Mariona Pons-Vigués1,2, Enriqueta Pujol-Ribera1,2, Yolima Cossio Gil1, Jose M. Valderas3

1 Institut Universitari d’Investigació en Atenció Primària Jordi Gol (IDIAP Jordi Gol). Universitat Autònoma de Barcelona, Gran Via Corts Catalanes, 587 àtic, Barcelona, Spain, 2 University of Girona, Carrer Emili Grahit, 77, Girona, Catalonia, Spain, 3 Health Services & Policy Research Group, School of Medicine, University of Exeter, Exeter, United Kingdom

* 42292qfb@comb.cat

Abstract

Objective
The purpose of this study was to identify clusters of diagnoses in elderly patients with multimorbidity, attended in primary care.

Design
Cross-sectional study.

Setting
251 primary care centres in Catalonia, Spain.

Participants
Individuals older than 64 years registered with participating practices.

Main outcome measures
Multimorbidity, defined as the coexistence of 2 or more ICD-10 disease categories in the electronic health record. Using hierarchical cluster analysis, multimorbidity clusters were identified by sex and age group (65–79 and ≥80 years).

Results
322,328 patients with multimorbidity were included in the analysis (mean age, 75.4 years [Standard deviation, SD: 7.4], 57.4% women; mean of 7.9 diagnoses [SD: 3.9]). For both men and women, the first cluster in both age groups included the same two diagnoses: Hypertensive diseases and Metabolic disorders. The second cluster contained three...
and Health Promotion Research Network (rediAPP), by ISCIII-RE TeCS (RD12/0005), by a 2011–2013 scholarship that aims to promote research in Primary Health Care by health professionals who have completed their specialty training, awarded by Institut Universitari d’Investigació en Atenció Primària Jordi Gol (IDIAP Jo rdi Gol), by a National Institute for Health Research Clinician Scientist Award (Jose M Valderas, NIHR/CS/010/024) and by a grant from the XIX call for research projects in the elderly population by Agrupació Mútua Foundation (Premio ámbito para las personas mayores, 2012). The funders had no role in the study design, collection, analysis and interpretation of data, writing of the manuscript or decision to submit for publication.

Competing Interests: The authors have declared that no competing interests exist.

diagnoses of the musculoskeletal system in the 65- to 79-year-old group, and five diseases coincided in the ≥80 age group: varicose veins of the lower limbs, senile cataract, dorsalgia, functional intestinal disorders and shoulder lesions. The greatest overlap (54.5%) between the three most common diagnoses was observed in women aged 65–79 years.

Conclusion

This cluster analysis of elderly primary care patients with multimorbidity, revealed a single cluster of circulatory-metabolic diseases that were the most prevalent in both age groups and sex, and a cluster of second-most prevalent diagnoses that included musculoskeletal diseases. Clusters unknown to date have been identified. The clusters identified should be considered when developing clinical guidance for this population.

Introduction

Increased life expectancy and improved health records systems have resulted in an increased population with diagnosed comorbidities. It is estimated that more than 95% of people older than 65 years in western countries will have coexisting diagnoses of two or more diseases at some point in time [1–5].

Multimorbidity (MM) measurement is a complex topic; one of the approaches that have been used to address it is to find the associations or patterns of diseases that tend to co-occur beyond the rate of chance. Systematic reviews have reported a range of statistical techniques used (prevalence figures, conditional count, odds and risk ratios, observed/expected ratio, factor analysis, cluster analysis, etc.) to identify MM patterns [1,2]. However, most of these analyses have been based on a restricted a priori list of clinical diagnoses [1,3]. Furthermore, few studies have differentiated the patterns by age and sex [1], although it is well known that differences based on these characteristics exist both in epidemiological profiles and in clinical care. A better approach to studying MM must be defined that includes a wide range of clinical diagnoses and is stratified by age and sex [3,5,6].

Cluster analysis can be used to identify patterns by establishing similarities within subgroups, with each subgroup characterized by a different profile; this is a useful method when the number and nature of the groupings is unknown a priori [7,8]. Cluster analyses have previously been used to discover MM patterns, but none considered the full range of diseases treated in Primary Care [1]. The identification of such patterns is essential to improve our knowledge about pathophysiological pathways shared by MM conditions, to guide the clinical and pharmaceutical management of these patients, and to support policy makers in the efficient allocation of resources and the design of effective health programs aimed at improving holistic, person-centred, primary health care [9,10].

Our hypothesis was that analysis of a large electronic health records (EHR) database containing all diagnoses pertaining to individual patients would identify new associations between diseases commonly present in MM patients and could improve care provided to patients who fit the profile of subgroups with these patterns. The purpose of this study was to identify clusters of diagnoses in elderly patients with MM in the primary health care system in Catalonia, by sex and age group (65–79 years and ≥80 years).
Materials and Methods

Design, setting and study population

A cross-sectional study was conducted in Catalonia (Spain), a Mediterranean region with 7,434,632 inhabitants, 81% of which live in urban municipalities (2010 census). The Spanish National Health Service (NHS) provides universal coverage, financed mainly by tax revenue. The Catalan Health Institute (CHI) manages primary health care teams (PHCTs) that serve 5,501,784 patients (274 PHCT), or 74% of the population; the remaining PHCTs are managed by other providers. The CHI’s Information System for the Development of Research in Primary Care (SIDIAP) contains the coded clinical information recorded in EHR by its 274 PHCTs since 2006. A subset of records meeting the highest quality criteria for clinical data (SIDIAP Q) includes 40% of the SIDIAP population (1,833,125 individuals), attended by the 1,365 general practitioners (GPs) whose data recording scored highest in a validated comparison process [11]. We selected individuals older than 64 years on 31 December 2010 with two or more diagnoses (Fig 1).

