Computers in Biology and Medicine 109 (2019) 1–13

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/compbiomed

A telemonitoring system for nutritional intake in patients with chronic kidney disease receiving peritoneal dialysis therapy

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ARTICLE INFO

Keywords:
Remote monitoring and control
Nutrition
Nutritional intake
mHealth
Chronic kidney disease
Peritoneal dialysis

ABSTRACT

Patients undergoing peritoneal dialysis (PD) therapy may present complications of protein-energy wasting, which may be partially produced by inadequate nutrition management and a protein or energy deficiency in the predialytic phase. Therefore, accurate monitoring of the nutrition status during PD therapy can prevent risk conditions in patients with chronic kidney disease (CKD). In this study, we present the analysis, design, and development of a telemonitoring system for the nutritional intake of patients with CKD receiving PD therapy. The proposed system consists of a mobile web application addressed to the nutrition specialist and a native Android application aimed at patients undergoing PD. Our system optimizes nutrition administration by providing services that allow the nutritionist to monitor the patient, assign a nutrition scheme based on the patient profile, manage intake phases and send recommendations to the patient. Furthermore, the system allows the patient to record the intake data daily, receive updates on diets generated by the nutritionist and communicate with the nutritionist through a consultation module. Finally, we performed a usability assessment of our system based on a laboratory study with two users: a nutritionist and a patient undergoing peritoneal dialysis treatment. Based on the obtained results, our telemonitoring system shows a favorable opinion in terms of usability from the perspectives of the patient and nutritionist.

1. Introduction

Chronic kidney disease (CKD) is a global public health problem that has a causal relationship with diabetes and hypertension, both of which are recurrent diseases in adults [1], although young people and children are not excluded from developing this condition. According to the World Health Organization (WHO), CKD is one of the leading causes of hospitalization and emergency services [2]. Currently, patients with CKD are treated with two different techniques, peritoneal dialysis (PD) and hemodialysis (HD) [3]. Although HD is a technique that emulates the primary kidney functions, PD uses a natural membrane as a filter (the peritoneum) for fluids without leaving the body [4]. However, different factors must be considered when determining what type of dialysis patients with CKD require, such as patient lifestyle, the availability of options within the hospital service and clinical contraindications [5].

The nutrition of the patient with CKD is essential because the patient's kidneys do not correctly perform essential biological functions, such as adequately removing waste products and fluids from the body [6]. Likewise, adequate nutrition is a strategy used to manage patients with kidney diseases who are undergoing PD and HD, and if not properly monitored, it could cause fatal outcomes or lead to eating disorders such as anorexia [7]. Furthermore, the percentage of patients currently on dialysis who experience malnutrition oscillates between 18 and 75% [8], and thus patients receiving PD therapy may present complications of protein-energy wasting, which might be partially produced by poor nutritional management and protein or energy deficiency in the predialytic phase [9]. Therefore, accurate monitoring of the nutritional status during PD therapy is critical to prevent risk conditions in patients with CKD [10].

With the evolution of mobile health (mHealth), diverse applications have emerged to offer an approach to control nutritional intake specifically in patients with CKD [11,12]. Although many of these applications comply with nutritional regulations and improve nutrient control, they lack the services that allow the integration of the self-management of food control with proper monitoring of patients receiving PD by the

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https://doi.org/10.1016/j.compbiomed.2019.04.012
Received 31 October 2018; Received in revised form 17 April 2019; Accepted 17 April 2019

nutritionist. Some approaches only offer guidance to the patient so that they self-manage their nutritional intake [13–17]. Other proposals offer advice regarding diets and food [18–20]. On the other hand, some studies have provided guidance for primary care physicians or health professionals making decisions about treatment and directing a patient with CKD to the nephrologist [21].

Therefore, in this study, we present the analysis, design, and development of a telemonitoring system for the nutritional intake of patients with CKD undergoing PD therapy. The proposed system enhances the nutrition administration by providing services that allow the nutritionist to monitor patients, assign a nutrition scheme based on the patient's profile, administer intake phases and send recommendations to the patient. Furthermore, the system allows the patient to record data corresponding to his/her daily intake, receive updates on diets generated by the nutritionist and communicate with the specialist through a consultation module. The objective of our system is to provide an integrated system between patient and nutritionist that accurately controls nutritional intake. Although the system is designed for patients undergoing PD, patients receiving HD may also benefit from using the system. Our system was validated through a set of unit and integration tests, verifying which modules of each application work correctly in different scenarios. Finally, we performed an assessment of the usability of our system based on a laboratory study with two users: a nutritionist and a patient undergoing peritoneal dialysis treatment. Based on the obtained results, our telemonitoring system shows a favorable opinion in terms of usability from the perspectives of the patient and nutritionist, who report satisfaction with the applicability of the system.

The article is structured as described below. Section 2 presents the methods used for the analysis and design of the models of the proposed system. Section 3 presents the results of the developed system, as well as the unit and integration tests performed to verify the correct performance of the system services. Section 4 presents a discussion of our proposed system and a comparison with state-of-the-art approaches. Finally, Section 5 discusses conclusions and future directions.

2. Methods

The design of our telemonitoring system is based on a requirements survey administered to nutritionists from the Mexican Social Security Institute (Instituto Mexicano del Seguro Social, IMSS), Zone 11, Veracruz, México, from which we modeled the diet assignment process for patients with CKD. Fig. 1 shows the process by which the nutrition specialist generates a diet through a patient evaluation based on the laboratory results and the intake trajectory. On the other hand, the patient must self-manage the assigned diet and attend the scheduled consultations.

Based on the modeled process, we propose a system to automate the management and monitoring of intake control for patients with CKD receiving PD. The system comprises two applications: a) a mobile web

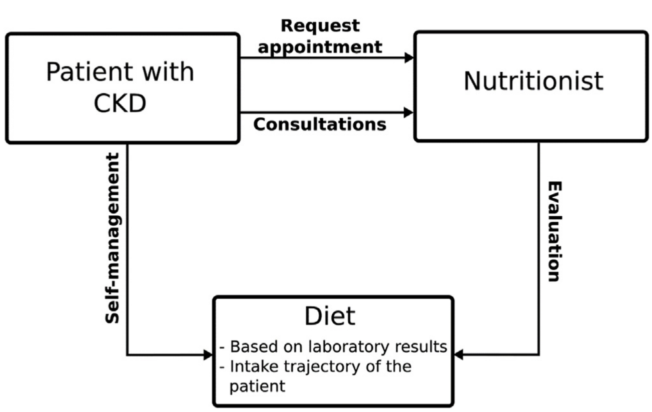

Fig. 1. Procedure used to assign the diet.

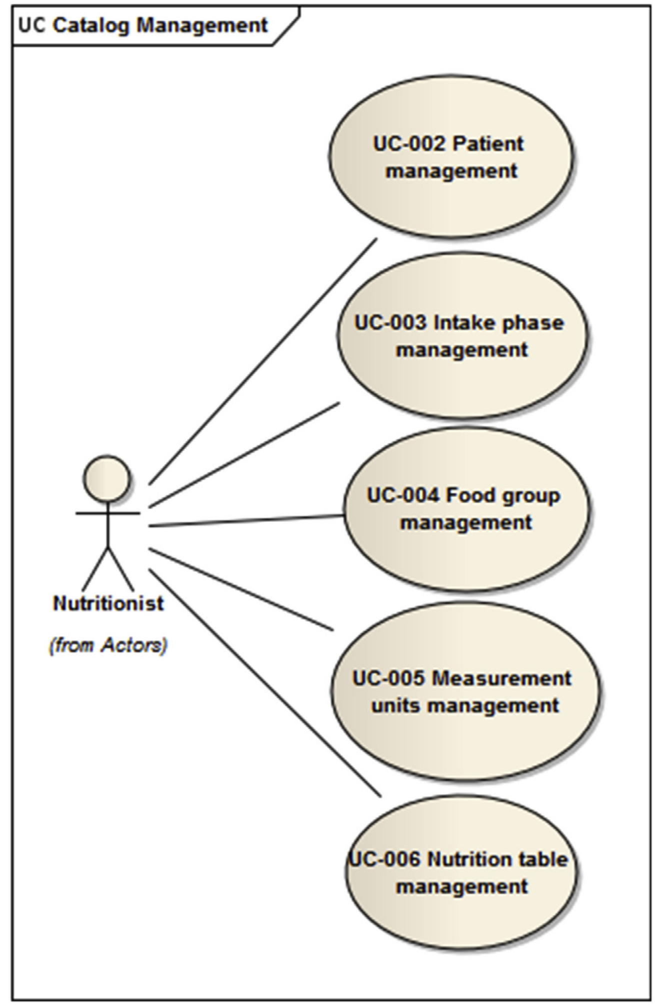

Fig. 2. Use case diagram for catalogue management.

