Personalized Nutritional Guidance System to Prevent Malnutrition in Pluripathological Older Patients

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Abstract: Malnutrition is a frequent problem in the elderly population, who usually is affected by one or more pathologies. The health status of these patients can get worsened if malnutrition is left untreated. Nutritional guidelines have been developed to fulfil the nutritional needs derived from certain pathologies, but still are not easy to use. Digital tools can help implement and use these guidelines in real clinical scenarios. Current solutions are designed around a single pathology or specific scenario, but the pluripathologic scenario presents a challenge when it comes to provide nutritional support. In this paper, we present an adaptative tool that provides personalized nutritional recommendations for pluripathological patients in an efficient way, and can be extended to include other pathologies.

1 INTRODUCTION

Nutrition is often focused on healthy habits to prevent obesity, diabetes and other diseases. However, advanced age brings with it a series of physiological (e.g., swallowing problems or inability to prepare the meals) and psychological (e.g., social isolation) changes that predispose people to inappropriate eating habits and/or imbalances between nutrient intake and the needs of the individual for an optimal physical status that leads in malnutrition (Agarwal, Miller, Yaxley, & Isenring, 2013). In addition, pathological problems (e.g., several medications) that accompany aging are considered one of the main reasons negatively affecting the motivation to eat and thus being possible causes of malnutrition within elderly population. It is triggered by loss, dependency, loneliness, and chronic illness, and potentially impacts on higher morbidity and mortality. Without intervention, it presents a downwards trajectory leading to poor health and decreased quality of life. That is why it is essential to consider new multidisciplinary approaches and the use of nutritional formulas to solve disease-related malnutrition, as it is a health problem of high prevalence and high costs for public health.

Nutritional guidelines have been developed to cope with the needs related with specific pathologies (NHLBI, 1998; Kushi, et al., 2012; Joint WHO/FAO Expert Consultation on Diet, Nutrition and the Prevention of Chronic Diseases, 2003). However, this type of traditional nutrition evaluations not only require the use of numerous tables and lists to provide sufficient nutritional recommendations for each patient, but are also very time-consuming due to cross-referencing and calculations (Kuo, et al., 2018). In this context, digital tools can help to develop more competitive and personalized nutritional recommender systems.

Different approaches have been recently carried out with the objective of offering this type of decision support systems both to patients (direct end-users) or to health professionals or caregivers. For instance, this recent study (Taweel, et al., 2016) presents the design of a system that enables homecare management in the context of self-feeding and malnutrition prevention through balanced nutritional

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intake. The design employs a service-based system that incorporates several services including monitoring of activities, nutritional reasoning for assessing feeding habits, and diet recommendation for food planning. In another study (Kuo, et al., 2018), a clinical nutritional information system was implemented to help hospital dietitians perform their daily work more effectively in terms of time management and paper work. The system mainly targets in-patients who require cancer-nutrition counselling.

As far as we can find in the state of the art, some studies focus their work in supporting patients that suffer from a specific disease or health problem (Paulsen, Varsi, & Andersen, 2021), while the others use patients' general information (e.g., demographic or socioeconomic data) without considering any clinical data (Leipold, et al., 2018). Nevertheless, the clinical information or health status of an older adult is a variable that is essential to be considered for obtaining a reliable nutritional recommendation. In this sense, approaches that support not only single pathologies but different combinations of comorbidity cases are needed.

In addition, the use of technologies that pursue knowledge sharing and interoperability is more and more important in this kind of DSSs. That is why recent approaches integrate semantic web technologies into their systems (Espín, Hurtado, & Noguera, 2016), allowing the inference of new knowledge that could not be extracted from traditional nutritional databases.

In this paper, the implementation of a solution that offers personalized nutritional recommendations taking into account not only the personal information (e.g., malnutrition risk, gender) but also the comorbidity profile of an elderly patient is presented. This solution provides health professionals and caregivers with a nutritional decision support system that considers not only the different nutritional needs, but also the whole environment of an elderly patient, such as socio-demographic factors (e.g., sex, age...), psychosocial factors (e.g., psychosocial disorders), and morbidity factors (diseases).

2 METHODOLOGY

In this study we present the following approach to develop a personalized nutritional guidance system, which consists in three different modules: (i) nutritional recommendations for each patient profile, (ii) nutritional rule flow to generate the personalized recommendations and (iii) nutritional ontology for standardize the nutritional knowledge across the platform.

2.1 Nutritional Recommendations

Nutritional guidelines were developed along with experienced nutritionists on the domain. These recommendations were generated for a set of possible profiles considering i) the age and sex of the user, ii) the malnutrition risk, iii) the need for texture adapted meals, and iv) the intake level.

