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Modeling stroke rehabilitation processes using the Unified Modeling Language (UML)

Simona Ferrante*, Stefano Bonacina, Francesco Pinciroli

Dipartimento di Elettronica Informazione e Bioingegneria, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, Italy

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ABSTRACT

In organising and providing rehabilitation procedures for stroke patients, the usual need for many refinements makes it inappropriate to attempt rigid standardisation, but greater detail is required concerning workflow. The aim of this study was to build a model of the post-stroke rehabilitation process. The model, implemented in the Unified Modeling Language, was grounded on international guidelines and refined following the clinical pathway adopted at local level by a specialized rehabilitation centre. The model describes the organisation of the rehabilitation delivery and it facilitates the monitoring of recovery during the process. Indeed, a system software was developed and tested to support clinicians in the digital administration of clinical scales. The model flexibility assures easy updating after process evolution.

1. Introduction

Rehabilitation is an individually tailored programme of medical practice focused to reverse all or the most of disabling conditions produced by a disease that cannot be reversed by medical care alone [1].

Stroke rehabilitation is the process of helping a post-stroke patient regain the highest possible level of independence and quality of life. A growing body of evidence indicates that effective rehabilitation interventions delivered just after medical stability has been reached [2] can enhance the recovery of functional disabilities [3,4].

Stroke continues to be a major public health concern, with more than 750,000 cases occurring each year in the United States; nearly one-third of these strokes are recurrent [5–7]. About 196,000 strokes occur in Italy every year, of which 80% are first strokes and 20% recurrent [8,9]. Stroke is the leading neurological cause of acquired adult disability, and the third most frequent cause of death in industrialised countries [10]. One year after the acute event, one-third of the patients continue to be totally dependent on their caregivers [8]. Furthermore, as the population ages, the social and economic burden of stroke is expected to increase.

The heterogeneity of stroke aetiology and the initial severity of the lesion, differences in the resulting impairments, the variability of responses to rehabilitation treatments, and individual characteristics such as motivation, social support and learning ability all make the process of post-stroke recovery difficult to predict.

The stroke rehabilitation guidelines are "systematically developed statements, grounded on the current scientific knowledge, to assist practitioner and patient decisions about appropriate healthcare for specific clinical circumstances" [11]. However, although they provide general recommendations, they should be interpreted by healthcare professionals in such a way as to ensure the best strategies at local level. There is therefore a considerable degree of discretion when going from reading the guidelines to treating patients in clinical practice [12,13]. Rehabilitation depends on organisational factors such as equipment, facilities, personnel competences, and the harmonised cooperation of staff in a particular healthcare institution. However, despite clinicians' general mistrust of clinical guidelines, it was shown that the improvement in patient outcomes is greater the more the rehabilitation process adheres to their recommendations [14]. Moreover, it is recognised that it has to be provided by a specialised and multidisciplinary team of health professionals [15–18].

An efficient and effective process must be well organised, characterised by a continuous improvement in outcomes, simple to control, clear in all its details to all of the players involved, and flexible enough in order to allow its frequent and easy updating [19]. The first step towards improving the complex process of post-stroke rehabilitation is to describe it clearly and in detail. One way of doing this is to model it because modelling makes it easier to break it down into its component parts, which can be handled one at a time. These are subsequently recombined in order to create a network of interdependence. Modelling increases the readability of a process and its evolution, and thus facilitates its control.

One widely used tool in process modelling is the Unified Modeling Language (UML), a visual modelling and specification

* Corresponding author. Tel.: +39 02 23999004; fax: +39 02 23999003.
E-mail address: simona.ferrante@polimi.it (S. Ferrante).

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language that is capable of providing multidimensional insights into a system using behavioural, conceptual, and physical abstractions [20]. It has not only become a gold standard in modelling complex processes and software systems, but has also been applied to e-healthcare with various objectives, including optimising hospital processes, [21] planning chemotherapy and organising hospital-based cancer registration processes, [22,23] modelling the organisation of randomised controlled trials, [24] and creating a medical image case-based retrieval system for pathologists [25]. The UML allows the whole application domain to be simply visualised and understood.

The aim of the study was to design the first UML model of the multidisciplinary stroke rehabilitation process. The model was grounded on international guidelines and refined following the clinical pathway adopted at local level by an Italian specialized rehabilitation centre. A process representation through a comprehensive conceptual model was implemented in UML and then a part of the model was translated into a relational database for the digital administration and collection of assessment tests by means of clinical scales.

2. Material and methods

2.1. Organisational framework in rehabilitation medicine

Rehabilitation is used in different contexts such as cardiology, oncology, neurology, orthopaedic. The rehabilitation objectives and the type of therapy are obviously different in the different contexts. An older person who has had a stroke may simply want rehabilitation to be able to dress or bath without the help of a caregiver. A younger person who has had a heart attack may go through cardiac rehabilitation to try to return to work and normal activities. Someone with a lung disease may get pulmonary rehabilitation to be able to breath better and improve their quality of life. Regardless to the medicine specialty chosen, rehabilitation starts soon after the disabling event and includes a series of nested phases called treatments, sessions and cycles that needs to be properly organised. Typically the single interventions are called treatments and are combined in sessions (for instance subsequent sessions) and repeated different times exactly in the same way or sometimes, if the patient condition changes, in a slightly modified way. These sessions, one after the other form the rehabilitation cycle that finishes (in the best cases) with the achievement of the initial objectives. The rehabilitation programme includes a time frame definition for the whole process and a continuous monitoring and control of the patient condition. In some paradigmatic cases, such as the chemotherapy process, the time interval between two successive treatments or sessions is highly dependent on patient condition and can be very variable during the whole cycle. Thus, it is possible to have a lot of rescheduling events that can be a priori hypothesised but not exactly scheduled. For this reason it becomes crucial to monitor continuously the patient condition to promptly update the patient rehabilitation pathway.

The rehabilitation of stroke patients is another hardly predictable process and exceptions to the initial planned pathway could always occur. Even if it is always possible to implement a generally predefined framework, the patient condition influences the speed to cover the whole path. The inter-patient variability during rehabilitation has to be monitored with fast reactions by the whole rehabilitative team.

The organisation of the rehabilitation pathway requires a precise knowledge of all of the actors involved with their roles in the rehabilitation process, of all the activities and sequence of activities (usually named workflows). Therefore, the first step towards an aware organisation of the rehabilitation is modelling the process in order to specify essentially the management and to monitor and improve its quality. A model can be defined as an approximation of a real system tuned to highlight those behavioural or structural elements affecting significantly the pursued purposes. Given the intense interactions between the health professionals involved in the rehabilitation team and the variability of patients recovery, greater detail is required concerning workflow on the post-stroke rehabilitation process.