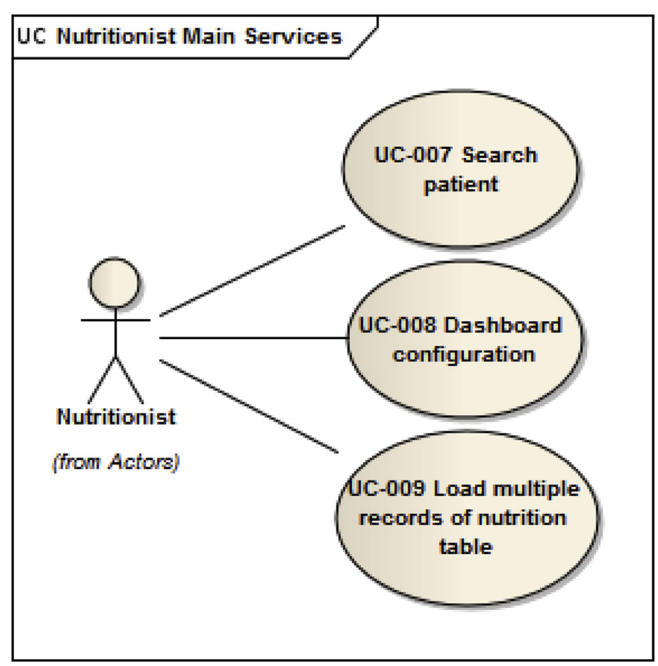

Fig. 3. Use case diagram of the specialist's main services.

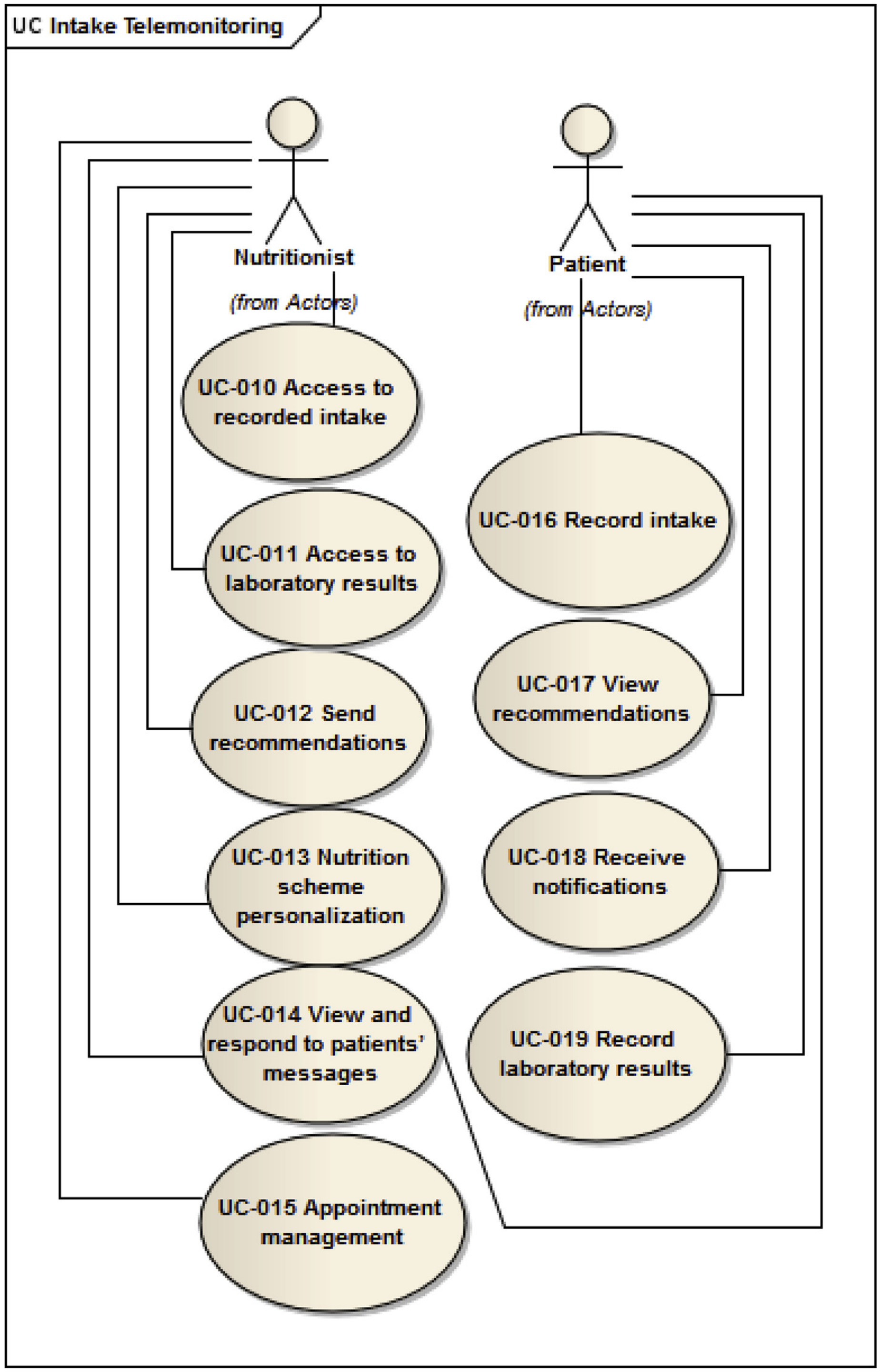

Fig. 4. Use case diagram of intake telemonitoring options.

application oriented to the nutrition specialist, and b) an Android native application aimed at patients. We based the development of the telemonitoring system on the ICONIX methodology [23]. ICONIX includes a set of artifacts that define the system, as described in the next subsections.

2.1. Use case diagrams

Use case (UC) diagrams present the services of the designed system and their interaction with users (actors). Figs. 2–4 show the UC diagrams for the system administration and operation, which are described below.

Catalog Management. This diagram (see Fig. 2) is composed of five UCs, which provide management operations in the system.

UC-002 Patient management. The specialist records new information from the patient or updates the patient's status from active to inactive or vice versa.

UC-003 Intake phase management. It allows the specialist to register, update or eliminate intake phases (breakfast, collation, lunch and dinner).

UC-004 Food group management. The specialist can register, update or delete foods or dietary groups.

