A PROPOSAL OF A WORKFLOW-BASED CBR FOR INTERVENTIONAL CDSS

Application to Transcatheter Aortic Valve Implantation (TAVI)

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Abstract: A Clinical Decision Support System (CDSS) is an interactive software designed to assist physicians, and other health professionals, with health decision-making tasks through an inference process that associates observations with conclusions supported by objective and expert knowledge on a specific application domain. As complexity of surgical processes arises, there is a demand from the clinicians to extend the capabilities from a pure research database towards a clinically integrated decision support system. The work presented in this paper details a proposal of a CDSS designed to to assess clinicians during interventions by retrieving and reusing past similar cases. Following an operative workflow, the designed software will use a Case-Based Reasoning (CBR) methodology to retrieve similar past cases from a case base to give case-specific advice at any particular point of the process, specially during preoperative and intraoperative stages. The proposal intends to develop a monitoring mechanism capable to recognize relevant data to every stage in the intervention workflow. Thus, measures and observations generated during the intervention will be used to retrieve the most similar cases occurred in previous occasions. The paper proposes an example application of the CBR strategy, where it is adapted to a recent complex minimally invasive intervention which is receiving growing attention lately, the Transcatheter Aortic Valve Implantation (TAVI).

1 INTRODUCTION

In a general term, CDSSs comprise a large spectrum of systems which provide clinicians, staff, patients, and other individuals with knowledge and person-specific information, intelligently filtered and presented at appropriate times, to enhance health and health care (Berner, 2009). CDSSs have been used in clinical practice since 1970, but despite several individual success since then, their impact on routine clinical practice has not been as strong as expected, specially due to the barriers to their implementation, which still remain in place. CDSSs should form an important part of the field of clinical knowledge management technologies through their capacity to support the clinical process and use of knowledge,including knowledge maintenance and continuous learning, from diagnosis and investigation through surgery, treatment and long-term care. Arguments for and against the value of CDSSs have been discussed over the years. Among its potential benefits, as stated in (Coiera, 2003), CDSSs could improve patient safety through reduced medication errors and adverse events. Also, they should improve quality of care by increasing pathways, guidelines and documentation available for patients. Another advantage is that CDSSs may improve efficiency in health care delivery, reducing costs through faster order processing and avoiding test duplication. As drawbacks, clinicians may see CDSSs as a threat to clinical judgment and sometimes too inflexible, with difficulties to depart from ordered, pre-prepared paths. Also, computer-supported decision systems promote over-reliance on software decisions which may limit clinicians' freedom to think at some point. In the same way, bad designed systems can create extra work or extend clinical procedures more than necessary. Finally, maintenance costs, professional support and training needed by the medical staff in order to use the software properly could also be seen as arguments against the utilization of CDSSs.

Decision support can be provided at various stages in the care process, from preventive care through diagnosis and treatment to monitoring and follow-up.

As detailed in (Perreault and Metzger, 1999), computer CDSSs can be designed to support four basic clinical functions. First, giving administrative support, aiding in clinical coding and documentation, authorization of procedures, and referrals. Second, managing clinical complexity, keeping patients on research and chemotherapy protocols, tracking orders, referrals follow-up, and preventive care. The third function deals with cost control, programming CDSSs to monitor medication orders with the objective of avoiding duplicate or unnecessary tests. A fourth stage of application, which represents the focus of this work, involves CDSSs with low level decision support, helping in clinical diagnosis and treatment plan processes, giving case-specific support in highly complex surgery operations or Minimally Invasive Surgerys (MISs), promoting use of best practices and guidelines based on population case management.