Coding and selection of diseases

Diseases are coded in SIDIAP using International Classification of Diseases version 10 (ICD-10). For this study, we selected all active diagnoses recorded in EHR as of December 31, 2010, except for R codes (symptoms, signs, and abnormal clinical and laboratory findings, not elsewhere classified) and Z codes (factors influencing health status and contact with health service).
services). Non-active diagnoses were excluded, based on the presence of an end date in the EHR. These diagnoses cover a broad list of acute diseases for which the system automatically assigns an end date (e.g., 60 days after the initial diagnosis).

To facilitate management of the diagnostic information, the diagnoses were extracted using the 263 blocks (disease categories) in the ICD-10 structure. These are homogeneous categories of very closely related specific diagnoses (for example, Hypertensive diseases includes Essential (primary) hypertension, Hypertensive heart disease, Hypertensive renal disease, Hypertensive heart and renal disease and Secondary hypertension). Throughout the manuscript, the ICD diagnostic blocks are italicized, followed by the most frequent specific diagnosis in parentheses where applicable. To obtain consistent and clinically interpretable patterns of association, and to avoid spurious relationships that could bias the results, we considered only diagnoses with greater than 1% prevalence in each stratum of age and sex. All patients with MM (2 or more coexisting diagnoses recorded in the EHR on 31 December 2010) were included.

Statistical analysis
Analyses were stratified by sex and age group (65–79 and ≥80 years). In a descriptive analysis, categorical variables were expressed as frequencies (percentage) and continuous variables as mean (Standard deviation, SD) or median (interquartile range, IQR).

A cluster analysis was performed in order to identify patterns of MM. This analysis allows the assignment of diagnoses into groups or clusters, so that diagnoses in the same cluster are more similar to one another than to diagnoses from different clusters. The unit of measurement was the diagnosis (values: 1 for present, 0 for absent). In order to assess how ‘close’ the diagnoses were to each other, a quantitative measure of closeness (or similarity) for binary data, the Jaccard coefficient, was used. This coefficient considers only the diagnoses that any two patients have and ignores the diagnoses that neither of them has [7].

As we do not know a priori the number of clusters to retain from the data, we used agglomerative hierarchical methods to identify possible clustering solutions: Average linkage, Ward, flexible beta and other methods with less bias, based on nonparametric estimates, such as Single Linkage and Density Linkage. All but Ward and the flexible beta methods successively chained the observations into one cluster. Therefore, the Ward method, which minimizes the variance within clusters and produces clusters of similar sizes, was chosen as the primary method based on dendrograms analysis [7].

Data were randomly split into test and training datasets, equal in size and analysed separately. We ran the Ward method on both samples. The semi-partial R2, Calinski-Harabasz pseudo-F- and pseudo-T2-statistic criteria for different numbers of clusters were examined [7]. Clustering solutions were compared between the test and training datasets, taking into account the number of clusters, Adjusted Rand Index and clinical criteria. After checking algorithm stability, Ward method was run on the full data set, applying the same criteria to different numbers of clusters. Results were compared with flexible beta results, with beta values set at -0.25 and -0.5. The criteria for selecting the number of clusters were the highest adjusted Rand index with a high number of clusters and a high pseudo T2 statistic [12]. Clinical criteria were used to evaluate the consistency and utility of the final cluster solution, based on clusters previously described in the literature and a consensus opinion drawn from the clinical experience of the research team (4 family physicians, 1 epidemiologist in daily patient care.

After identifying the clusters of diagnoses, the patients were assigned to clusters. We considered that a patient belonged to a given cluster if he/she had one or more of the diagnoses in that cluster. Thus, a patient could belong to more than one cluster. In order to facilitate interpretation, we also calculated cluster prevalence (overall and stratified by sex and age group),
further restricting the assignment of patients to those with ≥2 diagnoses. The prevalence of each specific diagnosis was calculated by stratum and cluster.

To assess the internal cluster quality, we applied multiscale bootstrap resampling to obtain an approximately unbiased (AU) probability. This probability (’p-value’) is the proportion of bootstrapped samples that contain the cluster; larger p-values indicate more support for the cluster [13].

For the purpose of illustration, we used Venn diagrams to show the overlap between the three most prevalent clusters in each stratum.

The analyses were performed using SPSS for Windows, version 18 (SPSS Inc., Chicago, IL, USA), SAS 9.2 for Windows (SAS Institute Inc., Cary, NC, USA) and R version 3.0.0 (R Foundation for Statistical Computing, Vienna, Austria).

Ethical considerations

The study protocol was approved by the Committee on the Ethics of Clinical Research, Institut Universitari d’Investigació en Atenció Primària Jordi Gol (IDIAP Jordi Gol) (Protocol No: P12/28). All data were anonymized and EHR confidentiality was respected at all times in accordance with national and international law.