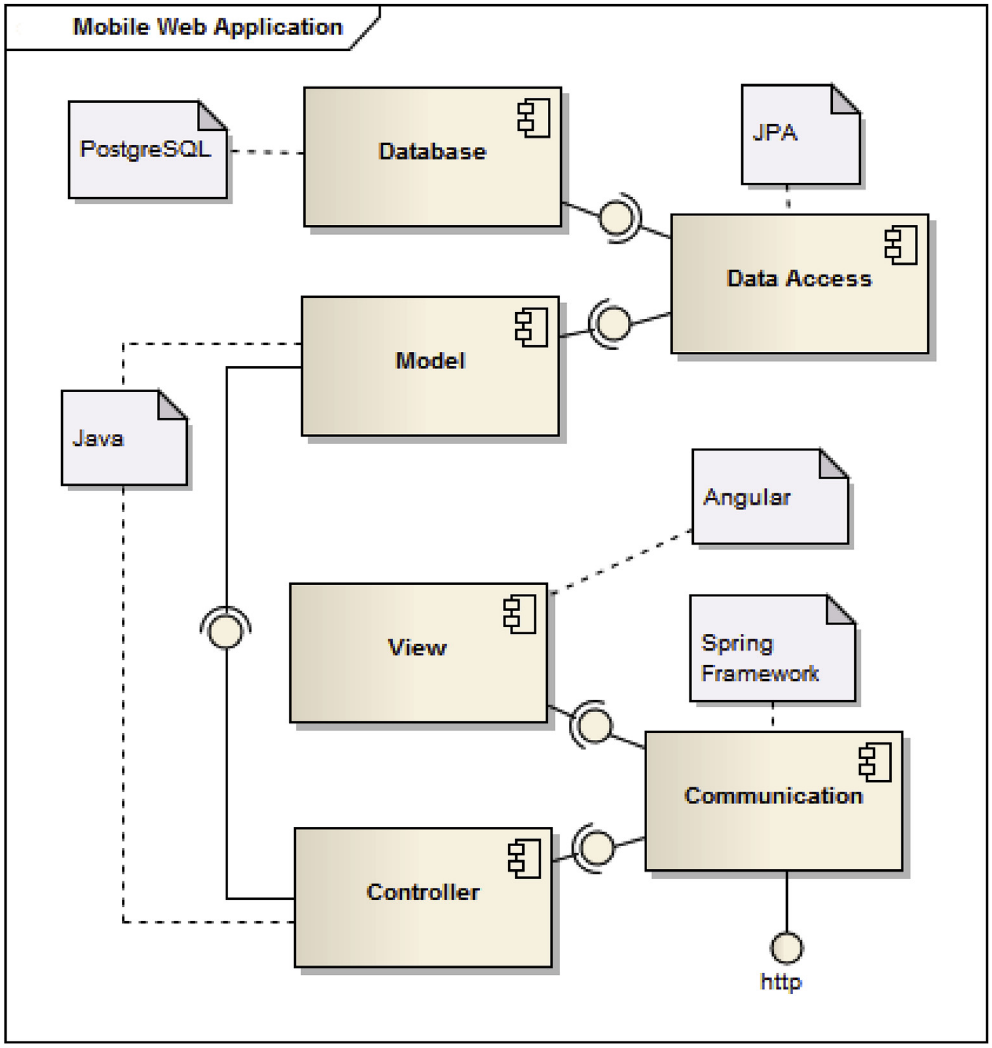

Fig. 5. Component diagram of the mobile web application.

UC-005 Measurement unit management. The specialist can register, update or delete measurement units used to express the equivalent food proportions in the nutrition table.

UC-006 Nutrition table management. The specialist can register, update or delete foods through their group to be assigned to the patient in the respective nutrition scheme.

Nutritionist Main Options. This diagram (see Fig. 3) is composed of three UCs:

UC-007 Search patient. The specialist can search for patients to view related information, manipulate their nutrition scheme or monitor their nutritional intake.

UC-008 Dashboard configuration. The specialist can handle general medical information to share with all active patients.

UC-009 Load multiple records of nutrition table. The specialist can load a nutrition table from an Excel file to reduce the time required to register the information in the nutrition table.

Intake Telemonitoring Options. Ten UCs are identified in this diagram, see Fig. 4:

UC-010 Access to recorded intake. In this case, the specialist can review the nutritional intake recorded by the patient, which is consolidated from a few days, with the possibility of observing details.

UC-011 Access to laboratory results. The specialist reviews the laboratory results registered by the patient, grouped by date.

UC-012 Send recommendations. The specialist reviews the patient's nutritional intake and can send recommendations, defining a priority.

UC-013 Nutrition scheme personalization. The specialist can configure a nutrition scheme for a patient. The goal is that the patient has a pattern of eating classified into intake phases.

UC-014 View and respond to patients' messages. The specialist can view the messages sent by the patient and respond to them. The patient always starts the thread of a conversation.

UC-015 Appointment management. The specialist can register, update and define the status of an appointment assigned to the patient, regardless of whether the appointment was kept. The objective is to maintain a traceable record of patient appointments.

UC-016 Record intake. The patient can configure their nutritional intake and then record it.

UC-017 View recommendations. The patient can visualize recommendations sent by the nutritionist, classified by date.

UC-018 Receive notifications. In this case, the patient receives message notifications and recommendations sent by the specialist.

UC-019 Record laboratory results. In this case, the patient can record the laboratory results by date.

2.2. Component diagram

Component diagrams (Figs. 5 and 6) present each technology employed to develop the system. The web application components (see Fig. 5) communicate through the Spring framework; therefore, Java technology supports all models and controllers. Controllers'

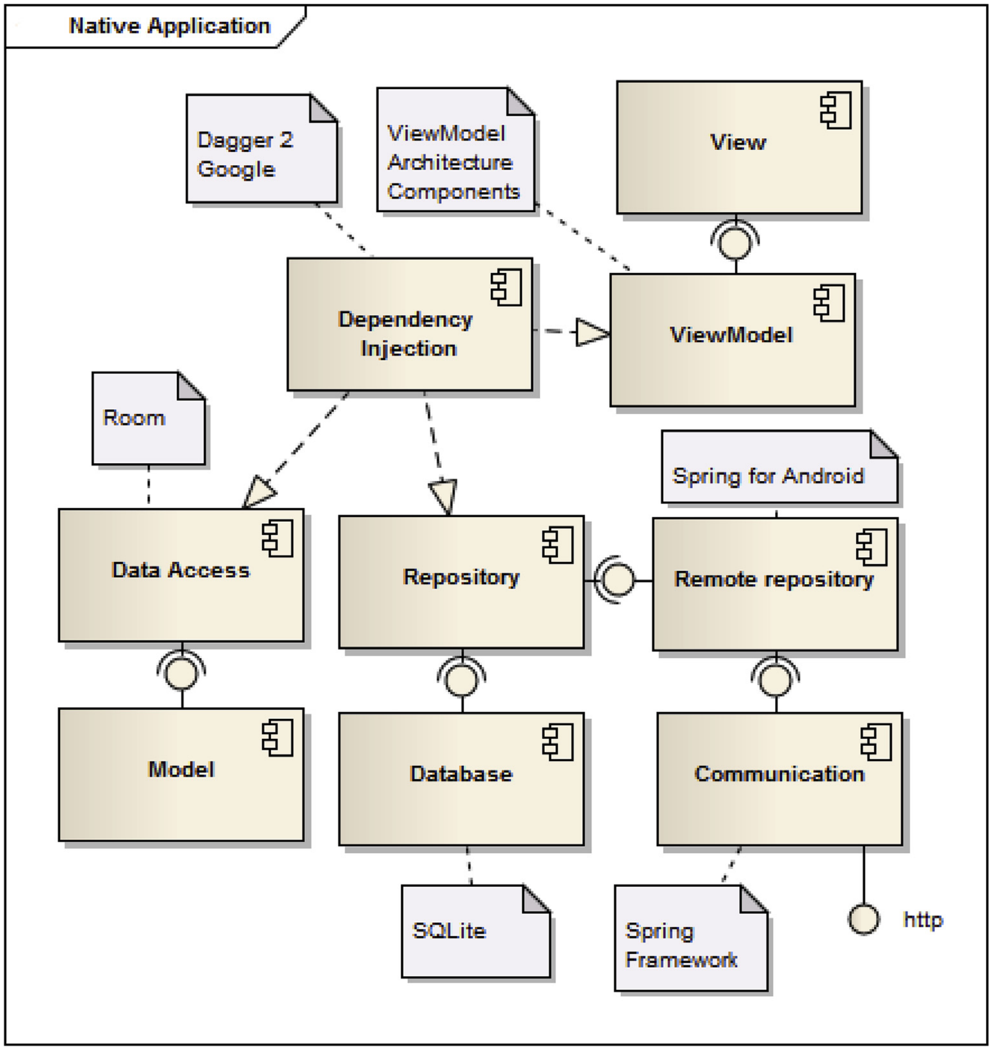

Fig. 6. Component diagram of the native application.

performance requests are transmitted through web services (RESTful) connected to entities by the Data Access; the database is constructed using PostgreSQL, which is accessed through the Java Persistence API (JPA).