The work presented in this paper details a proposal of a CDSS designed to give case-specific assessment to clinicians during complex surgery or minimally invasive interventions. Following a perioperative workflow, the designed software will use a Case-Based Reasoning (CBR) methodology (see Figure 2) to retrieve similar past cases from a case base to give case-specific advice at any particular point of the process, specially during preoperative and intraoperative steps. This support will be presented in the form of 2D/3D images, numerical data or decisions taken based on past similar cases. The intervention will be monitorized and used to recognize similar previous cases at any time during the intervention. The paper proposes an example application of the method, adapted to assist a recent complex minimally invasive surgery which is receiving growing attention lately, the Transcatheter Aortic Valve Implantation (TAVI). This paper is structured as follows. In Section 2 recent applications of CDSS for surgical processes are reviewed. Also, a description of the workflow management during an intervention is detailed. Section 3 describes the proposed workflow-based CBR for assessment in complex surgical procedures. In Section 4, the proposed support system is exemplified with its application to a minimally invasive surgical procedure, TAVI. Finally, conclusions and the future work to be done are included in Section 5.

2 CDSS INTEGRATION WITH CLINICIAN WORKFLOW

Over the past few years, significant research in the area of medical informatics points to the importance of understanding workflow processes to support the development of CDSSs for complex workspaces (Sittig et al., 2008; Patel et al., 2001). Nowadays there is a demand from the clinicians to extend the capabilities from a pure research database towards a clinically integrated decision support system. Recent introduction of new clinical techniques such as Minimally Invasive Surgery (MIS) has led to several technological innovations inside the Operation Room (OR). All these advances, however, create new difficulties, such as inadequate information transparency, limited access, and poor visualization. Therefore, clinicians must rely on advancements in medical imaging technology (Dugas et al., 2002). These limitations in MIS are constantly giving rise to new research and development in the area of decision support systems. Such systems are providing realtime image guidance and task automation support while the clinician is performing the intra-operative tasks (Wood et al., 2007). Empirical studies demonstrate the benefits of including decision support into complex workspace scenarios, which lead to safer working environments and prevention of errors (Durieux et al., 2000). Some examples of successful applications of CDSSs into clinical workflows comprise computer based patient record systems (Patel et al., 2000), knowledge management systems for biomedical engineering (Rinkus et al., 2004) and computer based training systems in pathology (Crowley et al., 2003). Although multiple factors are believed to affect the success or failure of CDSS intervention implementation, a helpful CDSS is dependent on the completeness and accuracy of the evidence base used to support it. Also, from the successful applications mentioned before it can be extracted that integration with workflow is key to success. How to integrate the CDSS with clinician workflow, however, remains a challenge, in part because there are no current standards for clinical workflow (Das and Eichner, 2010).

In order to implement a workflow-based CDSS, timing and involved subprocesses must by identified first. Figure 1 shows a schematic workflow of an exemplified operative process. Although the main information and support will be given during the intraoperative phase, some important aspects belonging to the pre and post-operative phases can also be included. As Figure 1 shows, the whole procedure has been split into *tasks*, a task being any particular step taken e.g. apply anesthesia, initial puncture location or valve final placement. Each task has a different number of distinguishable items or *attributes* associated. These attributes can be described as numerical data, text data or boolean data. During the intervention execution, and according to the information be-

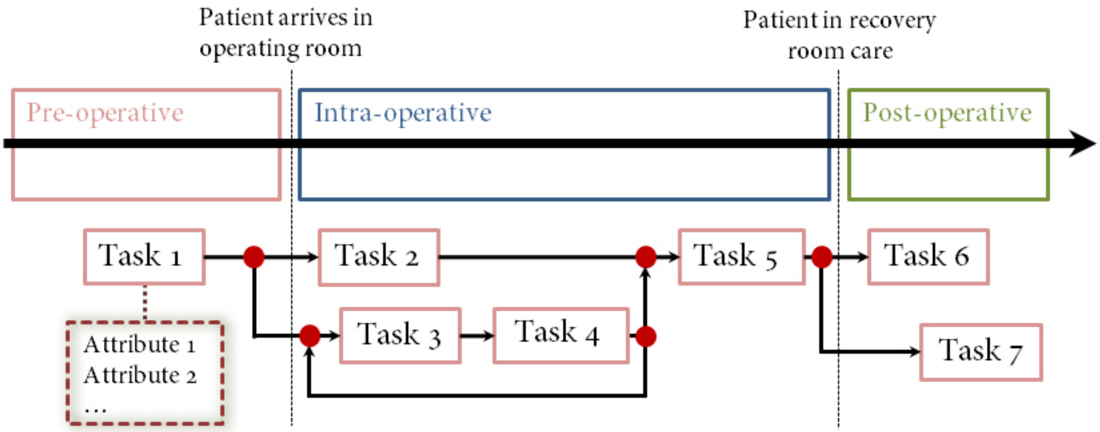

Figure 1: Schematic workflow showing an exemplified operative process.

ing generated, the CDSS has to be capable to identify current task in the workflow and search similar cases in the case base.