Results

Population description

A total of 343,358 individuals older than 64 years (57.4% women) were selected from Primary Care records. Of these, 322,328 (93.9%) met the MM criteria and were included in the cluster analysis. Mean age of MM patients was 75.4 years (standard deviation [SD]: 7.4), with a mean of 7.9 (SD: 3.9) diagnoses per patient. The group aged ≥80 years had only marginally higher MM than the younger group (94.9% vs 93.4%, respectively; p<0.001). Sex-related differences were found in both age strata. In participants aged 65–79 years, women had higher MM than men (94.1% vs 92.7%, respectively; p<0.001), but the reverse was true among those ≥80 years old (95.3% in men vs 94.7% in women; p<0.001) (Table 1).

Table 1. Multimorbidity in patients ≥65 years old, stratified by age group and sex.

| Included in the analysis   | N = 322,328 |
|----------------------------|-------------|
| Age Group 65–79 years      |             |
| Female                     | (n = 132,553) |
| Male                       | (n = 111,630) |
| ≥2 Diagnoses               |             |
| 2                          | 5,582 (4.5%)  | 6,195 (6.0%)  |
| 3                          | 8,150 (6.5%)  | 8,656 (8.4%)  |
| 4                          | 10,307 (8.3%) | 10,728 (10.4%)|
| ≥5                         | 100,623 (80.7%) | 77,933 (75.3%) |
| Median number of diagnoses (IQR) | 8 (5–11)  | 7 (5–9)  |

| Age Group ≥80 years        |             |
| Female                     | (n = 63,554) |
| Male                       | (n = 35,621) |
| ≥2 Diagnoses               |             |
| 2                          | 2,234 (3.7%)  | 1,162 (3.4%)  |
| 3                          | 3,288 (5.5%)  | 1,802 (5.3%)  |
| 4                          | 4,398 (7.3%)  | 2,589 (7.6%)  |
| ≥5                         | 50,278 (83.5%) | 28,403 (83.6%) |
| Median number of diagnoses (IQR) | 8 (5–11)  | 8 (5–11)  |

Abbreviations: IQR, Inter-quartile Range.
Note: P-values were significant at <0.001 (Chi-square test) in all comparisons except in number of diagnoses between females and males at age group ≥80 years.

doi:10.1371/journal.pone.0141155.t001
Identification of clusters of diagnoses

The number of clusters identified across all age and sex strata ranged from 42 to 85; however, the number of clusters with two or more diagnoses varied from 6 to 18 (Table 2). Clusters containing a single diagnosis had very low prevalence rates.

The vast majority of patients (63.2%-81.4%) had at least two diagnoses included in the most prevalent cluster (28.1% to 47.3% for the second most prevalent cluster). There was no consistency, however, in the specific composition of the most prevalent clusters across strata (Tables 3–6). In order to simplify the presentation of the results, we describe only the four most prevalent clusters. The description of all the clusters, using the Ward algorithm, is shown in S1–S4 Tables.

Several patterns were identified. The most prevalent cluster in all four strata included Hypertensive diseases and Metabolic disorders and tended to include other age-related and/or cardiovascular diagnoses. In the younger group (both sexes), Diabetes mellitus and Obesity and other hyperalimentation were also included. In the older group (both sexes), the most prevalent cluster included Other forms of heart disease (atrial fibrillation) as a third diagnosis. Arthrosis was part of this cluster in three strata, but was replaced by Diseases of male genital organs in males (hyperplasia of prostate) in men aged 65–79 years.

The second most prevalent cluster included diagnoses related to the musculoskeletal system: Other dorsopathies (dorsalgia), Other soft tissue disorders (shoulder injuries), and Other joint disorders. In women of both age groups, the cluster included two aging-related disorders: Disorders of bone density and structure (osteoporosis) and Disorders of lens (cataracts).

The cluster of third-most prevalence covers a range of diagnoses (Tables 3 and Table 6). In 65- to 79-year-olds, however, Chronic lower respiratory diseases and Mental and behavioural disorders due to psychoactive substance use (Tobacco) had a higher prevalence in men (Table 4). Two diagnoses were prevalent in women ≥80 years old: Diabetes mellitus and Obesity and other hyperalimentation.

We present Venn diagrams for the overlap of the three most prevalent clusters across all patients (Fig 2). Less than 2.5% of all patients in any group were free of all diagnoses in the three most prevalent clusters. The group with the largest overlap was women aged 65 to 79 years: 54.5% presented with diagnoses in all three clusters. The least overlap (18.8%) was observed in men of that age group. In general, women had a higher frequency of overlap between clusters (≥81.8%) than men (≥68.6), p<0.001.

Discussion

We observed a very high prevalence of multimorbidity among elderly individuals in primary care. Cluster analysis, including all conditions above a minimum prevalence threshold, showed

| Age group | Sex     | Number of diagnoses | Number of clusters | Number of clusters with ≥2 diagnoses | Median of diagnoses per clusters (IQR)* |
|-----------|---------|---------------------|--------------------|-------------------------------------|----------------------------------------|
| 65–79     | Female  | 94                  | 42                 | 18                                  | 2 (2–5)                                |
|           | Male    | 88                  | 67                 | 11                                  | 2 (2–3)                                |
| ≥80       | Female  | 99                  | 85                 | 6                                   | 2 (2–4)                                |
|           | Male    | 99                  | 58                 | 18                                  | 3 (2–4)                                |

Abbreviations: IQR, Inter-quartile Range

*Median of clusters with ≥2 diagnoses.
some well-known multimorbidity patterns and revealed others that have not been described previously. We detected substantial heterogeneity in the composition of multimorbidity clusters across age/sex strata, but several distribution patterns emerged: a) a circulatory-metabolic cluster was the most prevalent in all age groups, followed by a cluster that included mostly musculoskeletal diagnoses; b) aging-related diagnoses were consistently included in each of the four most frequent clusters in all age/sex strata; and c) sex related differences in the distribution of multimorbidity were observed for the younger stratum patients but not for the older groups.

