Workflow in Interventional Radiology: Nerve Blocks and Facet Blocks

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ABSTRACT

Workflow analysis has the potential to dramatically improve the efficiency and clinical outcomes of medical procedures. In this study, we recorded the workflow for nerve block and facet block procedures in the interventional radiology suite at Georgetown University Hospital in Washington, DC, USA. We employed a custom client/server software architecture developed by the Innovation Center for Computer Assisted Surgery (ICCAS) at the University of Leipzig, Germany. This software runs in an internet browser, and allows the user to record the actions taken by the physician during a procedure. The data recorded during the procedure is stored as an XML document, which can then be further processed. We have successfully gathered data on a number if cases using a tablet PC, and these preliminary results show the feasibility of using this software in an interventional radiology setting. We are currently accruing additional cases and when more data has been collected we will analyze the workflow of these procedures to look for inefficiencies and potential improvements.

Keywords: Surgical Workflow, Workflow Management Tools, Workflow Optimization, Surgical PACS

1. INTRODUCTION

The ability to systems engineer clinical environments in terms of formal workflow descriptions of processes and procedures has significant implications. Workflow analysis has the potential to dramatically improve the efficiency and clinical outcomes of medical procedures. From an operations standpoint, it allows inefficiencies to be identified and remedied more quickly. From a technology perspective, it enables a methodical and scientific approach to the specification, simulation, design and prototyping of new technology, allowing development to occur more efficiently.[1,2] In either case, it allows the impact of a new strategy to be assessed objectively.

The application of workflow analysis to the clinical environment is only beginning to emerge and is likely to gain more interest in the upcoming years. Significant workflow analysis research is currently being done by the Innovation Center for Computer Assisted Surgery (ICCAS) in the area of surgical interventions as the basis for the development of computer assisted surgery (CAS) systems.[1,2,3] ICCAS has focused its efforts on modeling surgical workflows by recording data from real world surgical interventions that can be associated with well-defined task of the intervention with high granularity. The development of a computerized workflow editor tool to record workflow data is crucial to the capability of the recorder to capture fine-grained data. The tool draws upon ontologies developed for different surgical disciplines and also includes a visualization tool to analyze the data.

Interventional Radiology (IR) can benefit from a similar effort. IR is an image-guided therapy, and can take advantage of any and all imaging modalities, and accompanying computer and mechanical enhancements. The capability to model IR procedures will allow new technologies to be developed and evaluated more quickly. Additionally, the boundaries between IR and surgery are blurring. While IR procedures include increasingly more invasive therapeutics, such as tumor ablation, surgeons are adopting the techniques and principles of IR, and are relying more heavily on intra-operative imaging. Thus, it is timely to apply the workflow analysis approach developed for surgical interventions to IR procedures.

In this study, the ICCAS workflow tool is adapted to the specific requirements of IR workflow. It is then used to record workflow data for nerve block and facet block procedures in the IR suite at Georgetown University Hospital in Washington, DC. The intent of the study is to determine the feasibility of recording workflows in an IR setting and to analyze the workflow of these procedures, identify inefficiencies, and potentially improve the efficiency of these procedures. This paper describes the development, of an IR-specific workflow tool and the results of using it to record workflow in an IR setting.

2. METHODS

We recorded workflows using a software package developed at ICCAS that facilitates the structured recording of surgical workflows. The ICCAS software uses a workflow editor to support the difficult process of dealing with the complex relationships and concurrencies that occur during surgical interventions. It then generates a structured description of the intervention in XML format that can be used for visualization and further analysis. Although the software was developed to record surgical workflow, its design makes it easy to adapt to other disciplines by changing the underlying ontology.[2] Since IR workflow had not been previously recorded, the approach was to first start with a simple procedure that is performed with some frequency. Nerve and facet block procedures were selected since they fit the outlined criteria. In this way, the ontology could be developed and integrated with the workflow application. Actual recording could then be conducted with enough frequency to provide an understanding of the feasibility of recording workflow data in the IR setting.