The main idea of the proposed computer CDSS is to define a case structure for every intervention based on the operation workflow we want to give support to. With a case base of indexed past interventions (organized as cases), clinicians would be able to retrieve on-line any similar case, task or attribute at any point along the surgical intervention together with a formed new solution, by adapting/combining solutions of the retrieved cases, for each of the similar cases which may help them to select the next step properly. Also, new, revised cases will be added to the case base for future use. The designed software will use a CBR methodology and to give case-specific advice at any particular point of the intervention workflow, specially focused along preoperative and intra-operative phases.

3 WORKFLOW-BASED CBR FOR DECISION SUPPORT

CBR is a technique of artificial intelligence that attempts to solve a given problem within a specific domain by adapting established solutions to similar problems (Aamodt and Plaza, 1994). As can be seen in Figure 2, CBR has been formalized for purposes of reasoning and learning based on the exploitation of existing similar historical records as humans do. A basic four-steps procedure is defined: retrieve, reuse, revise and retain. Given a target problem, during the retrieve step, cases from memory that are relevant to solving it are recovered. A case is a whole although usually two parts can be identified according to the

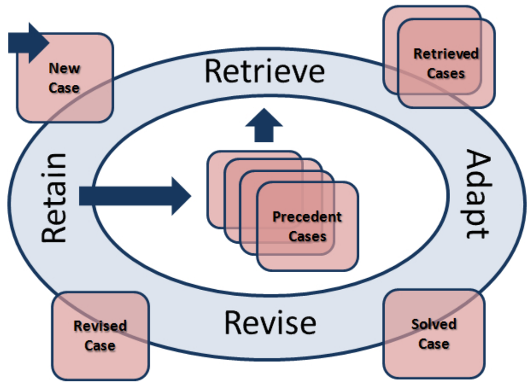

Figure 2: Four-step process of Case-Based Reasoning.

problem to be solved: problem and solution space. Problem space can incorporate specific case information and also contextual information useful for solving the problem whereas solution space incorporates information directly related with the solution for solving the problem. While in the reuse phase, solutions from previous cases are mapped to target the current problem. This may involve adapting the solution as needed to fit the new situation. Having mapped the previous solution to the target situation, during the revise step the new solution is tested and, if necessary, checked by clinicians. After the solution has been successfully adapted to the target problem, the retain last step concerns with storing the resulting experience as a new case in the case base. These features make CBR a good contender for any decision support system (Watson, 2002). CBR has been used in other medical decision support systems. An integration of CBR and rule-based reasoning was used in systems for the planning of ongoing care of Alzheimer's patients (Marling and Whitehouse, 2001) and for the management of Diabetes patients (Bellazi et al., 1999)

In order to design a case-based system adapted to an operation workflow like the one described in Section 2, we should determine a case model, case indexing and a similarity metric. As illustrated in Figure 3, every case of the case base is defined as a set of attributes classified among the different tasks which compound the whole operative workflow. The stored cases do not need to contain the same number of attributes, as it will depend on the amount of information available when storing each case. Therefore, some cases will be richly filled with useful information concerning all the tasks of the workflow while others can be poorly defined with missing information in certain tasks or even non-existent tasks at all, as not all of them are mandatory and depend on each patient.

When the intervention begins, parallel to the workflow progression described in Figure 3, the CBR mechanism retrieves specific and contextual problem information of similar past cases. Such assessment step determines which cases address problems most similar to the current problem, to identify them as starting points for solving the new problem. Next, the CBR gives the clinicians information about the solution for solving the problem by case adaptation, which forms a new solution by adapting/combining solutions of the retrieved problems. Once the operation ends, clinicians proceed with the new case revision, which evaluates and adjusts the adapted solutions and, if suitable, the new case will be retained with the system learning from the situation by storing the result as a new case for future use.