The structure of the recommendation provided by our solution is divided as follows:

- Diet: Daily intake of several nutrients such as carbohydrates, fats, cholesterol, proteins, fiber, liquids, or salt; and daily caloric and protein distribution.
- Fortification: Complement meals that help reach the daily caloric and protein intake values. These caloric and protein enrichments are given by means of natural foods. If natural fortification is not possible, it is carried out artificially, through protein and/or caloric modules.
- Food and liquid adaptation: Mainly texture adaptations in order to ease the swallowing process (i.e., solid food grinding). If these adaptations entail low energy and nutritional intake, Enteral Nutrition is recommended. In case the patient's intestinal tract is not functional, Parenteral Nutrition is prescribed.
- Supplementation: Recommendation of specific oral nutritional supplements such as hypercaloric and hyperprotein formulas.
- Enteral nutrition: Recommendations for patients in need of enteral nutrition.
- Follow-up: Re-evaluation of the nutritional status. For instance, the continuation, reduction, or withdrawal of the supplementation can be considered in this area.

Each of these areas is formed by different attributes. For instance, the *Diet* area is divided into different recommendations, each one containing the specific information about a different nutrient (see Figure 1).

```
{
    "type": "Diet",
    "conformance": "EQUAL_TO",
    "value": "2200",
    "valueUnit": "kcal/day",
    "key": "TotalCaloricValue",
    "information": "Daily caloric intake"
},
```

Figure 1: Example of a diet recommendation.

The presented structure is the core of the nutritional recommendations. For each pathology and user profile included in our platform, the first step was to develop a complete set of recommendations for the single pathology case. In the following step, the combination of pathologies was tackled, taking the single pathology case plans as the basis. In these pluripathological cases, the nutrition plans were generated by i) the combination of single pathology nutrition plans (i.e., nutritional needs from pathology 1 and supplement intake from pathology 2, ii) the generation of specific plans for each combination of pathologies, and iii) the re-use of the nutrition plans generated for the monopathological case if no adaptation needs to be done for a specific pluripathological case.

These recommendations are represented in a more visual form to the users in a web application described in Section 3. In Section 2.2 a detailed explanation on how the generated nutritional recommendations were introduced in a rule flow process is presented, for both single and pluripathological cases.

2.2 Nutritional Rule Flow

The business logic of the presented platform consists of a business process combined with a rule engine that evaluates the patients' data and generates the personalized recommendation in return. The logic implemented in this process consists, overall, on a series of nodes that direct the process execution to the set of nutrition recommendations that belong to the pathology or combination of pathologies of the evaluated patient. The specific recommendation is generated based on the input data, as the rule engine evaluates it and returns the nutritional recommendation triggered by the patients' data.

Our work is based on the previous work carried out in (Torres, Artola, & Naiara, 2020) where a platform for the development of domain independent rule based clinical decision support systems (CDSS) is described. From that starting point, jBPM processes were included in the developed rule engine (Drools). The BPMN Eclipse plugin was used to design and implement the flows, and to link them with the generated rules.

Three flows were configured, one for patients with one pathology, and the rest for pluripathological patients suffering from 2 or 3 of the included pathologies. The general structure of the flows is the same, an entry node, a set of decisional gateways and business rule tasks, and the end nodes for each possible pathological pathway (see Figure 2).

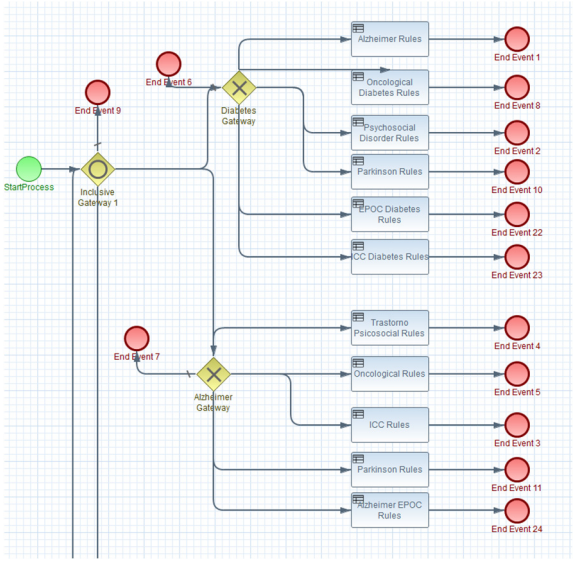

Figure 2: jBPMN process for the combination of 2 pathologies. Example of the combinations with Diabetes and Alzheimer.

The path followed to reach an end node is what we have called pathological pathway, theoretically, for each pathology and its combinations, a pathological pathway would need to be defined along with its defined set of rules, but our solution reduced the final amount of sets of rules needed by making use of the execution of specific rule flow groups in more than one pathway. The cases where the nutritional recommendations coincide were grouped under the same rule group attribute, reducing the total amount of nutrition plans and rules that were needed and avoiding duplicates.