2.2. Modelling processes using the Unified Modeling Language

The UML is an object-oriented modelling language used to specify, visualise, modify, construct and document even a complex process of software system under development [26–30]. It therefore identifies the components of a process as objects characterised by properties and methods describing their interactions, and the resulting model would be understood by users who are less familiar with the system or have less technical knowledge.

UML *structural diagrams* focus on a system's physical organisation (i.e. its structural components and how they statically interrelate), whereas UML *behavioural diagrams* focus on its behavioural aspects: i.e. how the components dynamically communicate with each other and how the system evolves.

One structural diagram, the class diagram, and three behavioural diagrams: use case diagrams, activity diagrams, and state machine diagrams were used. Class diagrams (the most common diagrams in object-oriented modelling systems) address the static design view of a system by showing classes (i.e. the entities forming its main building blocks) and their relationships [31]. Use case diagrams describe the relationships between the people or external systems (actors) that play a role in one or more interactions with the system, and a sequence of actions defined as use cases. An association exists whenever one of these actors is involved with an interaction described by a use case. Activity diagrams model the internal logic of complex operations and, in many ways, are the object-oriented equivalent of the flow charts and data flow diagrams of structured development. State machine diagrams are dynamic representations of the system that highlight the potential states of the objects and the state transitions triggered by specific events. The software used to design the diagrams was StarUML™[32].

2.3. Gathering requirements

The main challenge when developing a process model is the gathering of requirements. To fully understand the domain of interest the international guidelines have to be identified and analysed in detail. The international guidelines for stroke rehabilitation are timely-updated recommendations grounded on evidence-based material to assist the rehabilitation team in the choice of appropriate care for specific clinical circumstances. The main source of evidence used to define properly the stroke rehabilitation process was the National Guidelines Clearinghouse which is an online public database for evidence-based clinical practice guidelines [33].

Once the guidelines were read and fully understood, the adaptation of the process at local level started. This phase was aimed at the identification of the requirements and resources available at local level in order to adapt the process to the local domain (for instance a specific rehabilitation centre). Thus, the other crucial source used to define the process was the experience of the multidisciplinary rehabilitation team of an advanced Italian stroke-oriented rehabilitation centre. In particular, clinical pathways available at the rehabilitation centre were collected and interviews were made to part of the personnel involved in the process execution. Once the interviews were concluded the high level model was designed in UML. Then, the validation of the model began involving both the analysts (model developers) and the experts of the domain (rehabilitation team) and only when the model was collectively approved the validation was considered finished.

2.4. Development of a relational database for the clinical assessment

The requirement gathering phase ended with the identification of a specific need for the rehabilitation centre: the possibility to support the clinical assessment by a computerised system to facilitate the administration and collection of assessment tests by means of clinical scales.

A system composed by a relational database and a graphical user interface (GUI) was designed and implemented. The GUI was used to collect data for clinical assessment of patients under rehabilitation. Usually, a database lifecycle consists of the following main phases [34]: (1) Requirements collection and specification; (2) Conceptual design of the database; (3) Choice of a DataBase Management System (DBMS); (4) Logical design of the database; (5) Physical design of the database; (6) Database implementation; and (7) Use and maintenance.

For the conceptual database design phase, the Entity-Relationship (E-R) data model is the most widely used [34]. In our work, the static aspects of the process were modelled by a class diagram; then to design a database for clinical assessment the class diagram was translated into an E-R diagram. UML classes were translated into entities in the E-R diagram and analogously, UML relationships among classes were translated into relationships among entities in the E-R diagram managing their multiplicities. Then, following the database lifecycle, the MS Access was selected as relational Database Management System and the database was implemented using the Structured Query Language (SQL). As the database has to store patient's medical data, data structures to maintain confidentiality and protection against unauthorised access were implemented.

The design of the graphical user interface was based on the activities of clinical assessment: from medical doctor accessing to the system, to enquiring of the collected data. Furthermore, as highlighted by the interviews to the rehabilitation team, also the patients have to be allowed to fill in the questionnaire of some assessment clinical scales. In this case the assessment has to be validated by the doctor.

3. Results

3.1. The context of the stroke rehabilitation process

The rehabilitation of post-stroke patients is a proactive, person-centred and goal-oriented process aimed at improving function and/or preventing deterioration of function, and bringing about the highest possible level of patient independence [15]. The complete effective care of stroke includes the early management of acute stroke in the Emergency Department, the planning of post-acute rehabilitation in a specialised centre and finally at home, and following up the patient [12]. The proposed study focused on stroke patients in a post-acute phase (1–6 months after the event) admitted to a rehabilitation centre.

Starting from the National Guidelines Clearinghouse [33], the updated clinical guidelines from Australia [15], the United States of America [2], the United Kingdom [35], Canada[36], and Italy [8] were found and used as evidence-based general recommendations.

Then, to gather the needed requirements and the available resources at local level we collected textual and graphical clinical pathways adopted by the Rehabilitation Centre. In particular, a flow diagram was found describing the main phases of the process. Furthermore, textual material describing the main actors involved in each process phase and their main roles was found.

We carried out surveys to some representative people involved in the process. In particular, 2 medical doctors, 2 physical therapists, 1 language therapist, and 2 nurses were involved in the interviews and data on their role and activities were collected for what concerns the rehabilitation and the clinical pathway used with post-acute stroke patients. Starting from all the material collected, the high level model was designed in UML and the use case and activity diagrams were shown both to the interviewed personnel and to another group of personnel for validation. The validated UML diagrams are presented in Section 3.3.

In order to be able to export the model to other centres and make it a gold standard in post-stroke rehabilitation, it is crucial to define some commonly used terms [37]. They are:

Treatment: This is a single rehabilitation intervention: it may be physical treatment to improve motor control, speech treatment to recover language, or focused on everyday living activities to improve the quality of life.

Session: This includes all of the treatments a patient receives in a day: in-patients usually undergo 2–3 h of rehabilitation, which include an average of 3–6 different treatments.[8]

Rehabilitation cycle: This is the complete rehabilitation process as prescribed: divided into daily sessions, it lasts an average of one month.

Assessment tests: These are all of the tests performed by doctors and therapists to evaluate a patient′s condition: for example, the 6-min walking test is a very common assessment for physiotherapists [38], the token test for speech therapists [39], and the Functional Independence Measure and Barthel Index (general indicators of a patient's functional condition) for physicians [8].

Exception: This is a deviation from an ideal care delivery process that optimally uses available resources to reach a clinical goal [12,40]. Exceptions may be due to various causes, including changes in resource availability, anomalous therapeutic effects, delays, and contentions for resources between two or more distinct activities. As a consequence, the execution of the process may stop or deviate from the main flow.

