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Multi-Role BPMN Models for the Automatic Generation of Collaborative Checklists to Provide Role-specific Support in the OR

Proof of Concept for Computer-assisted Cochlea Implantations

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Abstract: The operating room demands well-functioning workflows and optimized communication. Based on the formalization of specific surgical interventions via BPMN, intraoperative checklists can automatically be generated to support the surgical team by the provision of relevant clinical information and situation-dependent assistive functions. While focusing on the surgeon, other actors have not yet been considered. The aim of this work is therefore the extension of the intraoperative checklist to enable role-specific support and improved communication between the actors. The BPMN approach is adapted to depict role-specific surgical steps and clinical information to realize the collaborative, multi-role usage of the checklist. The proof of concept demonstrates the automatic generation of intraoperative checklists which provide relevant information depending on the role. An initial evaluation of the checklist based on the cochlea implantation use case shows promising results.

Keywords: Checklist, BPMN, Role, Collaborative, Cochlea Implantation.

1 Introduction

Perioperative support of the surgical team is crucial for improved workflows, a reduced workload, and thus better outcomes. To achieve such support, surgical assistance systems can be used within the operating room (OR). An intraoperative checklist [1–2] can dynamically display the surgical steps and further clinical information, enable the recording of adverse events, and automatically prepare a preliminary surgical report. The checklist is tailored to assist the surgeon, focusing on surgical steps. However, the whole surgical team could benefit from checklists. A collaborative checklist could support the intraoperative actors individually, such as the circulating nurse via an overview of tasks [3] or medical students via additional information on the interventions, as attention for training is lacking [4]. Thereby, the communication between the surgical team can be optimized.

The existing intraoperative checklist [1–2] automatically generates checklists from Business Process Model and Notation (BPMN) models that represent the surgical workflow of a specific intervention and include additional information for intraoperative guidance at the corresponding surgical step. To extend the approach for multi-role usage, the BPMN-based concept must be expanded so that the role-specific provision of clinical information and assistance functions is enabled.

This work addresses the extension of the approach of intraoperative checklists for multi-role support in the OR. Based on requirements analysis, a concept for multi-role BPMN models and client-server system architecture is developed. Then, a prototype for role-specific checklists is realized. The feasibility of the collaborative checklist is evaluated via requirements and an expert interview.

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2 Methods

2.1 Roles and Requirements

Based on an expert interview with a clinician of the University Hospital Düsseldorf, roles were identified and requirements defined for the use case of cochlea implantations. For the proof

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of concept, the focus was on the following roles: surgeon, scrub nurse, circulating nurse, and medical student. The *surgeon* should be supported as before via the provision of surgical steps, additional information, events, and a preliminary surgical report. In addition, the checklist should enable to call for the circulating nurse. The *scrub nurse* should benefit from displaying the instruments to be prepared based on the current surgical step. The *circulating nurse* should get a prioritized list of tasks of assigned ORs including tasks on demand. The *medical student* should have access to additional teaching materials based on the current surgical step.

A total of 27 functional and four non-functional requirements were derived. These include, besides the present functionalities, requirements for the role-specific extensions and collaborative aspects, and were prioritized based on the implementation focus. The BPMN model should be able to depict all roles and their role-specific information. For collaboration, the progress depicted by the checklist should be synced between the roles.

2.2 Multi-Role Concept

Via a systematic literature review, approaches for multi-role BPMNs and the integration of additional information were identified. As BPMN tasks are shared by different roles, pools and lanes can only be used with restrictions, such as redundant tasks [5] or group lanes [6], which inflate the model. Other ways to represent shared tasks are colors [7], annotations [8], graphical extensions [9], or modeler-specific attributes. Furthermore, a metafile could be used. Other information can also be added via annotations, graphical extensions, or a metafile. In addition, role-specific metafiles or data objects could be used.

Contrasting the approaches based on criteria regarding reusability, analyzability, maintainability, and accessibility, the options revealed different characteristics and limits. Annotations and a metafile were the most suitable modeling approaches for roles and additional information in the case of the checklist. Annotations enable to visualize all information in the model, whereas a metafile outsources information not important at first glance. However, rich annotations may overload the model, thus making it confusing. In contrast, role information outsourced within a metafile will not be visible in the model. Thus, a combination of annotations in BPMN and a YAML-based metafile is proposed (see Fig. 1): for each task in the BPMN, an annotation is added that assigns the individual roles and refers to a specific section within the metafile via a unique ID. Any information for the roles is outsourced from the model into a “META.yaml” file which includes text or file names for each ID and role.