2.1 Developing the interventional radiology (IR) ontology

Although commonalities exist between IR procedures and surgical interventions, there are significant enough differences that the ICCAS tool must be modified to support IR. Therefore, the first step was to generate the appropriate ontology for IR workflow of nerve block and facet block procedures. After a thorough analysis through observation of multiple nerve and facet blocks procedures, the procedures were broken down into specific tasks each comprised of four components (1) participants involved (2) actions performed (3) instruments used and (4) anatomic structures treated. By combining the components across all identified tasks in a block procedure, comprehensive lists for each component were generated (See Figure 1). Each task executed during a procedure is defined as a combination of items from each of these

Participants Involved - operator (physician)	**Anatomic Structures Treated** **Nerve Blocks** - C1,C2,C3,C4,C5,C6,C7,C8 - T1,T2,T3,T4,T5,T6,T7,T8,T9,T10,T11,T12 - L1,L2,L3,L4,L5 **Facet Blocks** -C1-2,C3-4,C5-6,C7-8 -T1-2,T3-4,T5-6,T7-8,T9-10,T11-12,T12-L1 -L1-2,L3-4,L5-S1 **Side** -right -left -right/left Spine Levels C=Cervical T=Thoracic L=Lumbar S=Sacral
Actions Performed - acquire image - place - insert - remove - insert syringe - adjust angle and advance - inject - mix drugs	
Instruments Used - local anesthesia needle - syringe - local anesthesia needle with syringe - block needle - fluoroscopy	

Figure 1 – Specific ontology developed for IR

lists. Once the lists were completed, ICCAS incorporated the IR ontology into the workflow editor. The resulting interface is shown in Figure 2.