3.2. Process phases

The rehabilitation of post-acute stroke patients involves the services of a multidisciplinary team, whose required skills depend on the nature of the patient's deficits. The closest medical specialties are physical medicine, rehabilitation and neurology, although doctors specialised in internal medicine, psychiatry and cardiology may also be necessary. The therapists include a physiotherapist, occupational therapist and speech therapist, who are respectively responsible for assisting patients to recover their motor, everyday living, and language functions. The nurses have a crucial role in the process, not only because they are responsible for the hygiene, nutrition and care of the patients but also because, with their 24 h presence create and sustain the rehabilitation environment and provide a social evaluation of the patient recovery during daily life activities.

In order to model the main scenario of the rehabilitation process of sub-acute in-patients attending a rehabilitation centre, the following four phases (Fig. 1) were identified:

Phase 1: Patient enrolment
During this visit, the doctor must prescribe the diagnostic examinations and drug therapy needed by the patient.
Phase 2: Defining the rehabilitation programme.
After carefully evaluating the diagnostic examinations and updated medical record, the doctor has to decide the best rehabilitation

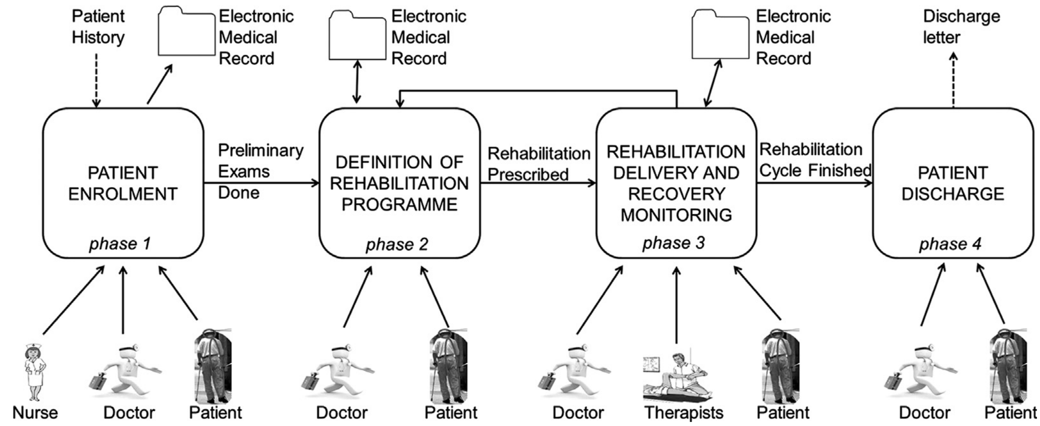

Fig. 1. The phases of the post-stroke rehabilitation process.

cycle for the patient. This visit has to be planned at least one working day after patient admission in order to fasten the beginning of the rehabilitation cycle thus augmenting the process efficiency [8].

Phase 3: Rehabilitation delivery and recovery monitoring.

This is the main phase of the process, and the recovery of the patient is monitored and evaluated by doctors and therapists. Depending on the results of the monitoring, the doctor has to decide whether the rehabilitation plan is still valid or needs to be modified (as shown by the loop in the flowchart in Fig. 1).

Phase 4: Patient discharge.

This is the end of the rehabilitation cycle, and consists of discharging the patient, prescribing any necessary ambulatory rehabilitation, and monitoring the follow-up.

For each of the above phases, the actors, their activities, and the time frame were identified and then UML diagrams were prepared and validated by the rehabilitation team. Moreover, to handle predicted deviations to the normal workflow a specific modelling of exceptions will be provided (see paragraph “Exception management” in Section 3.3).

3.3. UML modelling

3.3.1. UML use case diagrams

A set of use cases were defined to represent all of the considered phases in the process. Two examples of use case diagrams are shown in Fig. 2. Panel (a) shows a use case diagram of the patient enrolment phase during which, after carefully examining the patient’s medical history, the doctor can prescribe drug therapy and the diagnostic examinations needed to investigate the patient’s condition in detail: i.e., it is the initial screening of a patient as soon as he/she is admitted to the rehabilitation centre.

To clarify a use case diagram in detail, specific tables are used to describe all of the actions included in the main use cases. Table 1 shows the description of the basic and alternative scenarios associated with the use case “Initial visit”.

Fig. 2 panel (b) shows the use case diagram of the rehabilitation delivery and the recovery monitoring phase. It consists of two main use cases: the “Rehabilitation cycle” and “Assessment of recovery”. The former involves the therapist, and consists of all of the daily sessions in which the patient undergoes the prescribed treatments. The latter involves the doctor and therapist, and consists of all of the tests required to assess the patient’s weekly state. Tables 2 and 3 show the description of these two use cases.

The patient role with respect to the model of the rehabilitation process needs to be explained more in details. Even if the role of the patient has to be proactive in order to optimise his/her recovery, the model of the process has to focus on the actors that have a direct interaction with the implemented software. Therefore, as explained in Fig. 2, the patient is an actor of the process and he/she has an active interaction with the system only during phase 3 (Fig. 2 panel (b)) because one of the requirements of our system is to allow the digital filling by the patients of some assessment tests (patient-reported questionnaires). Concerning all the other use cases of the process the patient is modelled as a passive entity of the process.

3.3.2. UML activity diagram

An activity diagram was developed to describe the workflow of the main activities, starting from the definition of the rehabilitation programme and ending with patient discharge (Fig. 3). In this diagram, swimlanes (vertical columns) are used to represent the responsibilities for all of the activities (rounded blocks), and the activities are included in the swimlanes of the actor who is responsible for the activity. The activity diagram includes all of the input and output documents of the activities, such as the clinical database (which is continuously updated or examined by the doctor and therapists), the rehabilitation prescription and the discharge letter. Once the rehabilitation has been prescribed, all of the therapists (the physiotherapist, the occupational therapist and the speech therapist) can start the rehabilitation cycle according to their scheduled treatments. Everyday, they examine the clinical database and, if the patient is available, prepare the treatment with all the precautions required for that specific patient. The daily session lasts an average of two hours and includes the sequence of all the prescribed treatments. On some days, assessment tests to monitor the patient’s condition may be necessary. Every week, thus after 5 daily sessions, the doctor examines the patient and, on this occasion, all of the medical assessment tests are performed and the doctor prescribes any necessary diagnostic examinations. At the end of the visit, the doctor can decide to go on with the same rehabilitation cycle or to change it. All these activities are repeated until patient discharge respecting the same time constraints.