Table 3. Four most prevalent clusters of diagnoses: Prevalence and composition of clusters in women aged 65–79 years (n = 124,662).

| Cluster rank | Number of patients | Diagnosis prevalence in stratum (%) | Diagnoses                                                                 | Prevalence (%) |
|--------------|--------------------|-------------------------------------|---------------------------------------------------------------------------|----------------|
|              | ≥ 1 diagnosis       | ≥ 2 diagnosis                       | In stratum | In cluster |
| 1            | 113,667            | 91.2                                | Hypertensive diseases | 64.0 | 70.2 |
|              |                    |                                     | Metabolic disorders | 57.7 | 63.2 |
|              |                    |                                     | Arthrosis | 41.3 | 45.3 |
|              |                    |                                     | Obesity and other hyperalimentation | 26.5 | 29.1 |
|              | 96,131             | 77.1                                | Diabetes mellitus | 21.9 | 24.0 |
|              |                    |                                     | Other dorsopathies | 32.2 | 41.7 |
|              | 92,539             | 74.2                                | Disorders of bone density and structure | 27.5 | 35.7 |
|              |                    |                                     | Other soft tissue disorders | 26.8 | 34.8 |
|              |                    |                                     | Diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified | 26.7 | 34.7 |
|              |                    |                                     | Neurotic, stress-related and somatoform disorders | 21.4 | 27.8 |
|              |                    |                                     | Other joint disorders | 19.7 | 25.5 |
| 3            | 68,431             | 54.9                                | Other forms of heart disease | 16.9 | 22.8 |
|              |                    |                                     | Mood [affective] disorders | 16.3 | 22.0 |
|              |                    |                                     | Disorders of thyroid gland | 15.6 | 21.0 |
|              |                    |                                     | Other diseases of intestines | 14.5 | 19.6 |
|              |                    |                                     | Disorders of lens | 14.5 | 19.5 |
|              |                    |                                     | Diseases of oesophagus, stomach and duodenum | 14.0 | 18.8 |
|              |                    |                                     | Chronic lower respiratory diseases | 12.5 | 16.8 |
|              |                    |                                     | Noninflammatory disorders of female genital tract | 12.5 | 16.8 |
|              |                    |                                     | Benign neoplasms | 11.5 | 15.5 |
|              |                    |                                     | Hernia | 10.7 | 14.4 |
|              |                    |                                     | Glaucoma | 8.4 | 11.3 |
| 4            | 68,431             | 54.9                                | Diseases of oral cavity, salivary glands and jaws | 12.0 | 21.9 |
|              |                    |                                     | Other disorders of ear | 11.0 | 20.0 |
|              |                    |                                     | Acute upper respiratory infections | 10.6 | 19.4 |
|              |                    |                                     | Dermatitis and eczema | 9.9 | 18.0 |
|              |                    |                                     | Behavioural syndromes associated with physiological disturbances and physical factors | 8.4 | 15.3 |
|              |                    |                                     | Episodic and paroxysmal disorders | 8.4 | 15.3 |
|              |                    |                                     | Other diseases of urinary system | 8.1 | 14.8 |
|              |                    |                                     | Other diseases of upper respiratory tract | 7.4 | 13.5 |
|              |                    |                                     | Nerve, nerve root and plexus disorders | 6.6 | 12.0 |
|              |                    |                                     | Mycoses | 6.0 | 10.9 |

AU p-value: cluster 1: 0.99 (0.83–1); cluster 2: 1.00; cluster 3: 0.96 (0.95–0.98); cluster 4: 0.91 (0.87–0.94).

doi:10.1371/journal.pone.0141155.t003
Table 4. Four most prevalent clusters of diagnoses: Prevalence and composition of clusters in men aged 65–79 years (n = 103,512).

| Cluster rank | Number of patients | Diagnosis prevalence in stratum (%) | Diagnoses | Prevalence (%) |
|--------------|--------------------|-------------------------------------|-----------|----------------|
|              |                    | ≥ 1 diagnosis | ≥ 2 diagnosis | In stratum | In cluster |
| 1            | 92.419             | 89.3         | 63.2         | Hypertensive diseases | 60.6 | 67.9 |
|              |                     |              |              | Metabolic disorders   | 52.6 | 58.9 |
|              |                     |              |              | Diseases of male genital organs | 36.1 | 40.4 |
|              |                     |              |              | Diabetes mellitus     | 27.8 | 31.1 |
| 2            | 63.964             | 61.8         | 28.1         | Obesity and other hyperalimentation | 16.6 | 18.6 |
|              |                     |              |              | Other dorsopathies    | 25.7 | 41.6 |
|              |                     |              |              | Arthrosis             | 22.7 | 36.7 |
|              |                     |              |              | Other soft tissue disorders | 18.1 | 29.3 |
|            |                     |              |              | Diseases of oral cavity, salivary glands and jaws | 13.0 | 21.0 |
|              |                     |              |              | Other joint disorders | 11.9 | 19.3 |
|              |                     |              |              | Other disorders of ear | 11.6 | 18.8 |
| 3            | 35.334             | 34.1         | 5.6          | Chronic lower respiratory diseases | 21.5 | 62.9 |
|              |                     |              |              | Mental and behavioural disorders due to psychoactive substance use | 18.2 | 53.4 |
| 4            | 31.144             | 30.1         | 4.6          | Other forms of heart disease | 21.1 | 70.1 |
|              |                     |              |              | Ischaemic heart diseases | 13.6 | 45.2 |