4 EXAMPLE OF APPLICATION: TRANSCATHETER VALVE IMPLANTATION

In Transcatheter Aortic Valve Implantation (TAVI) (Webb and Cribier, 2011), a synthetic valve is transported to the heart through a small hole made in groin. This procedure can be compared to that performed when placing a stent, or performing balloon angioplasty. This technique was first developed in Europe, where it was initially performed in 2002. Since then, more than 10000 patients have benefit from it and the results have shown the procedure to be effective in improving functioning in the patients with severe aortic stenosis. In the recent years TAVI is assuming a major role in the routine management of patients with aortic stenosis and now TAVI is considered the standard in patients who are not candidates for conventional surgical Aortic Valve Replacement (AVR). On the basis of almost 10 years of experience TAVI also appears to be a reasonable option for some operable, but high-risk patients. Nevertheless considerable work needs to be done before TAVI is expanded into lower risk groups.

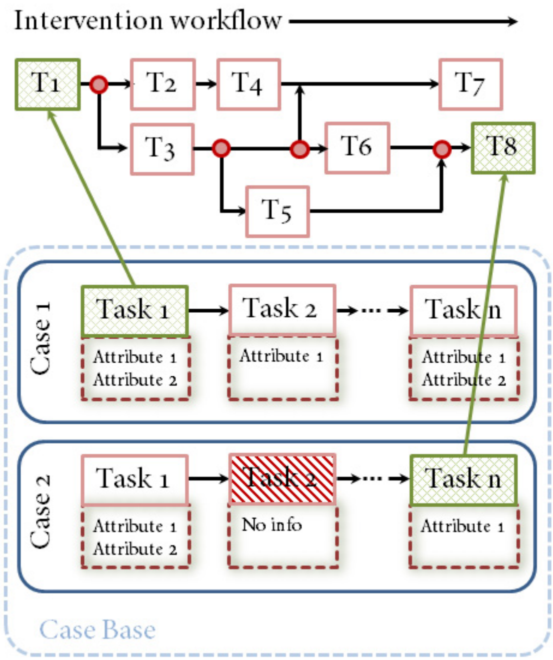

Figure 3: Case structure and retrieval process along the operative workflow.

Figure 4 shows the specific workflow for the TAVI example. As can be appreciated, the procedure (from pre-operative to post-operative treatment) is subdivided in 8 different tasks, starting with a study of patient suitability for TAVI in *Task 0*, to *Task 7* where the patient is finally transferred to the Intensive Care Unit (ICU). As illustrated in Figure 4, the workflow does not evolve only in a forward direction but it also turns backward if necessary, specially along the preoperative phase, where some contraindications could arise during the study which may turn the patient not eligible for TAVI. Parallel to the workflow progress, as can be seen along the bottom section of Figure 4, all the tasks are linked with the different information sources which will provide the necessary attribute data required for defining the patient case model. For the particular case of a MIS like TAVI, most of the information is acquired through imaging system devices.

As shown in Table 1, every attribute of the case model is matched to a task or group of tasks where clinicians consider it to be relevant or critic for the correct development of the operative process. Also, the attributes are linked with the source images or