3.3.3. UML class diagrams

The class diagram of the whole rehabilitation process details the defined classes, their hierarchy, their relationships and their attributes (Fig. 4). There, the methods are not shown for the sake of clarity. For each relationship the name and the multiplicity are specified to better clarify the model. The diagram includes two main classes: the core concept of the first class is “Activity”, which sets up “generalisation associations” links to specific activities

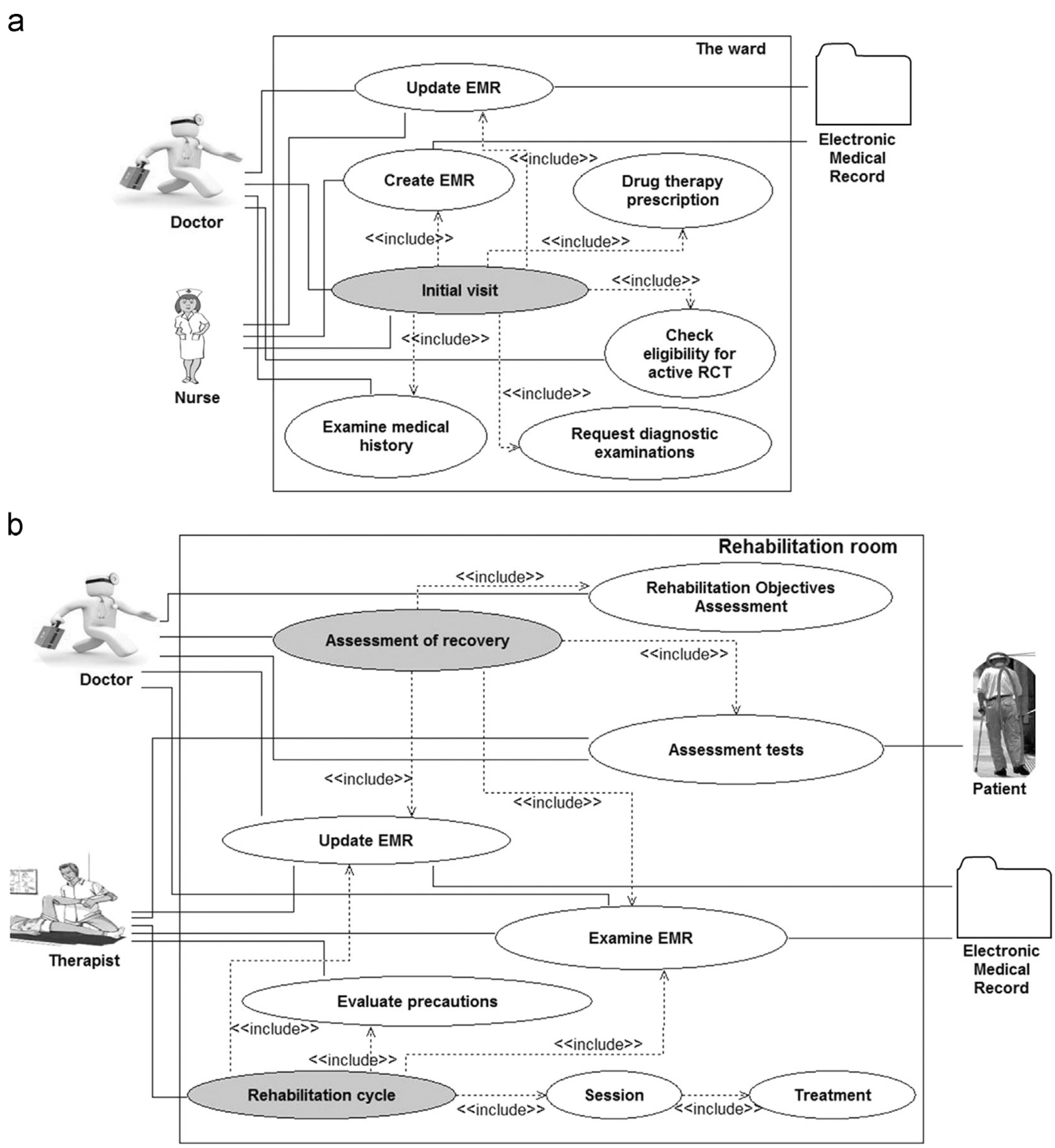

Fig. 2. Use case diagrams. Panel (a)—Phase 1: Patient enrolment. Panel (b)—Phase 3: Rehabilitation delivery and recovery monitoring. Non-standard UML notation was used to represent actors in order to improve consistency with Fig. 1.

Table 1
Use case table for "Initial visit".

Title	Initial visit
Aim	To examine the patient's condition, and prescribe drug therapy and all of the diagnostic examinations or observations needed to clarify his condition
Actors	Doctor, nurse, electronic medical record
Precondition	The patient has just been hospitalised and assigned to a bed in the ward
Post-condition	The patient care process started in the rehabilitation centre
Main scenario	1. The doctor examines the electronic medical record to understand the patient's condition properly 2. The doctor examines the patient's acute phase discharge documents 3. The doctor prescribes diagnostic examinations 4. The doctor prescribes drug therapy 5. The doctor updates the electronic medical record: e.g. therapy, diagnosis sections 6. The nurse updates the electronic medical record: e.g. the diary section
Alternative Scenario	3a Diagnostic examinations are not required, and so the doctor goes directly to the next step (4) 4a Drug therapy is not required and thus the doctor goes directly to the next step (5)

such as the Rehabilitation cycle, the Visit, the Drug therapy and the Observation; the core of the second class is "Actor", which may be a person involved in the rehabilitation process (Patient, Doctor, Therapist, Nurse), or a Device used during an intervention. The "Activity" and "Actor" classes are linked by associations defining the relationships between them. No information about the

Table 2
Use case table for the "Rehabilitation cycle".

Title	Rehabilitation cycle
Aim	Execution of all of the daily sessions including all of the prescribed interventions
Actors	Therapist, electronic medical record
Pre-condition	The rehabilitation cycle was prescribed by the doctor
Post-condition	The rehabilitation cycle is finished
Main scenario	Day-by-day scenario 1. The therapist examines the electronic medical record to verify the interventions that have to be performed and whether any changes have been made to the rehabilitation prescription 2. The therapist verifies patient precautions 3. The patient undergoes all of the interventions of the daily session 4. The therapist updates the electronic medical record with the daily results
Alternative Scenario	3a: An exception occurs that prevents the execution of the intervention; exception handling is activated

Table 3
Use case table for the "Assessment of recovery".