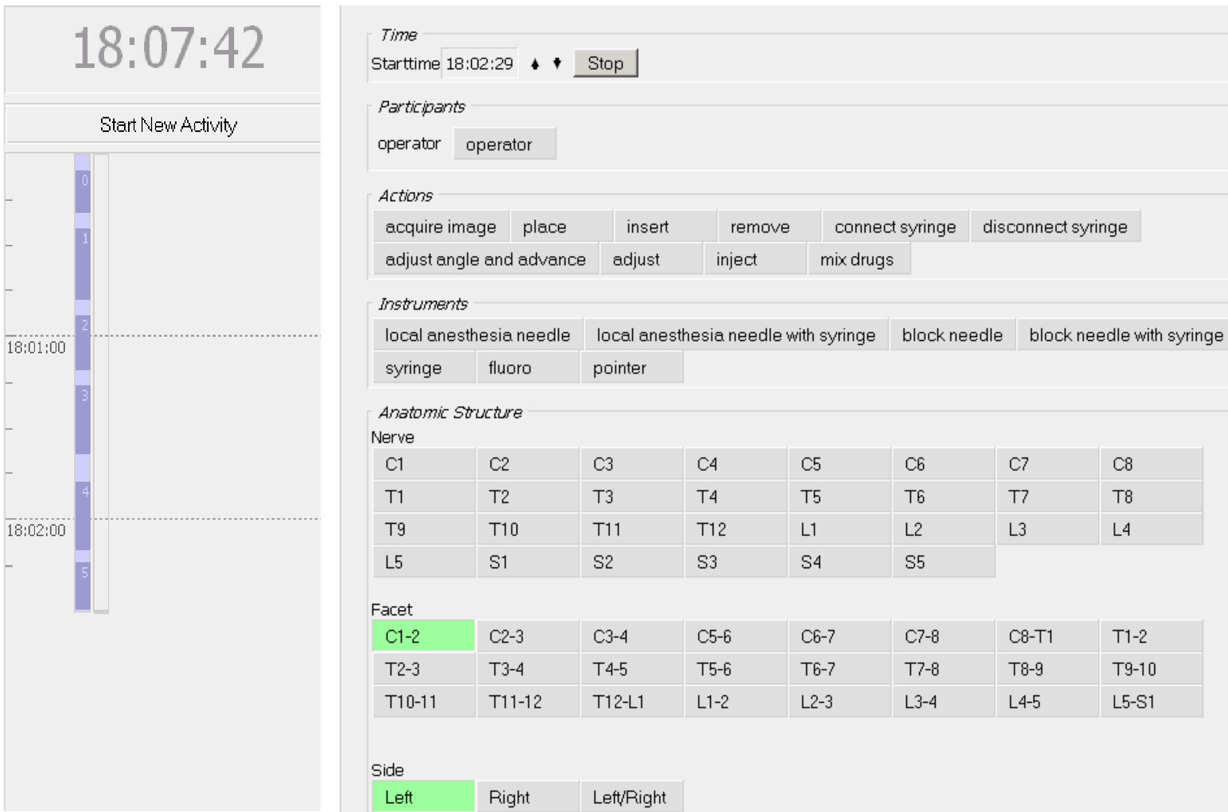

Figure 2 - ICCAS workflow editor modified to support IR nerve and facet block procedures

2.2 Technology description

For this study, we chose to run the software on a Tablet PC, which is portable and has a touch screen display for easy data entry. The workflow editor is run as a web application. It is programmed in Hypertext Preprocessor (PHP) which supports the development of web-based software applications. We used XAMPP, an easily installable and configurable Apache (A) distribution with combined MySQL (M), Perl (P) and PHP (P) support. The X stands for different distributions for Linux, MacOS and Windows.[4] We installed it on the PC in order to simplify the architecture and hardware requirements. For recording multiple workflows on multiple clients, a dedicated server and wireless network could be utilized. Pointing the Mozilla Firefox web browser to the PHP pages launches the application.

2.3 Workflow recording

Before recording can begin, the user must first collect data about the procedure. The workflow editor prompts the user to enter information about the recording person (user), location of the procedure, discipline, diagnosis, therapy, participants, and patient. Once this information has been entered, recording is initiated by selecting the ‘Start’ button to signify the start of the procedure. During the block procedure, the user selects the ‘Start New Activity’ button to indicate when a new task is beginning. The software records this timestamp as the start time of the task. The user then uses the graphical user interface (GUI) to select the items from each list that define the task, namely the participant (e.g. surgeon), action performed, the instrument used, and the anatomic structure involved. Once the participant has completed the action, the user selects the ‘Stop’ button and the software records this time as the stop time. This sequence is repeated for each task of the block procedure. Some procedures may involve multiple tasks occurring concurrently. The workflow editor handles this situation by providing a timeline of tasks on the screen. If a new task starts before the previous task ends, the user simply selects the 'Start New Activity' button without stopping the previous task. The user may then use the timeline to access and signal completion of previous tasks.

When the block procedure ends and recording is completed, the user selects the 'Save' button. The workflow editor creates an XML file consisting of a header and a body that contains all of the recorded data. The header contains the contextual data about the procedure that was entered before the start of the procedure.[1] It includes the following data elements:

(a) the *discipline* with the child elements
    (a1) *diagnosis*
    (a2) *therapy*
    (a3) *participant* with the elements position (e.g. interventionalist, technologist, nurse) and a note field
    (a4) a *note* field for discipline related information
(b) the *date of recording*,
(c) the *place of recording*, with the child elements
    (c1) country
    (c2) city
    (c3) hospital
    (c4) operating theatre
    (c5) a *note* field for recording place related information
(d) the *recording person* with the child elements
    (d1) first name
    (d2) last name
    (d3) status (e.g. medical student, recording experience)
    (d4) a *note* field for recording person related information
(e) an input field for *notes* regarding the whole intervention.