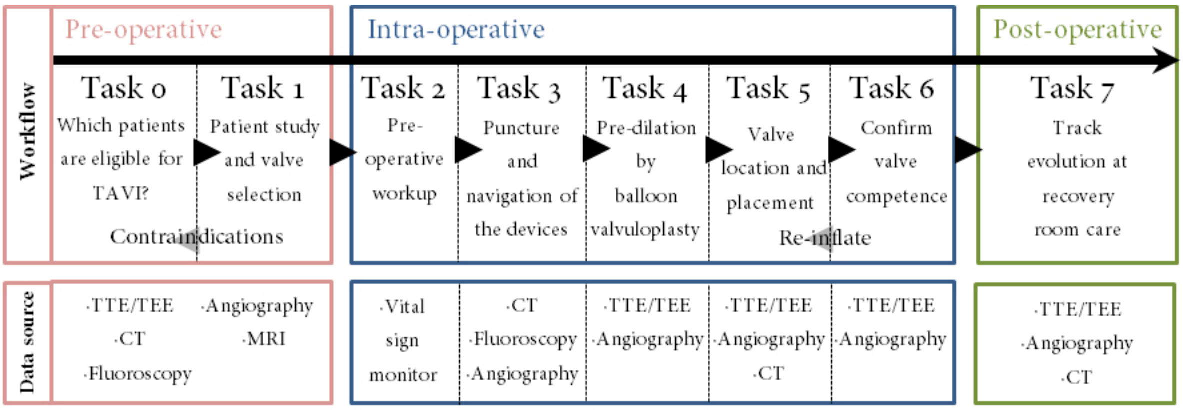

Figure 4: TAVI workflow showing tasks and data source where attributes are extracted from.

monitoring sensors used to assign them a value. As sources of different accuracy can be used to obtain the same attribute, the information will always be presented together with its origin so the clinicians have the last word to decide which source data is more reliable.

5 CONCLUSIONS AND FUTURE WORK

The work presented in this paper details a proposal of a CDSS designed to give case-specific assessment to clinicians during complex surgery or minimally invasive interventions.

The work progress is solid and consistent and, up to this point, the workflow has been structured and a case model defined together with specialized clinicians. Therefore, our efforts are currently centered on building an initial case base. For this purpose, past cases from collaborating hospitals and medical centers have been collected and they are being translated to match the case model previously defined. First simulated results are expected to be obtained soon before the end of the year. Also, more medical centers have been contacted in order to spread the case base along different hospitals within a cluster, and thus allowing clinicians from different teams to consult case problems and solutions from colleagues of other institutions. To finish, it is important to remark that the feedback received from the numerous physicians consulted has been very positive and the interest showed in this project is encouraging. Clinicians agree that CDSS are of high value specially in recently growing MIS like TAVI where the number of interventions per year is still low compared to common surgery and which also require expert hands due to its complex procedure.

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Table 1: Attributes obtained from source data and linked to the workflow tasks.

Attribute Name	Task Number	Data Source
Euroscore	Task 0	-
Mitral regurgitation	Task 0	US, A, CT, MRI
Other pathologies	Task 0	US, A, CT, MRI
Vascular diameters	Task 1, Task 3	CT, US, F, MRI
Calcifications	Task 1, Task 3	US, F, CT, MRI
Tortuosity	Task 1, Task 3	US, F, CT, MRI
Atherosclerosis	Task 1, Task 3	US, F, CT, MRI
Porcelain aorta	Task 1, Task 3	US, F, CT, MRI
Uncoiled aorta	Task 1, Task 3	US, F, CT, MRI
Iliac stenosis	Task 1	US, F, CT, MRI
Annular diameter	Task 1	US, A, CT, MRI
Sinus of Valsalva diameter	Task 1	US, A, CT, MRI
Ascending aorta diameter	Task 1	US, A, CT, MRI
Height of coronary arteries	Task 1	US, A, CT, MRI
Blood Count	Task 2, Task 3, Task 4, Task 5, Task 6, Task 7	Sensor
Blood Pressure	Task 2, Task 3, Task 4, Task 5, Task 6, Task 7	Sensor
Coagulation	Task 2, Task 3, Task 4, Task 5, Task 6, Task 7	Sensor
Electrolytes	Task 2, Task 3, Task 4, Task 5, Task 6, Task 7	Sensor
Vessel Rocked	Task 3	US, F, A
Cardiac pacing value	Task 4, Task 5	US, A
Inflate volume 1	Task 4	US, A
Inflate volume 2	Task 5	US, A
Valve planes	Task 5, Task 6	US, A, CT
Valve leak	Task 6, Task 7	US, A
Coronary flow	Task 6, Task 7	US, A
Aortic/Iliac injury	Task 6, Task 7	US, F
Femoral flow	Task 6, Task 7	US, F
Valve completely open	Task 6, Task 7	US, F

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