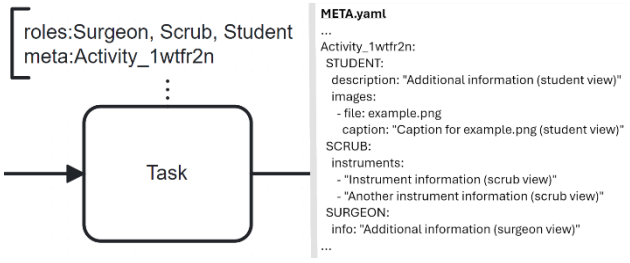

Figure 1: Annotations assigned to BPMN tasks depict the roles and metafile section (left), while the YAML-based metafile includes additional information per task and role (right).

The checklist system was then re-implemented as a client-server architecture. Therefore, the core elements of the existing prototype were used and extended by the role-specific functionalities. The web-oriented system architecture consists of several modules to display and manage the information. The *operation module* deals with the provision and persistence of intervention templates, in this case, the cochlea implantation. Therefore, an XML parser bundles the BPMN elements into an internal representation via defined database objects which can then be used to generate the checklists. The internal representation of checklist items is associated with the relevant data of the metafile and the according roles. The *sync module* is responsible for synchronizing the clients based on documentation entries (i.e. completed checklist items) that track the progress of the surgical workflow. Additional modules deal with client-side aspects, such as the definition of reusable components, and administrative features.

Based on the prototypical implementation, the checklist system was evaluated via the defined requirements by the developer using defined test scenarios. Feedback during another expert interview with the same clinician of the University Hospital Düsseldorf further provided details on the suitability of the expanded checklist for evaluation purposes. Therefore, test scenarios were set as tasks covering all roles and the results were retrieved using the think-aloud method.

3 Results

3.1 Role-specific Checklists

The resulting checklist system starts with a page for selecting the role, OR, and intervention template. Then, a new intervention can be started or a running intervention be attended. Based on the selection, one of the four role-specific checklists is automatically generated depending on the intervention template and currently running intervention.

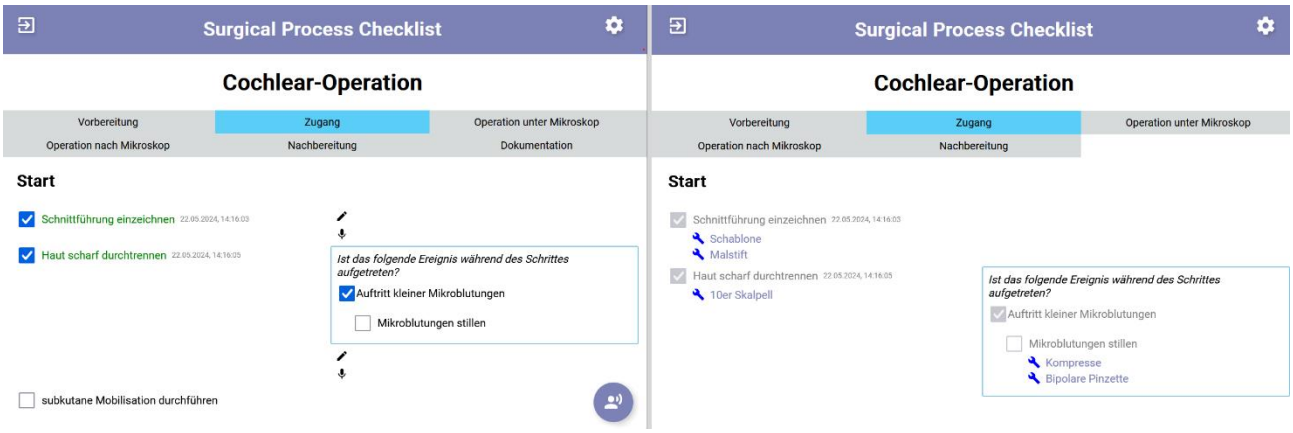

Figure 2: Excerpt of the checklist for the surgeon (left) and scrub nurse (right), depicting the different assistive functions including surgical steps, events, and additional information.

Furthermore, a configuration page can be opened for administration purposes.