Title	Assessment of recovery
Aim	To assess the patient's condition weekly in order to evaluate whether the rehabilitation objectives have or have not been reached, and decide how to proceed
Actors	Doctor, therapist, electronic medical record
Pre-condition	The patient has executed at least one week of rehabilitation
Post-condition	The rehabilitation cycle is updated, modified or finished
Main scenario	1. The doctor examines the electronic medical record to understand the patient's condition properly 2. The doctor examines the result of the assessment tests performed by the therapist 3. The doctor administers some additional assessment tests (clinical scales) to the patient 4. Instrumental tests are performed if necessary 5. The patient's condition is compared with the previous assessment 6. Objectives not reached: the doctor modifies or confirms the rehabilitation plan 7. The doctor updates the electronic medical record
Alternative	6. Objectives reached: The doctor decides that the rehabilitation is finished and discharges the patient. The doctor writes the discharge letter

rehabilitation centre is included in the class diagram for the sake of simplicity even though the model has to be thought as a module of the Hospital Information System, where several centres can be active in.

3.3.4. *Implementation of a relational database*

Starting from the class diagram of the rehabilitation process as a conceptual design, the architecture of a relational database was defined using only the classes and actors involved in the process of patient assessment by means of clinical scales. The classes used for the conceptual design of the relational database are shown in grey in Fig. 4. Firstly, an Entity-Relationships diagram was obtained from the class diagram, secondly, the logical design (Table 4) and the database schema were derived in an obvious manner following the common steps of relational database implementation [34], then Structured Query Language (SQL) scripts have been executed and the database tables generated.

At logical design level, the term relation indicates what it will become a table in the implementation phase of the relational database by Structured Query Language (SQL) scripts. Between two relations a referential integrity constraint is defined to maintain consistency among relation's tuples (i.e. the sets of values of the attributes along the rows). To describe referential integrity the concept of foreign key is helpful. Foreign key constraints identify and enforce the relationships between relations. In a foreign key reference, a link is created between two relations when the attribute or attributes that hold the primary key value for one relation are referenced by the attribute or attributes in another relation. This attribute or attributes become a foreign key in the second relation. For example, the ElectronicMedicalRecord relation (#1 in Table 4) in the database has a link to the Patient relation (#2 in Table 4) because there is a logical relationship between an Electronic Medical Record and the related patient. The PatientCode attribute in the ElectronicMedicalRecord relation is the foreign key to the Patient relation. Summarizing, there is a referential integrity constraint between the PatientCode attribute of the ElectronicMedicalRecord relation and the ID key attribute of the Patient relation.

For the relations 1, and 5–11 in Table 4 the existing referential integrity constraints are expressed indicating the external key with the ⟨external relation name⟩ followed by the word "Code"; for instance the PatientCode attribute of the ElectronicMedicalRecord with the key attribute ID of the Patient relation.

In addition, SQL queries were defined to support the activities of doctors and therapists during a rehabilitation programme (Fig. 3). Queries were related both to extract data from and insert data into the database.

Fig. 5 is an example of a GUI used by the therapist to fill in the knee injury and osteoarthritis outcome score (KOOS) clinical scale [41]. The doctor has to insert his/her name, the date, the name of the patient, the name of the scale and the timing in which the evaluation is performed. Once these fields are chosen the doctor can start selecting the questions, asking it to the patient and providing the electronic response to the software.

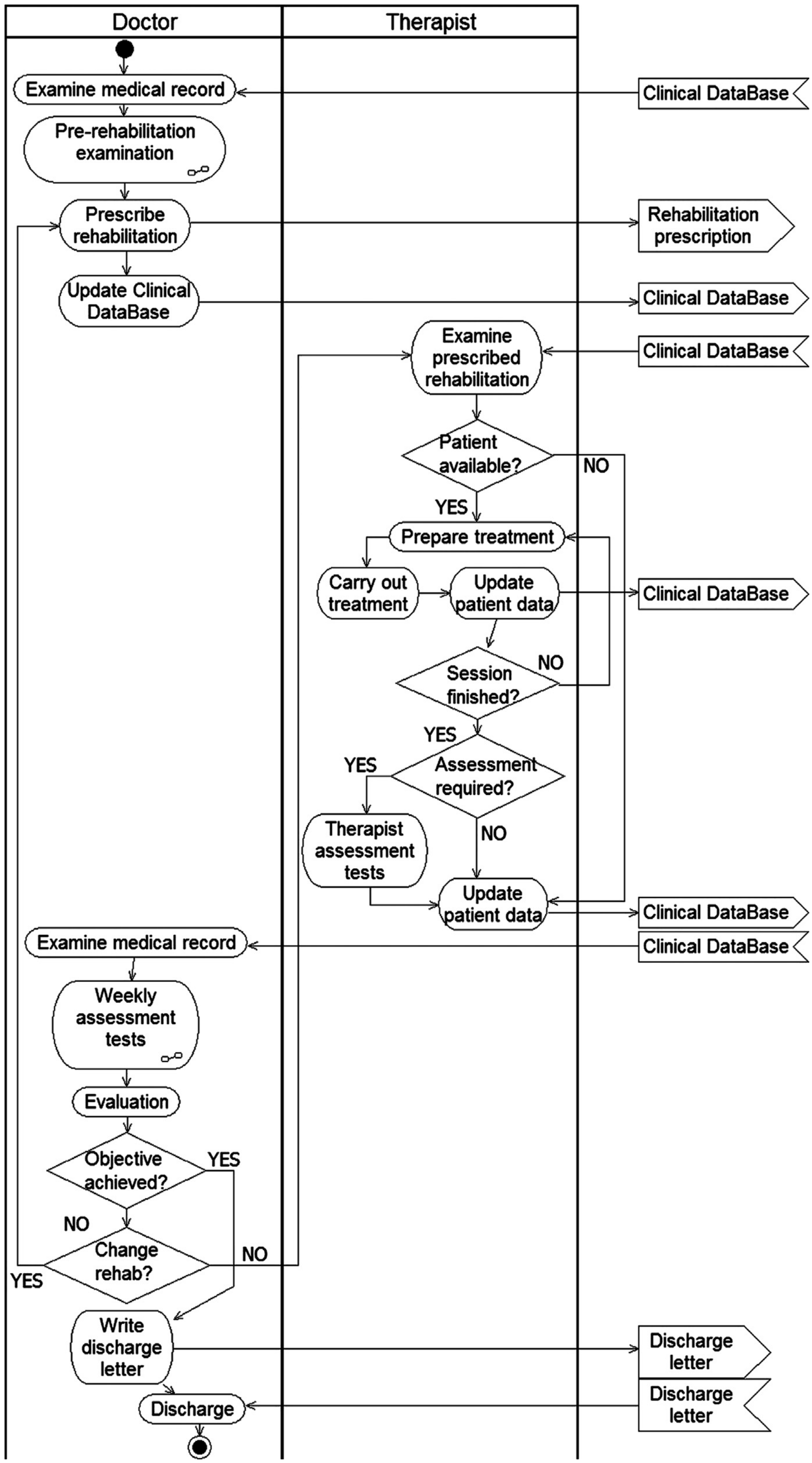

Fig. 3. Activity diagram of the rehabilitation programme.