2.3 Ontology

An ontology was developed for the nutrition recommendations formalization process. The variables formalized were differentiated between the variables related with the patient and the ones related with the nutritional recommendation. The ontology was generated using Protégé, and it can be easily updated with new pathologies apart from the ones specified in Section 3.

The ontology was used as the basis from which to formalize the diets generated by the nutritionist into business rules. Due to the vast number of recommendations that were entered into the system, the use of an ontology reduces the risk of human errors in the formalization process.

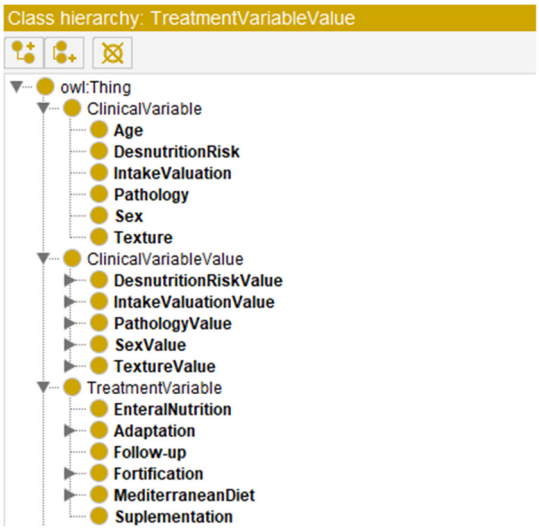

Figure 3: Structure of the ontology used to formalize the nutrition recommendations.

3 USE CASE

The presented solution was developed within the NUTRIGEP project. In this project, a platform for the management of elderly pluripathologic patients at risk of suffering malnutrition was developed. The main goals of the project are i) to determine the prevalence of malnutrition in admitted patients, ii) to analyse the possible relationship between different risk factors and the nutritional status of patients during admission, and iii) to correct each diagnosed malnutritional state through the management and personalization of diets and specific recommendations of food and/or supplements. The solution hereby presented corresponds with the third goal in charge of providing the specific nutritional recommendations that aim to improve the nutritional state of the users.

The pathologies that were included in the NUTRIGEP platform are representative of the ones present among the elderly, chronic patients of the Asunción Klinika (Tolosa, Spain), the hospital involved in the project: diabetes, Alzheimer, Parkinson, Chronic Obstructive Pulmonary Disease (COPD), cardiac failure, cancer and psychosocial disorders. For each of the included pathologies and its combinations, a nutrition plan was developed (see Section 2.1), and modelled into the rule flow process (see Section 2.2). Combinations of pathologies were limited to all possible combinations up to 3 pathologies in order to set the number of possible diets.

Table 1: Summary of Nutrigep use case data.

Item	Description	Amount
Pathologies	Pathologies considered in Nutrigep	7
Possible pathology combinations	Total amount of possible combinations of pathologies	63
Nutrition plans	Amount of generated nutrition plans	21
Nutrition recommendations /plan	Amount of recommendations per nutrition plan	378
Total nutrition recommendations	Total amount of recommendations of the Nutrigep platform	7938

The Nutrigep project is aimed at a specific population, the elderly. Due to this, for the development of the recommendations a minimum age of 65 was considered. The other factors taken into consideration to provide personalized nutrition recommendations were the sex, risk of malnutrition, need for food and liquid adaptation, the pathology(es) of the patient and a valuation of the quantity of food eaten normally by the user (see Table 2 for more detail).

Table 2: Description of patient's data used in the Nutrigep project.

Variable	Description	Values
Age	Age of the patient	>65
Sex	Sex of the patient	Male/Female
Risk of malnutrition	Qualitative assessment of risk of malnutrition	High / medium / low
Pathology	Pathology or combination of pathologies	Alzheimer / Diabetes / COPD / Cardiac failure / Psychosocial disorders / Cancer / Parkinson
Intake valuation	Qualitative estimation of the amount of food consumed by the patient	Appropriate / Moderate / Low
Texture	Texture adaptations needed by the patient	Normal / Soft / Lightly thickened / Little thick / Wet chopped / Blended-moderately thickened / Extremely thick mash/pudding