AU p-value: cluster 1: 0.76 (0.71–0.81); cluster 2: 0.77 (0.72–0.82); cluster 3: 1.00; cluster 4: 1.00.

doi:10.1371/journal.pone.0141155.t004

Table 5. Four most prevalent clusters of diagnoses: Prevalence and composition of clusters in women aged ≥ 80 years (60,198).

| Cluster rank | Number of patients | Diagnosis prevalence in stratum (%) | Diagnoses | Prevalence (%) |
|--------------|--------------------|-------------------------------------|-----------|----------------|
|              |                    | ≥ 1 diagnosis | ≥ 2 diagnosis | In stratum | In cluster |
| 1            | 56.509             | 93.9         | 71.2         | Hypertensive diseases | 77.4 | 82.4 |
|              |                     |              |              | Metabolic disorders   | 50.5 | 53.7 |
|              |                     |              |              | Arthrosis             | 46.9 | 50.0 |
|              |                     |              |              | Other forms of heart disease | 33.3 | 35.5 |
| 2            | 46.21              | 76.8         | 47.3         | Diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified | 25.7 | 33.5 |
|              |                     |              |              | Disorders of lens     | 25.0 | 32.6 |
|              |                     |              |              | Disorders of bone density and structure | 23.6 | 30.8 |
|              |                     |              |              | Other dorsopathies    | 22.5 | 29.2 |
|              |                     |              |              | Other diseases of intestines | 19.7 | 25.7 |
|              |                     |              |              | Neurotic, stress-related and somatoform disorders | 17.0 | 22.2 |
|              |                     |              |              | Other soft tissue disorders | 16.0 | 20.8 |
|              |                     |              |              | Other joint disorders | 14.1 | 18.3 |
| 3            | 22.592             | 37.5         | 6.8          | Diabetes mellitus     | 24.3 | 64.7 |
| 4            | 13.406             | 22.3         | 2.5          | Obesity and other hyperalimentation | 20.1 | 53.5 |
|              |                     |              |              | Diseases of oesophagus, stomach and duodenum | 12.7 | 36.9 |
|              |                     |              |              | Hemia                | 12.6 | 56.4 |

AU p-value: cluster 1: 1.00; cluster 2: 0.78 (0.73–0.83); cluster 3: 1.00; cluster 4: 0.61 (0.54–0.67).

doi:10.1371/journal.pone.0141155.t005
The patterns of associations between diagnoses are consistent with previous studies focusing on different populations and using other methodologies, such as the association between cardiovascular, endocrine and metabolic diseases [8, 14–17]. In our study, arthrosis tended to be clustered with diabetes and hypertension. Similarly, arthropathies (arthritis) have been identified along with diabetes and hypertension in participants older than 50 years [18]. The association of prostatic hyperplasia with endocrinal and cardiovascular diseases has been described in the same population using different statistical methods [19]. In our study, the musculoskeletal diagnoses included anxiety, limb varicose veins and osteoporosis in women. A very similar pattern was described previously by Prados et al [3,20]. An association between musculoskeletal disorders and gastro-esophageal reflux disease (GERD) was described by Cornell et al [8]. The relationships between these pathologies may be explained by the observed association between chronic pain and mental disorders [21,22], but also, as previously suggested, by gender stereotypes in the diagnostic process [23]. Our results suggest several possible pathophysiologic explanations for some of the observed associations that have not been previously reported, likely due to the limited number of clinical diagnoses assessed in earlier studies. For example, the musculoskeletal cluster in males aged 65 to 79 years also includes hearing loss; diseases of the oral cavity might be explained by bone degeneration and arthrosis of the small joints.

Table 6. Four most prevalent clusters of diagnoses: Prevalence and composition of clusters in men aged ≥80 years (n = 33,956).

| Cluster rank | Number of patients | Diagnosis prevalence in stratum (%) | Diagnoses | Prevalence (%) |
|--------------|--------------------|-------------------------------------|-----------|----------------|
| 1            | 32.608             | ≥1 diagnosis 96.0 ≥2 diagnosis 81.4 | Hypertensive diseases | In stratum 67.2 In cluster 70.0 |
|              |                    |                                     | Diseases of male genital organs | 44.0 45.8 |
|              |                    |                                     | Metabolic disorders | 43.0 44.8 |
|              |                    |                                     | Other forms of heart disease | 37.9 39.5 |
|              |                    |                                     | Arthrosis | 30.9 32.2 |
|              |                    |                                     | Chronic lower respiratory diseases | 27.9 29.0 |
|              |                    |                                     | Diabetes mellitus | 27.0 28.1 |
| 2            | 24.012             | 70.7 38.5                          | Disorders of lens | In stratum 23.2 In cluster 32.8 |
|              |                    |                                     | Other dorsopathies | 20.9 29.6 |
|              |                    |                                     | Other diseases of intestines | 18.4 26.0 |
|              |                    |                                     | Hernia | 16.9 23.8 |
|              |                    |                                     | Diseases of oesophagus, stomach and duodenum | 15.4 21.8 |
|              |                    |                                     | Diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified | 14.2 20.1 |
|              |                    |                                     | Other disorders of ear | 13.9 19.6 |
|              |                    |                                     | Other soft tissue disorders | 12.3 17.3 |
| 3            | 13.538             | 39.9 10.9                          | Ischaemic heart diseases | In stratum 18.9 In cluster 47.5 |
|              |                    |                                     | Renal failure | 16.0 40.2 |
|              |                    |                                     | Diseases of arteries, arterioles and capillaries | 10.6 26.5 |
|              |                    |                                     | Aplastic and other anaemias | 7.5 18.7 |
| 4            | 11.668             | 34.4 5.8                           | Obesity and other hyperalimentation | In stratum 12.7 In cluster 36.9 |
|              |                    |                                     | Glaucoma | 10.2 29.8 |
|              |                    |                                     | Inflammatory polyarthropaties | 9.8 28.3 |
|              |                    |                                     | Diseases of external ear | 8.0 23.4 |