α test experiments were carried out on the developed software in order to verify its correctness. However, a β testing phase was planned involving the clinicians of the rehabilitation centre who took part in the definition of the rehabilitation process model.

3.3.5. Exception management

The model of the exceptions was derived from the taxonomy presented in [12] and included exceptions related to the patient's trajectory, the execution of activities, the use of resources or the availability of personnel. A state machine diagram was used to

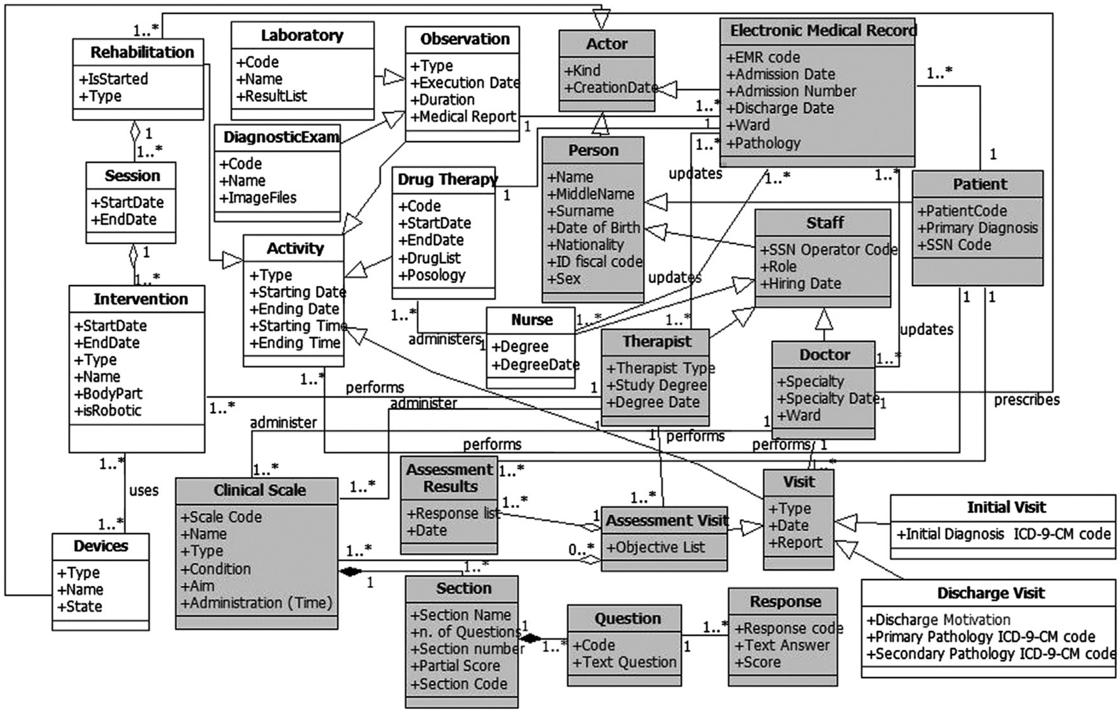

Fig. 4. Class diagram of the rehabilitation process. When the name of the association is not shown, the relationship "is associated to" is intended. The classes used in the relational database are shown in grey.

Table 4
The list of the relations of the database. The percentage symbol (%) after an attribute name means the attribute belongs to the primary key.

#	Relations and their attributes
1	ElectronicMedicalRecord(EMRCode%, AdmissionDate, AdmissionNumber, DischargeDate, Ward, Pathology, CreationDate, PatientCode, TherapistCode, DoctorCode)
2	Patient(ID%, Name, MiddleName, Surname, BirthDate, Sex, Nationality, IDFiscalCode, PrimaryDiagnosis, SSNCode, CreationDate)
3	Therapist(SSNOperatorCode%, Name, MiddleName, Surname, BirthDate, Sex, Nationality, IDFiscalCode, Role, HiringDate, TherapistType, StudyDegree, DegreeDate, CreationDate)
4	Doctor(SSNOperatorCode%, Name, MiddleName, Surname, BirthDate, Sex, Nationality, IDFiscalCode, Role, HiringDate, Specialty, SpecialtyDate, Ward, CreationDate)
5	AssessmentVisit(ID%, Date, ObjectiveList, Report, DoctorCode)
6	AssessmentResults(ID%, ResponseList, Date, PatientCode)
7	ClinicalScale(ScaleCode%, Name, Type, Condition, Aim, AdministrationTime, TherapistCode, DoctorCode)
8	Section(SectionCode%, ClinicalScaleCode%, SectionName, SectionNumber, NumberOfQuestions, PartialScore)
9	Question(Code%, TextQuestion, SectionCode)
10	Response(ResponseCode%, TestAnswer, Score, QuestionCode)
11	IsAssociatedTo(ClinicalScaleCode, AssessmentVisitCode)

clarify when the different exceptions may occur during the daily stroke rehabilitation session (Fig. 6).

The initial state is "Waiting for treatment N". Once all of the actors involved in treatment N are ready, it starts ("Treatment N in execution" state). Otherwise, if an exception (te) occurs, there is a transition to the "Exception handling 1" state. If the exception cannot be handled (eh0), notification of the modified session is sent and the treatment counter (indicated with N in Fig. 6) is increased. During the treatment ("Treatment in execution" state), other exceptions are considered and have to be handled by a transition to "Exception handling 2" state. Once the treatment is completed, the counter is increased; if the number of treatments already performed – or missed – is less than the total number in the session, there is a transition to the "Waiting for treatment N" state, otherwise the session is considered completed.

4. Discussion

A UML model providing an essential description of the stroke rehabilitation process was implemented. The model infrastructure is based on an organisational framework which is common to the rehabilitation medicine regardless the specialty chosen. The model describes what is needed to offer effective multidisciplinary rehabilitation to post-acute stroke patients admitted to an advanced Italian rehabilitation centre and how all of the actors take part in the process.