Fig. 6 shows the component diagram of the native application developed based on the Model-View-View-Model (MVVM) structure [24]. This architecture focuses on abstracting models and code to simplify programming and more easily achieve code reuse. In our case, the native application queries web-server services, depending on the service consulted, and the information is stored on the cell phone, where the data are stored in SQLite and accessed through the Room Persistence library. Regarding the injection of dependencies, the Dagger framework version 2 that is supported by Google and Square is adopted.

Notably, the Spring framework allows the configuration to operate on a Secure Socket Layer (SSL), ensuring the integrity and privacy of patient data transmitted using insecure communication channels. Therefore, both of the proposed applications protect sensitive patient information.

3. Results

3.1. System development

The proposed system was developed according to the design guidelines established in the previous section. In this regard, the main services integrating the system are described below.

3.1.1. Mobile web application services

Since this part of the system is oriented toward specialists, it is divided into three classes of services:

1) Management services: the specialist can create, read, update or delete information from different system entities (details in Table 1).
2) Configuration services: the specialist can configure different system options, as described in Table 2.
3) Operational services: This module allows the specialist to monitor patients for diet assignations, as well as help them remotely, as detailed in Table 3.

3.2. Android native application services

This part of the system allows patients to register their nutritional intake during the PD therapies and maintain a bidirectional communication with the specialist, see Table 4.

3.3. System tests

We performed two different tests (unit and integration) to verify the correct functioning of each proposed system service. Although unit tests are focused on confirming the correct performance of a single module of

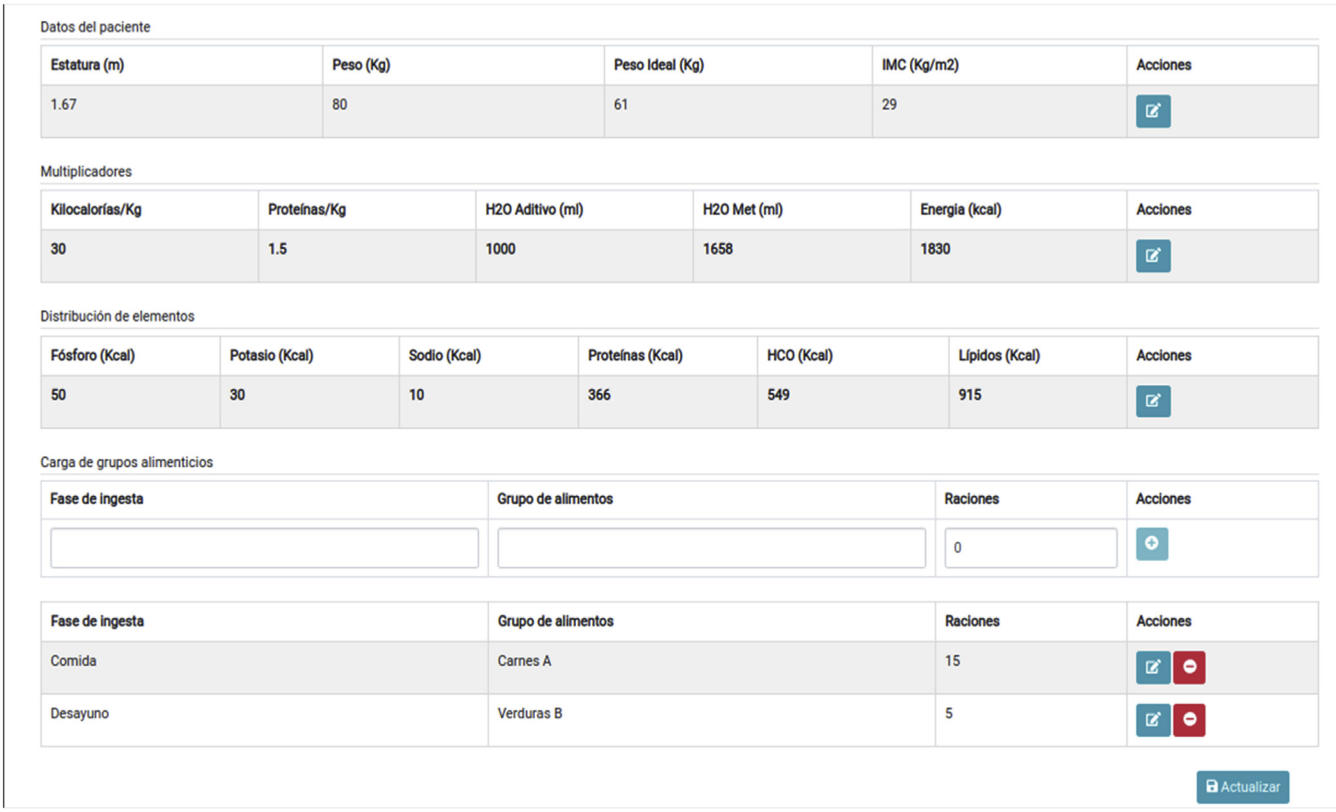

Fig. 7. User interface of the nutrition scheme personalization service.

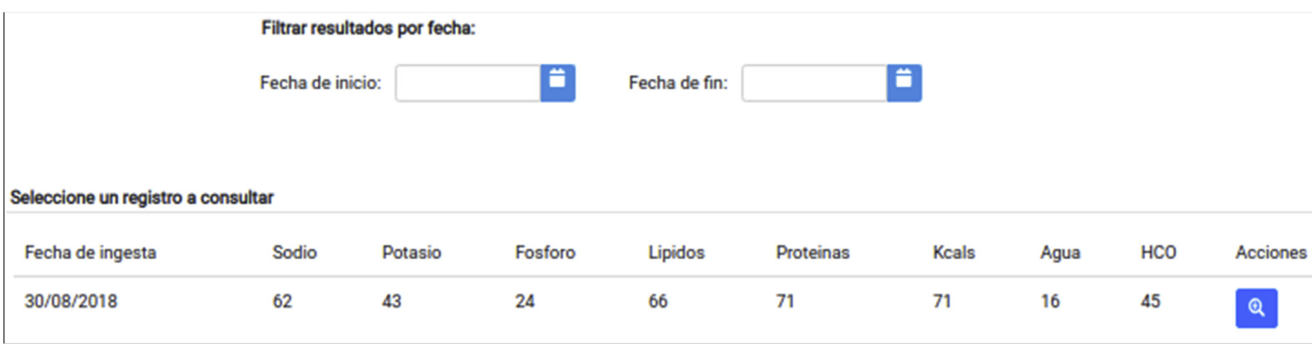

Fig. 8. User interface of the access to recorded intake service.

the system, integration tests are designed to verify the adequate operational flow of the whole system.

The test team performed the unit tests by applying a series of entries into each system service to check the server and client's capability to create, read, update and delete information correctly. All entries used in the unit test were assigned randomly to validate every user interface of both applications. These tests consider a result correct when the module can store and update data to achieve its purpose. The set of unit tests was executed according to the sequence defined in the use case models involved in each service, including actors, precondition, postcondition, exceptions, and business rules, e.g., the unit test for nutritional intake data record service detailed in Table 5 registers the food intake data, including portion and date, for every assigned phase of a patient. Table 6 summarizes the unit test results for both types of system users.

The integration tests verify that both web and native applications operate correctly together. These sets of tests receive a collection of inputs in the services and check the data flow along the modules of both types of users. A test is considered correct if the information manipulation actions are performed satisfactorily during the interaction of both applications, i.e., data manipulation in the patient application should be reflected in the specialist side without affecting the main functions. These tests are subject to a series of requirements that allow the data to flow between both applications that constitute the system. Table 7 provides a detailed description of the integration tests for the nutritional intake service, where the information flow between both applications is supported by the operation sequence in each involved module. Table 8 summarizes the integration tests showing the services and modules involved in the operation sequence of each application.