AU p-value: cluster 1: 0.80 (0.76–0.85); cluster 2: 0.81 (0.76–0.86); cluster 3: 0.81 (0.76–0.81); cluster 4: 0.74 (0.64–0.84).

doi:10.1371/journal.pone.0141155.t006
musculoskeletal/digestive cluster in older men included a range of digestive pathologies (haemorrhoids, diseases of the oesophagus and inguinal hernia) that have a better-known association with GERD than with musculoskeletal problems. Although this could be explained by aging-related changes in connective tissue that may be a risk factor for both skeletal and extraskeletal disorders (varicose veins, aneurysms, hernias, myopia, etc.) [24], other clusters are difficult to interpret from a pathophysiological point of view.

Fig 2. Percentage of individuals (%) with overlapping of the three most prevalent clusters by sex and age group.

doi:10.1371/journal.pone.0141155.g002
We note the higher overlap of clusters observed for women, particularly those aged 65–79 years. Previous studies have reported higher MM rates in women [6], but this was not the case for our older age group, in which men had marginally but significantly higher MM levels.

Elderly patients had a median of 7 to 8 diseases, indicating a need for appropriate methods of grouping diseases beyond combinations of 2 or 3 highly prevalent diseases in order to study the complexity of multimorbidity in this population. Although various approaches (cluster analysis, factor analysis, latent class analysis, etc.) have been applied to date, there is no agreement about which is the most accurate [1, 25]. The present data provide information about the application of the cluster method in-depth to a large sample of diseases in order to advance the discussion about which of these methods might be the most recommended for the study of multimorbidity.

The clusters here identified can be used to prioritize interventions addressing some of the most common problems encountered in primary care, such as disorganisation and fragmentation of care, the improvement of current specific guidelines, challenges in delivering patient-centred care and barriers to shared decision making [26].

Strengths and limitations
The major strength of this study is the analysis of a large, high-quality database of primary-care records that have been shown to be representative of a much larger population. Other studies have shown that more accurate conclusions can be drawn from EHR data than from survey-based datasets [27–29]. Analysing almost all potential diagnoses could have added a complexity that may hinder interpretation of findings and comparison with other studies.

This wide range of diagnoses stratified by sex and age allowed us to find associations that have been little studied or have not been suggested before. Unlike previous studies, we did not explore only the associations between diagnoses but also the distribution of the resulting clusters in the studied population. This provided empirical evidence of clinical relevance and offers an approach to MM analysis that is patient-centred, rather than disease-centred.

A number of limitations need to be taken into account as well. Cluster analysis is exploratory in nature, and different clustering algorithms may produce different results [30]. The final clustering solution presented here was obtained through a systematic and rigorous process, including comparing the results from a randomly split dataset, testing different clustering algorithms, using different objective numeric criteria to decide the number of clusters, as well as subjective clinical criteria applied by a panel of experts in order to assess whether the groupings were clinically interpretable. An important limitation is our use of agglomerative hierarchical clustering, which forces every unit (i.e., diagnosis) into a single cluster. Hierarchical algorithms are considered more appropriate for classification problems that share common underlying factors, and may be a useful starting point when the number and structure of the clusters is unknown [7]. Another limitation is our use of ICD-10 3-character codes as the unit of analysis, rather than the more specific individual diagnosis.

Implications for clinical practice and policy
Longitudinal and genetic studies are needed to confirm or refine the observed patterns, which would give clinicians and policy makers now have access to information on how diseases are clustered in the older adult population. This is important for developing disease-specific Clinical Practice Guidelines that appropriately reflect the co-occurrence of conditions in this population and can anticipate tailored approaches based on the comorbidity profile of the individual patient. In day-to-day clinical practice, this information is useful to increase clinical suspicion and case-finding of conditions within the same cluster when considering the differential diagnosis of new health concerns.
Future research

To further assess the stability of these clusters over time and confirm that the observed results are not simply due to chance, longitudinal studies are needed and the new clinical hypotheses should be tested. Longitudinal studies would show when second- and third-level diseases are added to first-level diagnoses during the individual's lifetime. They would also allow exploration of factors that produce or lead to comorbidity; these data could be used to design individualized preventive strategies. Analysis is needed of potential confounding factors such as greater disease severity, socioeconomic status, place of residence, comorbid conditions, or functional limitations [10]. Clinical studies could assess clusters that are biologically plausible or have an unknown clinical relationship, but are potentially important for clinical practice. Clinical trials are needed to determine which therapeutic approaches best address the most prevalent clusters and to develop prevention strategies based on these clusters. Additional research priorities should be to explore the impact of these disease clusters on patients' quality of life, activities of daily living and prognosis [31]. These clusters have to be tested with networks methods to identify genetic abnormalities or the interplay of multiple molecular processes that may be involved with multimorbidity [32]. Future replication in other databases from other countries is also needed in order to explore the external validity of the present findings and to assess whether the multimorbidity patterns obtained could be generalized to multimorbidity patients in a broader context.