First, the main phases of the process have to be identified defining properly the actors involved in each of them together with their roles. Then, the workflow and the interactions between the main phases has to be defined highlighting a feedback loop useful to monitor and continuously check and update when necessary the whole rehabilitative programme. To define this loop it is important to have a clear idea of the process context paying particularly attention to specific guidelines. For instance in our model, once defined the relationship between the main phases (Fig. 1), the indications on the proper time frame to cover, monitor and update the process were derived from the available clinical guidelines [2,8,15,35,36] and our active interaction with experts in the field. Once identified these main framework, the workflow of the main phases can be drawn; the core of rehabilitation process has always to be built on a common infrastructure including the nested relationship between treatments, sessions and the overall rehabilitation cycle. This infrastructure

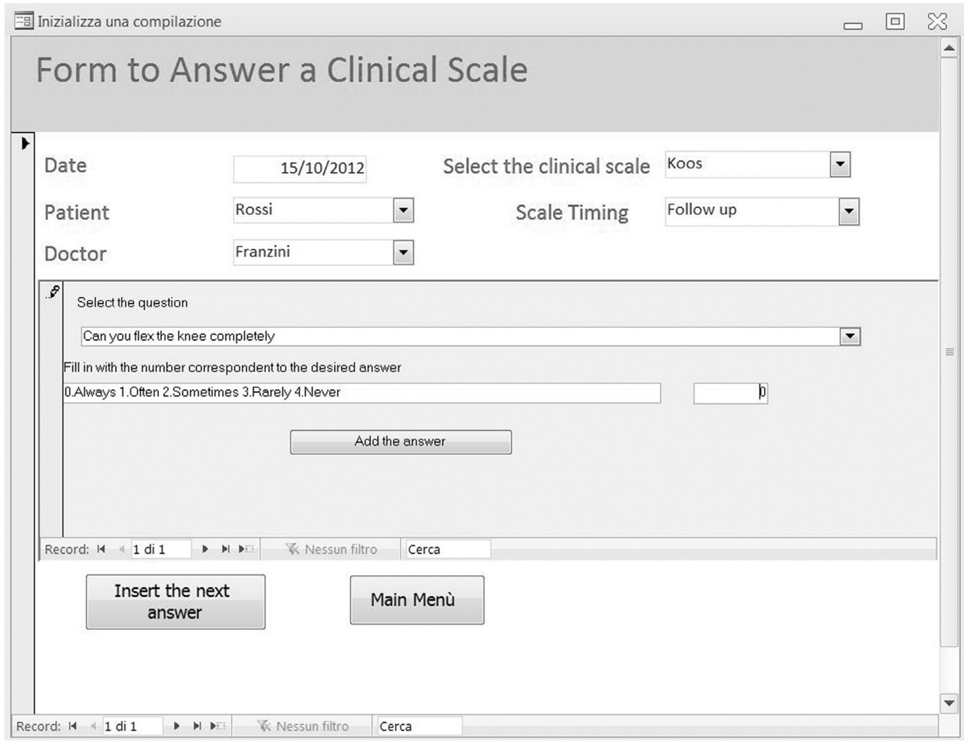

Fig. 5. An example of the GUI to fill in a clinical scale. The doctor has to insert the date, the name of the patient and the doctor, the name of the scale and the timing in which the evaluation is performed. Once these fields are chosen the doctor can start selecting the questions, asking it to the patient and providing the electronic response to the software.

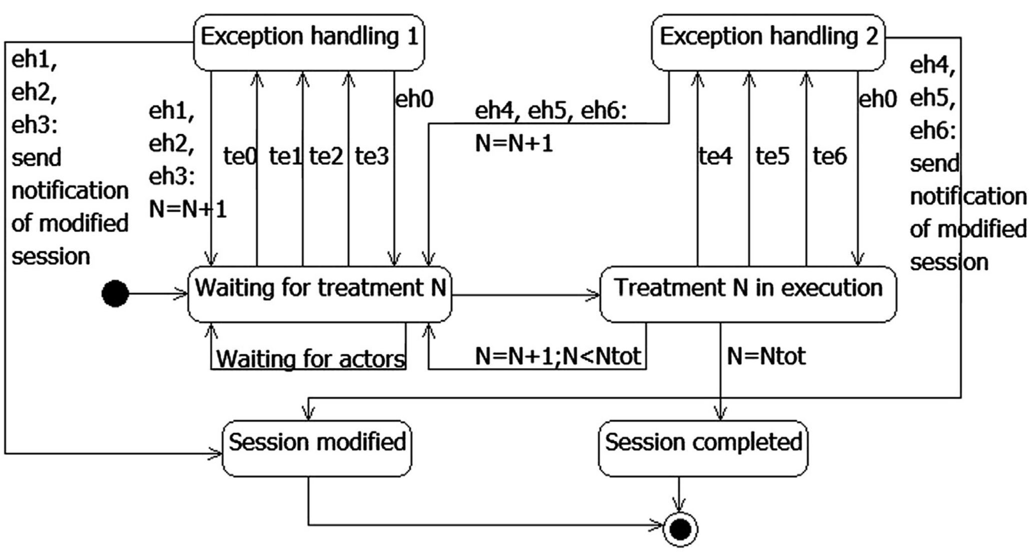

Fig. 6. State machine diagram of the rehabilitation cycle with definitions of the types of exception (te) and exception handling (eh). Codes for types of exception (te): te0 = the patient is not available; te1 = the therapist is not available; te2 = the device is not available; te3 = the device breaks during use; te4 = treatment interrupted because of an unexpected event affecting the patient; te5 = treatment interrupted because of an unexpected event affecting the therapist. Codes for exception handling (eh): eh0 = the treatment can be executed in the scheduled time slot; eh1 = the treatment cannot be executed because the patient is not available; eh2 = the treatment cannot be executed because the therapist is not available; eh3 = the treatment cannot be executed because the device is not available; eh4 = the treatment cannot be finished because of an unexpected event affecting the patient; eh5 = the treatment cannot be finished because of an unexpected event affecting the therapist; eh6 = the treatment cannot be finished because of an unexpected event affecting the device.

common to all the specialties makes our model generalisable in other domains.

Furthermore, modelling by means of a widely used graphical language means that the model can be implemented in different environments. As an example, a software system for the clinical assessment was designed and implemented starting from the proposed modelling. Even though a common database management system (DBMS) was used, the SQL scripts developed for implementing the database can be adapted to be used under other relational DBMSs. In addition, the same Graphical User Interface could be implemented as the hypertext of a web application. The developed computerised system facilitates the data analysis of the clinical scales used in the rehabilitation centre to assess the patient recovery during longitudinal studies. The relational database for data collection could reduce the errors in transferring the hand written filled in questionnaires in computerised form and facilitate the recruitment process of specific categories of patients allowing a fast research for inclusion and exclusion criteria based on assessment scales. The model of the process allows to widen the software system. For instance a log book of patient interventions or of drug therapy administration can be developed and added to the system software in order to support the process with electronic data continuously collected and available for the control and the optimisation of the process itself. Furthermore, the rehabilitation interventions can be detailed in terms of used devices giving a valid support for the clinical engineering services in the device management and maintenance.