3.4. Usability assessment

We conducted an assessment of the usability of the system proposed in this study using a laboratory test [26] with two users: a nutritionist and a patient undergoing peritoneal dialysis treatment at the General Hospital of Zone no. 11 of the IMSS. First, the nutritionist and patient were trained in the use of their respective applications that comprise the system. Subsequently, the participants were asked to individually perform different activities associated with the services provided by

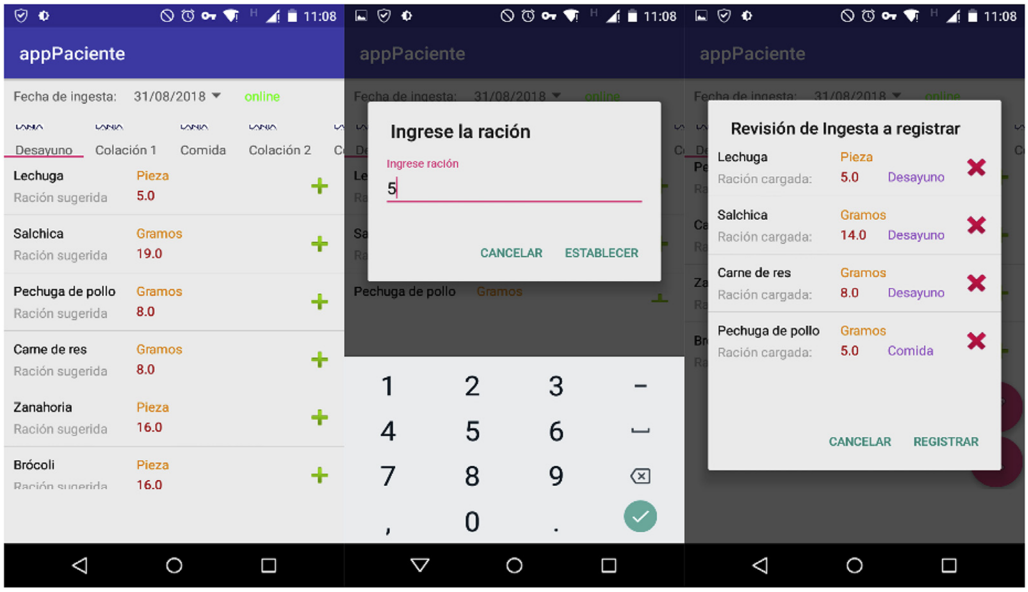

Fig. 9. User interface of the record intake service.

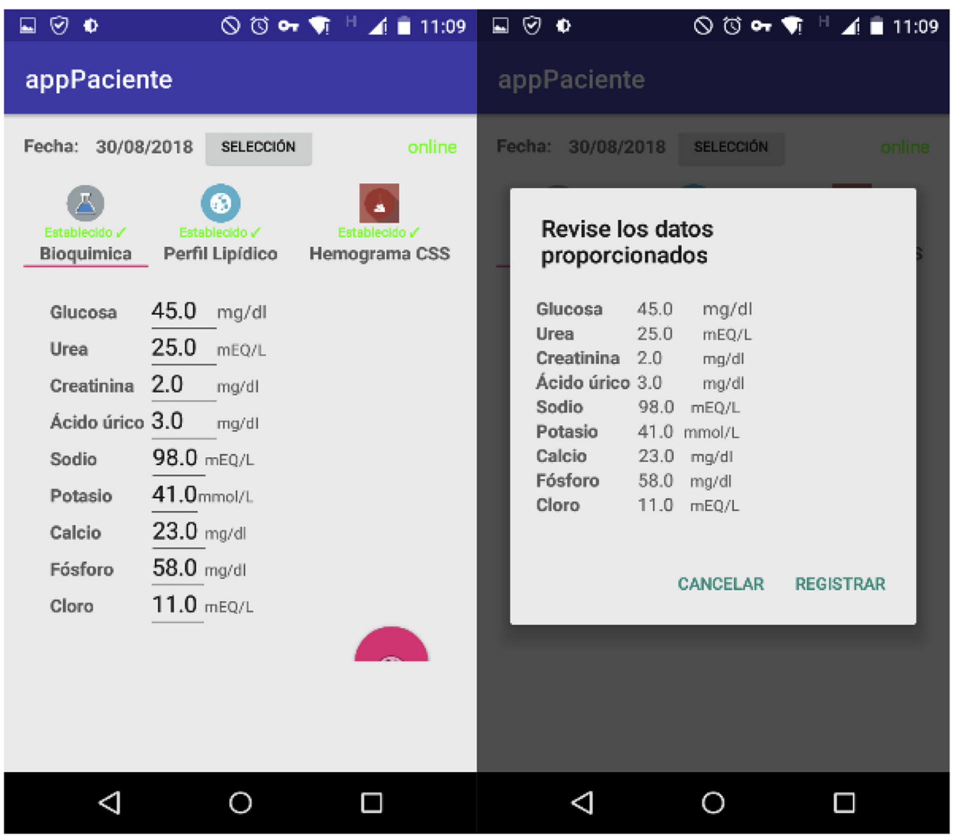

Fig. 10. User interface of the record laboratory results service.

their applications. Finally, following the guidelines of the usability standard ISO/IEC 25010 [27], the users' satisfaction was assessed by applying the questionnaire QUIS 7.0 [28,29]. This questionnaire consists of a set of questions grouped into aspects such as: a) General reaction to the software; b) System user interface (Screens); c) Terminology and system information; d) Learning; e) System capabilities; and f) Technical manuals and online help. In this instrument, the Likert scale selected for each question consists of nine conceptual levels of satisfaction, where 1 point is the lowest rating and 9 points represent the highest rating. The assessment scale is dichotomized by grouping the responses with scores ranging from 1 to 6 points as negative or unfavorable rating responses, and scores ranging from 7 to 9 points as positive or favorable rating responses to simplify the presentation of the results and provide a general picture of the bias associated with the perceptions of the patient and nutritionist. The results obtained based on the responses to the QUIS 7.0 satisfaction questionnaire of the patient-user are presented below in Table 9.

Regarding the general reaction to the software, the patient

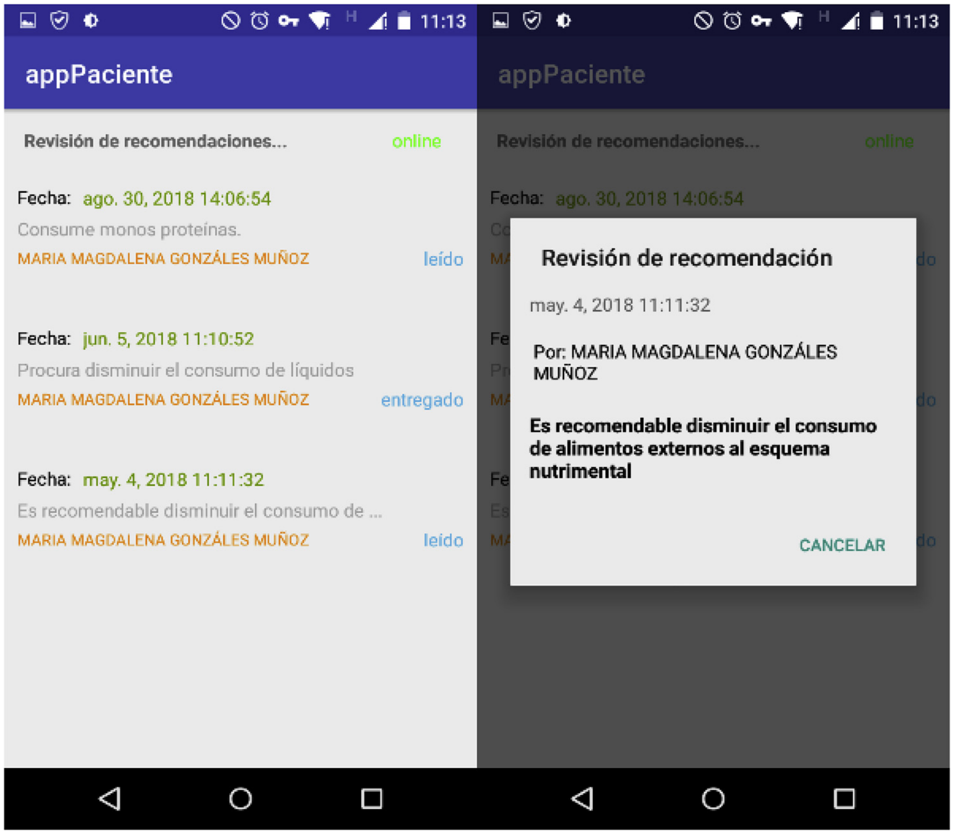

Fig. 11. User interface of the view recommendations service.