In the body of the XML file, the data are partitioned into *tasks* that represent the work steps of the IR procedure.[1] Each task has the following structure:

(a) the *tasktime* with the child elements
    - *start time*
    - *stop time*
    - *duration*
(b) an *actuator* that
    - has the same *position* as indicated by the *participant* element inside *discipline* (e.g. interventionalist, technologist, nurse) and a note field
    - a *note* field for participant related information
    - an element that indicates various *used body parts* (in regarding of granularity level (ii) or (iii)), such as 'left hand', 'right hand'. The consideration of other parts of the body like 'right foot' for the operation of foot pedals or 'gaze' for the gathering of information from monitors is also possible.
(c) the accomplished *activity*,
(d) the *instrument* used in the work step,
(e) the treated *anatomic structure*,
(f) an input field for *notes*

Figure 3a and 3b illustrate the XML file The XML data can also be transformed into a two-dimensional Scalable Vector Graphic (SVG) for semantic analysis of the single workflow activities.[3] It allows the workflow to be generalized and analyzed, allowing suggestions to be made to improve the efficiency of the procedure.

```
<rec_workflow workflowID="wf1132676025687.2">
    <discipline discipline="Interventional Radiology">
        <diagnosis>pain</diagnosis>
        <therapy>nerve block</therapy>
        <participant>
                <position>operator</position>
                <name>Dr. E. Nostaw</name>
                <note></note>
        </participant>
        <patient>
                <age>84</age>
                <sex>m</sex>
                <position>prone</position>
                <note></note>
        </patient>
        <note></note>
    </discipline>
    <rec_date>2005-11-22</rec_date>
    <rec_location>
        <country>USA</country>
        <city>Washington, DC</city>
        <institution>Georgetown Univ Hospital</institution>
        <building>CCC</building>
        <operatingtheatre>IR Room 6</operatingtheatre>
        <note></note>
    </rec_location>
    <rec_by>
        <name>Donald Siddoway</name>
        <status>medical student</status>
        <note></note>
        </rec_by>
```

Figure 3a –Header component of XML file for IR workflow

```
<task taskID="1">
    <tasktime>
        <starttime>1122395258.1117</starttime>
        <stoptime>1122395261.2262</stoptime>
        <duration>3.1144998073578</duration>
    </tasktime>
    <actuator>
        <position>operator</position>
        <usedbodypart>operator</usedbodypart>
    </actuator>
    <activity>
        <action>place</action>
    </activity>
    <instrument>
        <usedinstrument>pointer</usedinstrument>
    </instrument>
    <anatomic_structure>
        <treatedStructure>
                <structure>Nerve</structure>
                <level>L3</level>
                <side>Left</side>
        </treatedStructure>
    </anatomic_structure>
</task>
```

Figure 3a –Body component of XML file for IR workflow

3. RESULTS

3.1 Workflow results

IR workflow was recorded for 7 nerve block procedures and 1 facet block procedure (Table 1). Analysis indicates that the tasks are short in duration and that the idle time between tasks is very short. The workflow editor successfully generated the appropriate XML files. These data files provide a thorough record of all the actions taken by the interventional radiologist during block procedures. Figure 4 shows a sample of an XML workflow file with the accompanying SVG representation. These can then be analyzed in order to assess the efficiency of the procedure, both on the basis of the individual case, and for the procedure in general.

3.2 Usability of the workflow editor in IR

The tablet PC is a good choice for recording workflow because it offers access to an external keyboard and a touch screen. Having access to a keyboard makes it easy to enter text data about the procedure while the tablet mode is better suited for the workflow recording - it is easier to hold in the procedure room, and the touch screen display eliminates the need for a mouse and keyboard. With respect to recording the workflow of block procedures, we found that the high level of granularity defined for the workflow editor combined with the very rapid pace of the block procedures made workflows difficult to record. In general, the tasks were very short in duration and the idle time between tasks was even shorter making it difficult for the recording person to accurately capture the end of one task and the start of a new one. It became particularly difficult when several short-duration tasks occurred sequentially. For example, when positioning the needle, the steps of adjusting the needle and taking an X-ray image alternate until the needle is properly positioned. Neither of these steps takes very long and the idle time between them is short. It was not always possible to capture the task accurately or at all, thereby, decreasing the reliability of the data.