Conclusions

We identified several clusters of diagnoses that are most prevalent by age group and sex in older adults. Some of these clusters were not previously observed but show a high degree of consistency across all strata. This study included a broad range of diagnoses, and corroborated some clusters of diseases that do not co-occur by chance. In all strata, hypertensive diseases and metabolic disorders consistently made up the most prevalent cluster, followed by the musculoskeletal diseases cluster. The results of this study offer the opportunity to shape future research on combined preventive measures for the different conditions within a given cluster and to inform clinical practice guidelines as well as diagnostic procedures and algorithms in the primary care setting.

In summary, the identification of MM patterns facilitates the holistic approach to health care, focusing not only on a specific disease, but on the whole person and health promotion. The results of our study add knowledge to encourage this paradigm shift in health care.

Supporting Information

S1 Table. Prevalence and composition of diagnostic clusters in women aged 65–79 years. (XLSX)

S2 Table. Prevalence and composition of diagnostic clusters in men aged 65–79 years. (XLSX)

S3 Table. Prevalence and composition of diagnostic clusters in women aged ≥80 years. (XLSX)

S4 Table. Prevalence and composition of diagnostic clusters in men aged ≥80 years. (XLSX)
**Author Contributions**

Conceived and designed the experiments: QFB CV JMV MPV EPR. Performed the experiments: QFB CV JMV MPV EPR. Analyzed the data: TRB ARL YCG. Contributed reagents/materials/analysis tools: QFB CV JMV MPV EPR YCG. Wrote the paper: QFB CV TRB JMV MPV EPR YCG.

**References**

1. Violan C, Foguet-Boreu Q, Flores-Mateo G, Salisbury C, Blom J, Freitag M, et al. Prevalence, determinants and patterns of multimorbidity in primary care: a systematic review of observational studies. PLoS One 2014; 9:e102149. doi: 10.1371/journal.pone.0102149 PMID: 25048354

2. Marengoni A, Angleman S, Melis R, Mangialasche F, Karp A, Garman A, et al. Aging with multimorbidity: a systematic review of the literature. Ageing Res Rev 2011; 10:430–9. doi: 10.1016/j.arr.2011.03.003 PMID: 21402176

3. Prados-Torres A, Calderón-Larrañaga A, Hancco-Saavedra J, Poblador-Plou B, van den Akker M, et al. Multimorbidity patterns: a systematic review. J Clin Epidemiol 2014; 67:254–66. doi: 10.1016/j.jclinepi.2013.09.021 PMID: 24472295

4. Fortin M, Stewart M, Poitras ME, Almirall J, Maddocks H. A systematic review of prevalence studies on multimorbidity: toward a more uniform methodology. Ann Fam Med 2012; 10:142–51. doi: 10.1370/afm.1337 PMID: 22412006

5. Schäfer I, Hansen H, Schön G, Höfels S, Altiner A, Dahlhaus A, et al. The influence of age, gender and socioeconomic status on multimorbidity patterns in primary care. First results from the multicare cohort study. BMC Health Serv Res 2012; 12:89. doi: 10.1186/1472-6963-12-89 PMID: 22471925

6. Foguet-Boreu Q, Violan C, Roso-Llorach A, Rodriguez-Blanco T, Pons-Vigués M, Muñoz-Pérez MA, et al. Impact of multimorbidity: acute morbidity, area of residency and use of health services across the life span in a region of south Europe. BMC Fam Pract 2014; 15:55. doi: 10.1186/1471-2296-15-55 PMID: 24666526

7. Everitt BS, Landau S, Leese M, Stahl D. Cluster Analysis. 5th ed. Chichester, UK: John Wiley & Sons, Ltd; 2011.

8. Cornell JE, Pugh JA, Williams JW, Kazis L, Lee AFS, Parchman ML, et al. Multimorbidity clusters: Clustering binary data from multimorbidity clusters: Clustering binary data from a large administrative medical database. Appl Multivar Res 2007; 12:163–82.

9. Weiss CO, Varadhan R, Puhan MA, Vickers A, Bandeen-Roche K, Boyd CM, et al. Multimorbidity and evidence generation. J Gen Intern Med. 2014; 29(4):653–60. doi: 10.1007/s11606-013-2660-5 PMID: 2444333

10. Blozik E, van den Bussche H, Gurtner F, Schäfer I, Scherer M, et al. Epidemiological strategies for adapting clinical practice guidelines to the needs of multimorbid patients. BMC Health Serv Res 2013; 13:352. doi: 10.1186/1472-6963-13-352 PMID: 24041153

11. García-Gil M del M, Hermosilla E, Prieto-Alhambra D, Fina F, Rosell M, et al. Construction and validation of a scoring system for the selection of high-quality data in a Spanish population primary care database (SIDIAP). Inform Prim Care 2011; 19:135–45. PMID: 22688222

12. SAS Institute Inc: SAS/STAT® User’s Guide, Version 9.2 Cary, NC: SAS Institute Inc: 2008.

13. Shimodaira H. Approximately unbiased tests of regions using multistep-multiscale bootstrap resampling. Annals of Statistic. 2004; 32: 2616–2641.