Table 1
Management services.

Service	Purpose
Personalized nutrition scheme for the patient	It helps the specialist to define the intake framework for the patient and to set rations per food group in a particular intake phase. See Fig. 7.
Dashboard configuration	Using this service, the specialist loads the nutrition table from multiple records through an Excel file. Additionally, the nutritionist defines a dashboard that can be consulted from the patient application. This service benefits the nutritionist by reducing the time spent loading the nutritional table and sending general information.

Table 2
Configuration services.

Service	Purpose
Information catalog	It provides a maintenance benefit to the system, establishing attributes that affect change, for example, adding an intake phase or adding a new measurement unit.
Patients	It allows the nutritionist to access the patient's data or record a new patient when direct channeling or another related event occurs, which happens without prior registration of the patient.
Nutrition table	It benefits the specialist providing a special repository to store food sorted by its nature, with its respective ration, measurement unit, food group, and nutritional characteristics.

Table 3
Operational services.

Service	Purpose
Access to laboratory results	It helps the specialist assign the nutrition scheme; the laboratory results serve as an important parameter of scrutiny.
View and respond to patients' messages	A service that allows the specialist to read and answer the patients' messages, providing a bilateral specialist-patient communication. The specialist optimizes the time to eliminate the patient's concerns during the consultation to focus on the patient's follow-up.
Access to recorded intake	It lets the specialist access the intake recorded by the patient. This service benefits the nutritionist in a traceable nature since the intake is the core of the system operations. See Fig. 8.
Send recommendations	This service provides a benefit for the follow-up from the specialist, by guiding patients to make better decisions and improve their intake habits
Record/update appointments for patients	A service that benefits the specialist by maintaining the traceability of appointments for patients such that the specialist can record the appointment and then define whether it was kept, as well as to record his/her respective observations.

Table 4
Android native application services.

Service	Purpose
Record intake	It benefits the patient and the doctor, since, it optimizes the time spent by the patient in recording the daily intake and avoids omissions, whereas it allows the doctor to monitor the patient's dietary intake See Fig. 9.
Record laboratory results	It allows patients to register their laboratory results, providing information to the specialist for making decisions about the treatment and evaluation of the nutrition scheme assigned to the patient See Fig. 10.
Send messages to the specialist and view answers	The patient can send messages to the specialist, access answers, and reply to messages.
View recommendations	It provides orientation to patients since the nutritionist can provide suggestions based on the patient's registered intake See Fig. 11.
Appointment reminders	This service decreases patient non-attendance to scheduled appointments by receiving notifications.
Access to dashboard	The patient can access the general information supplied by the specialist from the dashboard.

Table 5
Unit test for the nutritional intake data record service.

Module	Intake	User	Patient	Test	UT-SP -02
Submodule	UC-016				
Purpose	***Client:*** Record the nutritional intake. ***Server:*** Receive requested data after native application sent it.				
Requirements	The user must be authenticated. The user must have a nutrition scheme assigned by the nutritionist. The user must select the nutritional intake option.				
Entry	<u>Intake load</u> Intake phase: Breakfast Food: Carrot Portion: 5 Date: current <u>Intake load</u> Intake phase: Collation 1 Food: Chicken breast Portion: 20 Date: current <u>Intake load</u> Intake phase: Lunch Food: Lettuce Portion: 2 Date: current <u>Intake load</u> Intake phase: Collation 2 Food: 15 Portion: 18 Date: current <u>Intake load</u> Intake phase: Diner Food: Carrot Portion: 1 Date: current				
Action	Native application: sends information to the server.				**Result**: Correct
Action	Server: Collect data and store it in database.				**Result**: Correct

considered that the system was wonderful, satisfying, stimulating, easy to use (easy), suitable (adequate power), and flexible to use, indicating a 100% favorable opinion. Regarding the screens category, the patient considered the characters easy to read, images were clear, the character font was quite readable, the words or highlighted text was useful, the interface design was useful with an adequate volume of information displayed, logical organization, clear interface sequence, predictable, easy to use and clearly showed the activity progress, see Table 9. These results also indicate a 100% favorable perception of this category by the patient. On the other hand, regarding the terminology and system information category, the patient considered the adoption of the terms consistent, appropriate, precise, clear and adequately related to the domain of his/her disease and treatment throughout the system, including messages from help, confirmation, and error. For this category, the patient did not believe that the system always informed the user about the task they were completing, for example, processing and/or sending information to the server. Based on these results, the patient holds a 94% favorable opinion for this category. Concerning the learning category, the patient considered the application easy and quick to learn to use, discovering new functionalities was safe and easy, tasks were performed directly with an adequate number of steps (just right) and in a logical sequence; additionally, the feedback provided by the application to complete a task is clear. Nevertheless, the patient considered that exploring the functionalities of the application through trial and error was not truly supportive (encouraging). Therefore, the favorable opinion percentage for the learning category was 90%. Finally, for the system capabilities category, the patient considered that the application was sufficiently fast in terms of response times and the display of information in each service, appropriate correction of typography errors and the ability to undo operations was easy, simple and adequate. Therefore, the favorable opinion percentage in this last category was 100%.

On the other hand, Table 10 shows the results obtained based on the responses of the nutritionist user to the QUIS 7.0 satisfaction questionnaire. Regarding the general reaction to the software, the nutrition specialist from the IMSS considered the system wonderful, pleasant (satisfying), stimulating, easy to use (easy), with adequate power, and flexible in its use, indicating a 100% favorable opinion. In the screens category, the nutritionist believed the characters were easy to read, images were clear, the character font was highly readable, the words or highlighted text was useful, and the design of the interfaces was useful with an adequate volume of information displayed, logical organization, clear, predictable, and easy interface sequence and clearly shows the activity progress. These results indicated a 100% favorable perception. In the category of terminology and system information, the nutritionist considered a consistent use of the terms that were appropriate, precise, clear and related adequately to the scope of monitoring and treatment of the patient throughout the system including help messages, confirmation, and error. Furthermore, the system always informed her about the task she was completing. Based on these results, the nutritionist held a 100% favorable opinion of this category. Regarding the learning category, the nutritionist considered that the application was easy and quick to learn to use, the discovery of new functionalities was safe and easy, tasks were performed directly with a conventional number of steps (just right) and in a logical sequence. In addition, the feedback provided by the application to complete a task was clear and the nutritionist also considered that an exploration of the functionalities of the application through trial and error was encouraging. The favorable opinion percentage for the learning category was 100%. Finally, in the system capabilities category, the nutritionist believed that the application is sufficiently fast in terms of response times and information deployment in all services, adequate correction of typography errors and the ability to undo operations was easy, simple and appropriate. As a result, the favorable opinion percentage in this last category was 100%.

Table 6
Summary of the unit test.

Role	Service	Module	Result
Nutritionist	Catalogs	Intake phase record	Correct
	Patients	Patient record	Correct
	Nutrition table	Food record	Correct
	Nutrition scheme	Nutrition scheme personalization	Correct
	Laboratory results	Access to laboratory results	Correct
	Messages	Respond to patients' messages	Correct
	nutritional intake	Access to recorded intake	Correct
	Recommendations	Recommendation record	Correct
	Appointments	Appointment record	Correct
	Configuration	General information update	Correct
Patient	nutritional intake	Record intake	Correct
	Laboratory results	Record laboratory results	Correct
	Messages	Send messages to the specialist	Correct
	Recommendations	View recommendations	Correct
	Configuration	Access to dashboard	Correct

Table 7
Integration test for the food intake service.