Procedure	Type	Number of tasks/procedure	Total time/procedure (seconds)	Mean duration time/task (seconds)	Mean idle time/task (seconds)
Workflow1	nerve	31	342.0	7.7	3.3
Workflow2	nerve	31	414.0	9.1	3.2
Workflow3	nerve	21	240.0	3.8	3.1
Workflow4	facet	10	192.0	15.1	4.0
Workflow5	nerve	25	453.0	13.4	3.5
Workflow6	nerve	24	257.0	7.9	2.8
Workflow7	nerve	10	245.0	17.8	6.6
Workflow8	nerve	21	265.0	8.1	4.9
Mean		21.6	301.0	10.4	3.9

Table 1 - IR workflow for eight procedures

The GUI itself exacerbated the issue because for each new task, the recording person must select a minimum of four buttons. Sometimes the task would be completed before all selections could be completed. There were also some problems adapting the software to our particular recording devices. Most notably, the GUI did not fit on the screen, so some scrolling was required to press some of the buttons. This further slowed the recording process. Some modifications were made to the GUI to allow for quicker recording. One such optimization involved the selection of the involved anatomic structure. For block procedures, the anatomic structure changes only once or not at all. To address this issue, the software was changed so that when an anatomic structure was selected, it would remain selected throughout the procedure.

4. DISCUSSION

As a proof of concept, this study has been successful in demonstrating the feasibility of recording workflow in IR and in providing important lessons learned that will be critical to improving subsequent workflow studies. This block procedure workflow study has established that the process of recording workflow in IR is feasible. The ICCAS workflow editor was able to be adapted to IR workflow, resulting in the appropriate XML data files and accompanying SVG graphical representations. Recording was not disruptive to the any aspect of the block procedure itself and from an ergonomic perspective the tablet PC was a good match for recording workflow.

The primary lesson learned was that the physical act of recording must be able to support the selected granularity of the procedure. It is critical to balance the type of procedure, the granularity of described tasks within the procedure and the interface to the workflow editor. The block procedures were selected because they represent straightforward procedures with very little concurrent tasks and they are performed weekly at Georgetown University Hospital. The basis for this choice was that it would allow rapid development of the necessary ontology and that recording could be conducted regularly, providing data for workflow analysis. The problem encountered is that in setting up the ontology, we chose a description of high granularity. We did not recognize that the rapid pace of the procedure coupled with such a detailed description would cause difficulty in accurately recording the procedure. Future studies must take this into account whether it means modifications to the recording interface or changing the granularity of the procedure description

For this study specifically, some of the issues can be remedied. The ontology can be collapsed where commonly used steps occur in a specific sequence extending the duration time. It is also possible to combine several commonly used steps in the ontology into fewer button presses. It may also be possible to integrate voice commands, rather than button pushes, to allow for quicker recording and to allow the person using the workflow editor to always watch the procedure. Video recordings could also be used to validate workflow data and make corrections where necessary.


```
<task taskID="19">
    <tasktime>
        <starttime>1122394250.5829</starttime>
        <stoptime>1122394255.7404</stoptime>
        <duration>5.1575002670288</duration>
    </tasktime>
    <actuator>
        <position>operator</position>
        <usedbodypart>operator</usedbodypart>
    </actuator>
    <activity>
        <action>acquire image</action>
    </activity>
    <instrument>
        <usedinstrument>fluoro</usedinstrument>
    </instrument>
    <anatomic_structure>
        <treatedStructure>
        <structure>Nerve</structure>
        <level>L4</level>
        <side>Left</side>
        </treatedStructure>
    </anatomic_structure>
</task>
<task taskID="20">
    <tasktime>
        <starttime>1122394256.7118</starttime>
        <stoptime>1122394261.9593</stoptime>
        <duration>5.2474999427795</duration>
</tasktime>
```