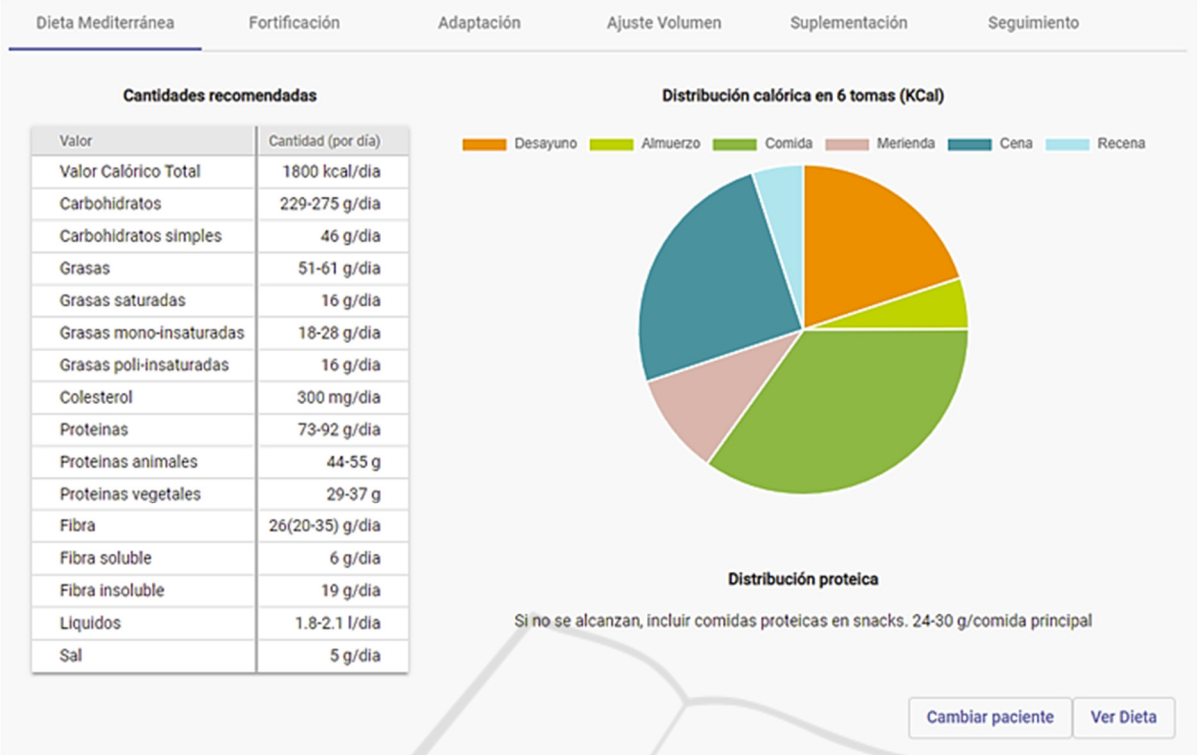

Figure 4: Example of the visualization of a nutritional recommendation in the Nutrigep web application for health professionals.

The personalized nutritional recommendations are visualized in a web application designed for health professionals to aid them in the management of their patients, where the developed recommendation system was integrated. In this platform, the clinicians can select the patient they need to evaluate from the list of all the patients in the database, and receive the personalized nutritional recommendations given by our solution (Figure 4).

The clinical value of this recommender system will be assessed in a clinical validation study that will be carried out in Asuncion Klinika. This validation will enrol twenty older patients suffering from one or more of the pathologies included in the developed system. The health professionals responsible for these patients will access the web platform developed for the Nutrigep project and enter the data of the patients for the generation of personalized nutritional recommendations. In the following three months, the health status of the patients will be monitored and a final evaluation will be done to assess the impact that the nutritional guidance of Nutrigep can have on it.

4 CONCLUSIONS AND FUTURE WORK

This paper presents a solution that can prevent malnutrition in the geriatric environment, contributing to the good nutritional management of the elderly in order to improve their state of health. It provides health professionals and caregivers with a tool that offers personalized nutritional recommendations for elderly pluripathologic patients with risk of suffering from malnutrition. Not only the personalized diet plans are generated for a specific pathology and the patient's malnutrition risk, but also our solution generates specific diet plans for patients that suffer from a combination of the diagnosed pathologies, a typology of patients for which, according to our research, current platforms cannot properly offer nutritional recommendations.

Furthermore, the logic of the system can be easily followed thanks to the visual representation of the business processes that is being used. The system was implemented in a real clinical scenario, where a clinical study is going to be carried out. The clinical study will show the impact of the developed platform

and the developed nutritional guidelines in the patients' health status.

We have identified some future work to improve the current platform. Firstly, in order to widen the scope of potential users, other pathologies should also be included. Furthermore, recommendations should include other information related with the health status, such as physical or wellbeing recommendations, in order to provide not only diet recommendations, but a more holistic set of recommendations that could help improve the overall wellbeing of the patients. Lastly, in order to make the system easy to configure, a web authoring tool is being developed where the user will be able to define the different combinations of pathologies that are supported by the platform. The diet plans will also be generated using the same tool, as a result of this, the scalability of the system will be increased as the addition of new logic and new recommendations will be supported from the same tool, reducing the work needed to update the platform.

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The study complies with the current laws of Spain and Europe.

All authors declare that they have no competing interests.

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