Test	IT-001	Modules	Mobile web application: Access to recorded intake Native application: Record intake
Purpose	Record and access to nutritional intake information.		
Requirements	The user must be authenticated. **Mobile web application**: The nutritionist must select a patient. The nutritionist must have assigned a nutrition scheme. The nutritionist must select the Access nutritional intake option **Native application**: The user must select the nutritional Intake option.		
Action	**Native application**: The intake load is performed by intake phases, food, and its portions, to later send data to the server.		
Result	**Mobile web application**: The nutritional intake records are received by the server. **Server**: Collect the information and store it in the database. Data are recorded in the patient application and accessed by the nutritionist application.		
Achieved	Yes, in both applications.		

Table 8
Summary of the integration test.

Service	Application	Module	Result
Nutritional intake	Mobile web Native	Access recorded intake Record intake	Correct
Laboratory results	Mobile web Native	Access to laboratory results Record laboratory results	Correct
Messages	Mobile web Native	Respond to patients' messages Send messages to the specialist	Correct
Recommendations	Mobile web Native	Send recommendations View recommendations	Correct
Dashboard of general information	Mobile web Native	Configuration Access to dashboard	Correct
User authentication	Mobile web Native	Login Login	Correct

4. Discussion

Since PD therapy is performed autonomously at home by patients with CKD, the frequency of their visits to the hospital center are lower than in patients receiving other types of treatment, such as HD. For this reason, aspects related to nutrition must be self-managed by the patient, based on the conditions established by the nutritionist responsible for the patient. In this context, different mHealth approaches to manage and control the nutritional intake of patients with CKD have emerged, including studies where a set of applications were evaluated in terms of functionality and information accuracy based on specialized evidence [11]. Likewise, tools for assessing the quality of mHealth-type applications have been proposed [25]. Due to the use of different approaches to develop applications and differences in the group of patients to which they are directed, we are able to determine a set of features of the type of services for mHealth applications should provide to achieve an adequate control of nutritional intake in patients with CKD, which are listed below [11,25].

- Self-management of nutritional intake (SMNI) to allow the registering and monitoring of the daily feeding behaviors of the patient undergoing PD.
- Nutritional recommendation (NR) that offers dietary options for the patient, considering portions and quantities of necessary elements according to the patient's biomedical data.
- Hydric balance (HB) allows the recording of liquid intake and monitoring of fluid loss to calculate the patient's water balance.
- Risk warnings (RW) allow the application to calculate if the nutrient intake quantity is exceeding the allowed ranges in patients' diet and notify the patient about the risk.
- Reminders (Rem) allow the application to handle programmed medication reminders for the patient.
- Appointment control (AC) in the application offers a schedule of appointments with the nutritionist.
- The contact with a specialist (CS) service offers a communication channel with a specialist to answer questions regarding nutritional intake.
- The informative module (IM) in the application should provide the patient information that helps him/her learn more about the role of nutrition in CKD, as well as an option to search for different types of diets and recipes.

Table 11 shows a comparison of applications for nutrition management and follow up in patients with CKD based on the characteristics identified in the descriptions provided by the authors. Likewise, these applications are supported by experts in nephrology and associations dedicated to kidney health, such as the Spanish Society of Nephrology and the National Kidney Foundation.

The information presented in Table 11 shows that although applications focused on the nutritional self-management of patients with CKD exist, not all of them consider monitoring services provided by the nutritionist. Likewise, services such as appointment management and risk alerts are considered by a small number of approaches. Therefore, the system designed in the present study considers these characteristics that are integrated with a set of services oriented to the nutritionist, enabling the nutritionist to perform accurate telemonitoring of their patients. The informative module (IM) was not contemplated in our system, because the diets are determined by the specialist, who provides the patient with different food options in different intake phases. However, the inclusion of this module within the proposed system in the future has not be excluded.

On the other hand, considering the star rating provided by the users in the store of the Android and iOS applications, we were able to analyze features related to the functionality of the applications for intake control in the market. Furthermore, this analysis discards those applications that do not have user evaluation rates in the analysis summarized in Table 12, which shows the overall rating of the application and the average rate obtained from all comments related to issues with the usability of the application. The methodology employed to analyze the user ratings from the application market consisted of a review of every user comment for each application. Next, we separated all comments on usability issues from the remaining opinions. Finally,

Table 9
Results of the QUIS questionnaire for assessing patient user satisfaction using a 9-point Likert scale, with 1 point as the lowest rating and 9 points as the highest rating.

Aspect or category												
1. Overall reactions to the system		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
1.1 Terrible vs. Wonderful	Terrible									*	Wonderful
1.2 Frustrating vs. Satisfying	Frustrating								*		Satisfying
1.3 Dull vs. Stimulating	Dull								*		Stimulating
1.4 Difficult vs. Easy	Difficult									*	Easy
1.5 Inadequate power vs. Adequate power	Inadequate power									*	Adequat power
1.6 Rigid vs. Flexible	Rigid							*			Flexible
2. Screen		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
2.1 Characters on the computer screen	Hard to read									*	Easy to read
2.1.1 Image of characters	Fuzzy									*	Sharp
2.1.2 Character shapes (fonts)	Barely legible									*	Very legible
2.2 Highlighting on the screen	Unhelpful							*			Helpful
2.2.1 Screen layouts were helpful	Never									*	Always
2.2.1.1 Amount of information that is displayed on the screen	Inadequate									*	Adequate
2.2.1.2 Arrangement of information on the screen	Illogical								*		Logical
2.2.2 Sequence of screens	Confusing									*	Clear
2.2.2.1 Next screen in a sequence	Unpredictable								*		Predictable
2.2.2.2 Going back to the previous screen	Impossible								*		Easy
2.2.2.3 Progression of work-related tasks	Confusing								*		Clearly, marked
3. Terminology and system information		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
3.1 Use of terminology throughout system	Inconsistent									*	Consistent
3.1.2 Work-related terminology	Inconsistent									*	Consistent
3.1.3 Computer terminology	Inconsistent							*			Consistent
3.2 Terminology relates well to the work you are doing?	Never								*		Always
3.2.1 Computer terminology is used	Too frequently							*			Appropriately
3.2.2 Terminology on the screen	Ambiguous									*	Precise
3.3 Messages that appear on the screen	Inconsistent									*	Consistent
3.3.1 Position of instructions on the screen	Inconsistent									*	Consistent
3.4 Messages on the screen that prompt the user for input	Confusing									*	Clear
3.4.1 Instructions for commands or functions	Confusing									*	Clear
3.4.2 Instructions for correcting errors	Confusing									*	Clear
3.5 Computer informs you about what it is doing	Never						*				Always
3.5.1 Animated cursors keep you informed	Never									*	Always
3.5.2 Performing an operation leads to a predictable result	Never									*	Always
3.6 Error messages	Unhelpful									*	Helpful
3.6.1 Error messages clarify the problem	Never									*	Always
3.6.2 Phrasing of error messages	unpleasant									*	Pleasant
4. Learning		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
4.1 Learning to operate the system	Difficult								*		Easy
4.1.1 Getting started	Difficult									*	Easy
4.1.2 Learning advanced features	Difficult									*	Easy
4.1.3 Time to learn to use the system	Slow									*	Fast
4.2 Exploration of features by trial and error	Discouraging						*				Encouraging
4.2.1 Exploration of features	Risky								*		Safe
4.2.2 Discovering new features	Difficult									*	Easy
4.3 Tasks can be performed in a straight-forward manner	Never									*	Always
4.3.1 Number of steps per task	Too many								*		Just right
4.3.2 Steps to complete a task follow a logical sequence	Never									*	Always
4.3.3 Feedback on the completion of sequence of steps	Unclear									*	Clear
5. System capabilities		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
5.1 System speed	Too slow									*	Fast enough
5.1.1 Response time for most operations	Too slow									*	Fast enough
5.1.2 Rate at which information is displayed	Too slow									*	Fast enough
5.2 Correcting your mistakes	Difficult									*	Easy
5.2.1 Correcting typos	Complex									*	Simple
5.2.2 Ability to undo operations	Inadequate									*	Adequate
5.3 Designed for all levels of users	Never								*		Always
5.3.1 You can accomplish tasks even if you only know a few commands	With difficulty								*		Easily

we separately averaged the star rating of the set of usability comments (positive and negative) of applications. Therefore, we obtained two measures, 1) the star rating for the general users' opinions, and 2) the average usability rate.