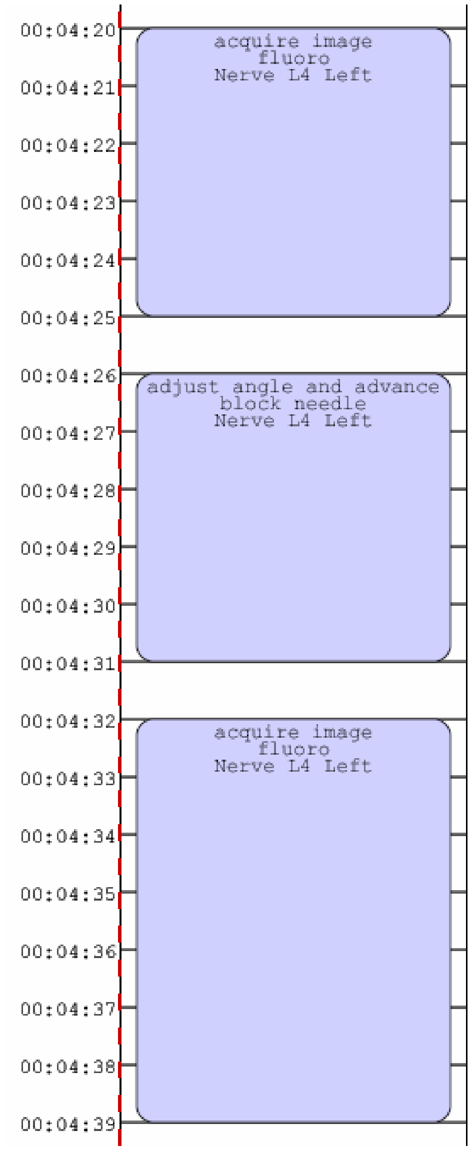

Figure 4 – Text on the left represents recorded data for tasks 19-20 in a typical case with the corresponding SVG representation on the right. Each blue blocks represents a task with the top of block indicating the start time and the bottom of the block indicating the stop time (the height of the block is the duration). The time between blocks represents idle time. The SVG representation allows one to quickly visualize the workflow.

5. CONCLUSION

Workflow recording and analysis in IR is a work-in-progress. It has the potential to be a valuable tool in creating formal descriptions of IR procedures that can then be used to evaluate new diagnostic and therapeutic strategies, and launch the development of new devices or image-guided systems (e.g. using a telemanipulator compared to manual intervention).

Workflow is also at the foundation of integrating IR with other clinical services using the Integrated Health Enterprise (IHE) approach and standards development such as Digital Imaging and Communications in Medicine (DICOM).[5,6] The intent is to refine the work done on block procedures by modifying granularity of the procedure description and further improve the workflow editor GUI to enable more accurate recording. The next step will be to incorporate more IR procedures into the workflow editor and begin collecting data on those procedures.

Although this study was limited to workflow recording of the procedure itself, workflow recordings could also provide additional benefit by expanding the scope beyond the actual procedure. Following the flow of patient along with the flow of the procedure is a critical component to creating a greater efficiency not only in the procedure room, but also in the perioperative environment. Many of the inefficiencies found in hospitals today involve the flow of patients, which should be optimized so as to minimize the time physicians spend waiting for the next patient, and minimizing the time that patients spend waiting for the physician. Using workflow recording and analysis at the departmental level may aid in revealing inefficiencies and assessing strategies to overcome them.

ACKNOWLEDGEMENTS

The work at Georgetown University was supported by U.S. Army grants DAMD17-99-1-9022 and W81XWH-04-1-0078. The Innovation Center Computer Assisted Surgery (ICCAS) at the Faculty of Medicine at the University of Leipzig is funded by the German Federal Ministry for Education and Research (BMBF) and the Saxon Ministry of Science and Fine Arts (SMWK) in the scope of the initiative Unternehmen Region with the grant numbers 03 ZIK 031 and 03 ZIK 032.

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