The robustness of the UML makes it possible to reduce the number of discretionary choices in the specific process of post-stroke rehabilitation, clarifies responsibilities, and specifies the timing of patient assessments and the choice of the best interventions. In addition, its object-oriented approach makes it easy to update the model as the stroke rehabilitation process evolves (model flexibility). Classes represent entities of the real world, and defining new classes and adding them to the class diagram assures the model's re-use capability; for example, if a class adopts a different behaviour, a specialized class can be defined and added without any effort.

As an image is often a powerful communication tool, the graphic nature of the UML visualises the actors, their roles in the process, the activities to be done, and the sequences to be respected. When used by different research groups, it makes communications easier and faster. During the design of the model, it was possible to hold continuous and beneficial discussions concerning its requirements and specifications with a team of rehabilitation professionals who could adapt it to their own organisational setting and experience. Although this exchange took up a large part of the development time, it was crucial because the final model has to satisfy all of the actors involved in the process, and was considered finished only after a general consensus had been reached.

The developed model included the representation of exception handling because designing prompt responses is crucial for the success of the rehabilitation process [24]. The exceptions were embedded as they can reveal elements requiring further investigation or weaknesses in the management of care. As soon as an exception is detected, an alert is activated and the possible reactions are shown.

The critical aspects of our study concern the overall transferability not of its approach but of its results because of the heterogeneity of rehabilitation teams operating in different places and the clinical lack of perception of the importance of modelling in improving the rehabilitation process. Overall transferability is affected by differences in locally but consolidated clinical pathways, biomedical equipment, interactions with local hospital information systems, and cost/reimbursement procedures. Each of these aspects may require the significant local adaptation of the model, which would involve continuous interactions between the local rehabilitation team and the model analysts (or bioengineering team): the analysts can take advantage of the rehabilitation team to capture the core of the process, and the rehabilitation team can understand the benefits of a modelling approach that makes it easier to observe outcomes and control the process itself.

However, what can be easily transferred is the approach and methodology adopted to model the chosen case study. The proposed method started from the domain analysis, continued with the conceptual modelling of the whole process using a top-down approach and ended only when the full agreement between experts and analysts was reached. The importance of modelling healthcare processes through a formal graphical notation language can be the starting point for the improvement of the process itself. Indeed, a good model allows the detection of the weaknesses and strengths of the process, offering the possibility to propose corrective measures; it allows all the involved actors to fully understand the process and their role in all of its phases (this aspect becomes crucial for new employers); it can be the basis for the facilitation of the process certification (e.g. JCAO, ISO), a mandatory step for the quality improvement of any hospital. Once the conceptual model is finished, it can be exploited to implement a relational database useful in the domain. Furthermore, the usefulness of the modelling method can be also extended beyond the rehabilitation care and into more general healthcare processes and their subsequent technology.

Anyway, model transferability is hindered by the fact that the usefulness of modelling is not always perceived by clinicians because there is no direct or striking improvement in their patients. The uncertainty of the rehabilitation process can be partly solved by means of rationalisation [42] but, until the ongoing regulations for the quality of care demand a modelling approach, clinicians will tend to continue not to take it seriously.

Finally, when a healthcare process is well established and has clear rules governing doctor decision making and the quantification of the results, the usefulness of a UML model may be twofold: it can help in providing a checklist of requirements allowing experts to assure the completeness of the process, and this checklist could also be used by the institutions responsible for checking the quality of healthcare.

5. Conclusions

To the best of our knowledge, ours is the first UML model of the multidisciplinary stroke rehabilitation process. It assumes post-acute stroke patients admitted to a specialised rehabilitation centre, and concentrates on representing the fundamental entities involved in the rehabilitation process. The model is grounded on and coherent with the international guidelines for the stroke rehabilitation process. It is then refined according to the clinical pathway adopted by a specific rehabilitation centre. Even in its present coarseness, the model well describes the organisation of rehabilitation delivery and in particular, it facilitates the monitoring of recovery during post-stroke rehabilitation. Indeed, a software system to support clinicians in the digital administration of clinical scales was developed and tested.

The flexibility and reuse properties of the model of the process will also allow to widen the software system including the log book of patient interventions or of drug therapy administration. Furthermore, the rehabilitation interventions could be detailed in terms of used devices giving a valid support for the device management and maintenance.

6. Summary

The heterogeneity of stroke aetiology and of the initial severity of the lesion, differences in the resulting impairments, the variability of responses to rehabilitation treatments, and individual characteristics such as motivation, social support and learning ability all make the process of post-stroke recovery difficult to predict. In organising and providing rehabilitation procedures for stroke patients, the usual need for many refinements makes it inappropriate to attempt rigid standardisation, but greater detail is required concerning workflow. The aim of this study was to build a model to describe the post-stroke rehabilitation process.

Materials and methods: The model was based on the current international clinical guidelines modified to adjust for the local working organisation of an advanced stroke-oriented rehabilitation centre. The model was implemented using Unified Modeling Language (UML), a visual modelling and specification language that is capable of providing multidimensional insights into a complex process using behavioural, conceptual, and physical abstractions.

Results: The model covered the four major phases of post-acute stroke in-patient rehabilitation. The players of the multidisciplinary process and their main activities in each phase were mainly modeled using the UML's use case and activity diagrams. A class diagram with its associated definitions was designed to capture all of the elements of the process and their static relationships.

The model included also a state machine diagram that deals with possible exceptions and how to handle them. Starting from the developed model, a relational Database for the assessment through clinical scales was implemented using Microsoft Access®. Experiments on the developed DataBase (α test) in order to verify its correctness were performed. A β testing phase is planned involving the clinicians of the rehabilitation centre who took part in the definition of the rehabilitation process model.

Discussion: During the design of the model, it was possible to hold continuous and beneficial discussions concerning its requirements and specifications with a team of rehabilitation professionals who could adapt it to their own organisational setting and experience. The use of the UML language with its simple graphical notation, facilitated the communication between informatics and experts of the domain. This communication phase was crucial because the final model has to satisfy all of the actors involved in the process, and was considered finished only after a general consensus had been reached. The obtained model has a number of promising strengths: it can facilitate rehabilitation management by limiting the degree of discretion in going from written guidelines to the best treatment to adopt; it can facilitate the management of treatment plans and the monitoring of recovery during post-stroke rehabilitation; and its flexibility assures easy updating after process evolution.

Conflict of interest statement

None declared.

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