According to the star rating scale, five stars is the highest score achieved, whereas one and two stars denote an unfavorable rating of the product. Four of the seven applications analyzed were not considered competent for the control of intake according to the users. Concerning usability, five of the seven applications were evaluated as having issues with the user interface, such as difficulty in generating records and tracking of nutritional intake. On the other hand, some people on peritoneal dialysis commented that they did not consider the food recommendations appropriate for their condition. Although the comparison may not determine the quality of the software, it identifies the overall acceptance of real users. In contrast, the results obtained from the usability assessment of our system show that the services offered to the patient and nutritionist by the system received high satisfaction scores for aspects such as General reaction to the software; System user interface (Screens); Terminology and system information; Learning; and System capabilities.

Finally, our study has some limitations. The main limitation is that the system has not been tested in a real work environment, i.e., it was

Table 10
Results of the QUIS questionnaire for assessing nutrition specialist user satisfaction using the 9-point Likert scale, with 1 point as the lowest rating and 9 points as the highest rating.

Aspect or category											
1. Overall reactions to the system		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
1.1 Terrible vs. Wonderful	Terrible									*	Wonderful
1.2 Frustrating vs. Satisfying	Frustrating									*	Satisfying
1.3 Dull vs. Stimulating	Dull									*	Stimulating
1.4 Difficult vs. Easy	Difficult									*	Easy
1.5 Inadequate power vs. Adequate power	Inadequate power									*	Adequate power
1.6 Rigid vs. Flexible	Rigid									*	Flexible
2. Screen		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
2.1 Characters on the computer screen	Hard to read									*	Easy to read
2.1.1 Image of characters	Fuzzy									*	Sharp
2.1.2 Character shapes (fonts)	Barely legible									*	Very legible
2.2 Highlighting on the screen	Unhelpful									*	Helpful
2.2.1 Screen layouts were helpful	Never									*	Always
2.2.1.1 Amount of information that is displayed on the screen	Inadequate									*	Adequate
2.2.1.2 Arrangement of information on the screen	Illogical									*	Logical
2.2.2 Sequence of screens	Confusing									*	Clear
2.2.2.1 Next, screen in a sequence	Unpredictable									*	Predictable
2.2.2.2 Going back to the previous screen	Impossible									*	Easy
2.2.2.3 Progression of work-related tasks	Confusing									*	Clearly, marked
3. Terminology and system information		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
3.1 Use of terminology throughout the system	Inconsistent									*	Consistent
3.1.2 Work-related terminology	Inconsistent									*	Consistent
3.1.3 Computer terminology	Inconsistent									*	Consistent
3.2 Terminology relates well to the work you are doing?	Never									*	Always
3.2.1 Computer terminology is used	Too frequently									*	Appropriately
3.2.2 Terminology on the screen	Ambiguous									*	Precise
3.3 Messages that appear on the screen	Inconsistent									*	Consistent
3.3.1 Position of instructions on the screen	Inconsistent									*	Consistent
3.4 Messages on the screen that prompt the user for input	Confusing									*	Clear
3.4.1 Instructions for commands or functions	Confusing									*	Clear
3.4.2 Instructions for correcting errors	Confusing									*	Clear
3.5 Computer informs you about what it is doing	Never								*		Always
3.5.1 Animated cursors keep you informed	Never									*	Always
3.5.2 Performing an operation leads to a predictable result	Never									*	Always
3.6 Error messages	Unhelpful									*	Helpful
3.6.1 Error messages clarify the problem	Never									*	Always
3.6.2 Phrasing of error messages	unpleasant									*	Pleasant
4. Learning		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
4.1 Learning to operate the system	Difficult									*	Easy
4.1.1 Getting started	Difficult									*	Easy
4.1.2 Learning advanced features	Difficult								*		Easy
4.1.3 Time to learn to use the system	Slow								*		Fast
4.2 Exploration of features by trial and error	Discouraging								*		Encouraging
4.2.1 Exploration of features	Risky									*	Safe
4.2.2 Discovering new features	Difficult								*		Easy
4.3 Tasks can be performed in a straight-forward manner	Never								*		Always
4.3.1 Number of steps per task	Too many									*	Just right
4.3.2 Steps to complete a task follow a logical sequence	Never									*	Always
4.3.3 Feedback on the completion of sequence of steps	Unclear									*	Clear
5. System Capabilities		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
5.1 System speed	Too slow									*	Fast enough
5.1.1 Response time for most operations	Too slow									*	Fast enough
5.1.2 Rate at which information is displayed	Too slow									*	Fast enough
5.2 Correcting your mistakes	Difficult									*	Easy
5.2.1 Correcting typos	Complex									*	Simple
5.2.2 Ability to undo operations	Inadequate									*	Adequate
5.3 Designed for all levels of users	Never									*	Always
5.3.1 You can accomplish tasks even if you only know a few commands	With difficulty									*	Easily

limited to laboratory studies. However, a future goal is to test the system in a real environment with patients and nutritionists of Clinic 11 of the IMSS to obtain real feedback in terms of the usability of the system. Likewise, aspects of the security of the private data of patients using in our system is important to consider, although the technology proposed in our system is capable of flexibly supporting security protocols, i.e., the implementation of the services presented in this study should not be altered.

5. Conclusions

This study presents the analysis, design, and development of a telemonitoring system for the nutritional intake of patients with chronic kidney disease receiving peritoneal dialysis (PD) therapy. The proposed system is composed of a mobile web application that is addressed to the nutrition specialist and a native Android application aimed at patients undergoing PD. The main contribution of this study was the optimization of the nutrition administration by providing bidirectional services between the actors involved that allows the nutrition specialist to monitor patients, assign a nutrition scheme based on the patient's

Table 11
Comparison of mobile applications.

APPLICATIONS	*SMNI*	*NR*	*HB*	*RW*	*Rem*	*AC*	*CS*	*IM*
Nefrodiet [13]	✓	✓	✓	✓				✓
BCX Diálisis 24 h [14]	✓	✓	✓		✓			✓
Pukono [15]	✓	✓						✓
RenalTracker [16]	✓	✓	✓				✓	✓
MyFoodCoach [18]		✓					✓	✓
Phosphorus Foods Diet Guide [19]		✓						✓
Renal Disease Inf & Diet Tips [20]								✓
SodiumOne [21]		✓	✓					
H2Overload [22]			✓	✓		✓		
Proposed Approach	✓	✓	✓	✓	✓	✓	✓	

Table 12
Acceptance ratings of applications from the application market. NR means "not rated" and NUC means "no usability comment".

APPLICATIONS	*Star Rate*	*Average Usability Rate*
Nefrodiet [13]	3.7	2.45
BCX Diálisis 24 h [14]	NR	NUC
Pukono [15]	4.4	2.75
RenalTracker [16]	NR	NUC
MyFoodCoach [18]	2.4	1.0
Phosphorus Foods Diet Guide [19]	4.6	NUC
Renal Disease Inf & Diet Tips [20]	4.0	NUC
SodiumOne [21]	2.0	1.65
H2Overload [22]	2.5	2.5

profile, manage intake phases and send recommendations to the patient. Moreover, the system allows the patient to record the intake data daily, receive updates on diets generated by the nutritionist and communicate with the nutritionist through a consultation module. The use of the development methodology adopted in this work (ICONIX) allowed us to conduct an adequate analysis, design, and development of the system. Our system was validated through a set of unit and integration tests, verifying that modules of each application function correctly in different scenarios. Additionally, we performed a usability assessment of our system based on a laboratory study with two users: a nutritionist and a patient undergoing peritoneal dialysis treatment. Based on the obtained results, a patient and a nutritionist held favorable opinions of the telemonitoring system proposed in this study. Finally, our telemonitoring system considers and satisfies the requirements and suitable parameters that should be monitored regarding the nutritional intake of patients with chronic kidney disease receiving peritoneal dialysis therapy, according to the specialized literature. In the future work, we propose to assess the performance of the system in a field study using a real scenario.

Acknowledgements

This project was supported by the National Council of Science and Technology (CONACYT) of Mexico with project number 1525.

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