14. Schäfer I, von Leitner E-C, Schön G, Koller D, Hansen H, et al. Multimorbidity patterns in the elderly: a new approach of disease clustering identifies complex interrelations between chronic conditions. PLoS One 2010; 5(12):e15941. doi: 10.1371/journal.pone.0015941 PMID: 21209965

15. Freund T, Kunz CU, Ose D, Szecsenyi J, Peters-Klimm F. Patterns of multimorbidity in primary care patients at high risk of future hospitalization. Popul Health Manag 2012; 15:119–24. doi: 10.1089/pop.2011.0026 PMID: 22313440

16. Prados-Torres A, Poblador-Plou B, Calderón-Larrañaga A, Gimeno-Feliu LA, González-Rubio F, Porcel-Falcó A, et al. Multimorbidity patterns in primary care: interactions among chronic diseases using factor analysis. PLoS One 2012; 7:e32190. doi: 10.1371/journal.pone.0032190 PMID: 22983389

17. Van den Bussche H, Koller D, Kolonko T, Hansen H, Wegscheider K, Glaeske G, et al. Which chronic diseases and disease combinations are specific to multimorbidity in the elderly? Results of a claims data based cross-sectional study in Germany. BMC Public Health 2011; 11:101.
18. Garin N, Olaya B, Perales J, Moneta MV, Miret M, Ayuso-Mateos JL, et al. Multimorbidity patterns in a national representative sample of the Spanish adult population. PLoS One 2014; 9:e84794. doi: 10.1371/journal.pone.0084794 PMID: 24465433

19. Viñolá C, Foguet-Boreu Q, Roso-Llorach A, Rodríguez-Blanco T, Pons-Vigués M, Pujol-Ribera E, et al. Burden of multimorbidity, socioeconomic status and use of health services across stages of life in urban areas: a cross-sectional study. BMC Public Health. 2014; 14:530. doi: 10.1186/1471-2458-14-530 PMID: 24885174

20. Abad-DXez JM, Calderón-Larrañaga A, Poncel-Falcó A, Poblador-Plou B, Calderón-Meza JM, Sicras-Mainar A, et al. Age and gender differences in the prevalence and patterns of multimorbidity in the older population. BMC Geriatr 2014; 14:75. doi: 10.1186/1471-2318-14-75 PMID: 24934411

21. Gatchel RJ, Worzer W, Brede E, Ashi S, Hartzell M, Choi Y. Etiology of Chronic Pain and Mental Illness: The Biopsychosocial Component. Pract Pain Manag 2011; 11:1–11.

22. McWilliams LA, Cox BJ, Enns MW. Mood and anxiety disorders associated with chronic pain: an examination in a nationally representative sample. Pain 2003; 106:127–33. PMID: 14581119

23. Velasco S, Ruiz MT, Alvarez-Dardet C. Attention models to somatic symptoms without organic cause: from physiopathologic disorders to malaise of women. Rev Esp Salud Publica 2006; 80:317–33. PMID: 16913608

24. Frost HM. New targets for fascial, ligament and tendon research: A perspective from the Utah paradigm of skeletal physiology. J Musculoskelet Neuronal Interact 2003; 3:201–9. PMID: 15758342

25. Haregu T, Oldenburg B, Setswe G, Elliott J. Perspectives, Constructs And Methods In The Measurement Of Multimorbidity And Comorbidity: A Critical Review. The Internet Journal of Epidemiology. 2012.

26. Wallace E, Salisbury C, Guthrie B, Lewis C, Fahey T, Smith SM. Managing patients with multimorbidity in primary care. BMJ 2015; 350:h176. doi: 10.1136/bmj.h176 PMID: 25646760

27. Viñolá C, Foguet-Boreu Q, Hermosilla-Pérez E, Valderas JM, Fàbregas-Escurriola M, Brugulat-Guiteras P, et al. Comparison of the information provided by electronic health records data and a population health survey to estimate prevalence of selected health conditions and multimorbidity. BMC Public Health 2013; 13:251. doi: 10.1186/1471-2458-13-251 PMID: 23517342

28. Fortin M, Hudon C, Haggerty J, Akker MV, Almirall J. Prevalence estimates of multimorbidity: a comparative study of two sources. BMC Health Serv Res 2010; 10:111. doi: 10.1186/1472-6963-10-111 PMID: 20459621

29. Raina P, Torrance-Rynard V, Wong M, Woodward C. Agreement between self-reported and routinely collected health-care utilization data among seniors. Health Serv Res 2002; 37:751–74. PMID: 12132604

30. Aldenderfer MS, Blashfield RK. Cluster Analysis: Quantitative Applications in the Social Sciences. Beverly Hills, CA: Sage Publications; 1984.

31. Hemingway H, Croft P, Perel P, Hayden JA, Abrams K, Timmis A, et al. Prognosis research strategy (PROGRESS) 1: a framework for researching clinical outcomes. BMJ 2013; 346:e5595. doi: 10.1136/bmj.e5595 PMID: 23386360

32. Menche J, Sharma A, Kitsak M, Ghiaissian SD, Vidal M, Loscalzo J, et al. Disease networks. Uncovering disease-disease relationships through the incomplete interactome. Science 2015; 347 (6224):1257601. doi: 10.1126/science.1257601 PMID: 25700523