The *surgeon* checklist dynamically transfers all surgical steps and events that were assigned to the surgeon from the underlying BPMN model into checklist items (see Fig. 2 left). Furthermore, additional information, such as comments or images, is loaded and displayed for the respective surgical steps based on the metafile. By ticking off the checklist items during surgery via a sterile touch display, the surgical workflow including events is tracked and a preliminary report is automatically generated in the background. Color coding indicates completed (green) and skipped (yellow) tasks. Adverse events can be documented using text and audio. Furthermore, tasks assigned to the circulating nurse are displayed but cannot be ticked off by the surgeon (see Fig 3 left). Color coding indicates completed (green) and active (yellow) tasks. If the surgeon requires unscheduled assistance from the circulating nurse, this can be communicated via a button that is visible at all times in the right bottom corner.

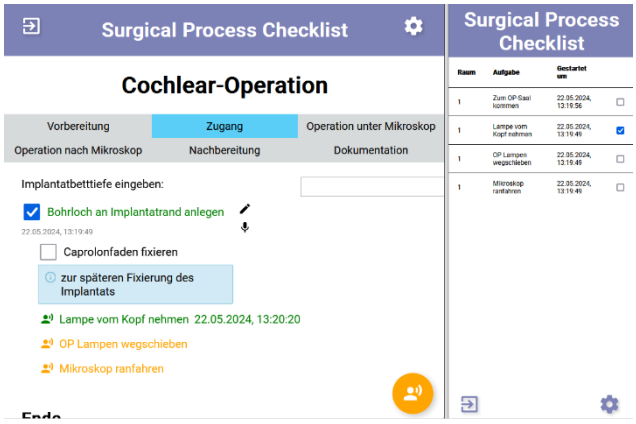

Figure 3: Excerpt of the checklist for the surgeon (left) and circulating nurse (right), depicting the different assistive functions focusing on the collaborative support.

The *scrub nurse* and *medical student* checklist normally display the same checklist items as for the surgeon. In contrast, these items are read-only and thus cannot be ticked off. Based on the metafile, additional information is provided for the respective surgical steps. The scrub nurse primarily gets access to the instruments needed for the next steps in order to prepare them for the surgeon (see Fig. 2 right). The medical student can view further information on the surgical intervention, such as explanatory texts or images.

The *circulating nurse* checklist dynamically loads and displays upcoming tasks that were assigned to the circulating nurse as checklist items (see Fig. 3 right). If the surgeon needs unscheduled assistance, a new task is added to the checklist. Via timestamp, the tasks can be prioritized. By ticking off the checklist items, the surgeon is informed about the completion.

3.2 Evaluation

Within the functional evaluation, the fulfillment of the functional and non-functional requirements was assessed. 22 out of 27 functional requirements were fulfilled. Four requirements, referring to interfaces for administration and clinical integration (lower priority), have not been fulfilled yet and need to be addressed in future work. Furthermore, for a partially fulfilled requirement, that reflects the initial functionalities of the checklist, one interface is pending. All four non-functional requirements were fulfilled.

The feedback during the expert interview was fundamentally positive. The new functionalities are intuitive and easy to understand. The greatest added value, besides the initial use case of surgical reports, is the possibility of using the checklist for education. New scrub nurses can gain confidence in preparing the needed instruments and medical students can get information that they would normally receive

from the surgeon. Nevertheless, optimization potentials are also present. For example, the arrangement of the checklist items could be improved overall, the number of additional information displayed at the same time be reduced for the medical student, or the communication with the circulating nurse be made more flexible.

4 Discussion

In contrast to the initial intraoperative checklist [1–2], the extended version enables multi-role support for the surgical team. The surgeon can use the checklist during surgery and further benefit from an automatically prepared preliminary surgical report. The scrub nurse and medical student can follow the surgical workflow depending on the ticked-off checklist items. Depending on the role, access to instruments needed for the next steps or training material is provided. The circulating nurse can use the checklist as a task list for several ORs. By synchronizing all checklist instances, improved communication could be enabled to relieve the surgical team and minimize adverse events [10].

Nevertheless, the support is not limited to these roles and information types. The BPMN approach using annotations and metafiles enables the extension to further use cases, e.g. a checklist for the anesthesiologist. Furthermore, the checklist can be used for other types of interventions by formalizing the new intervention via BPMN and adapting the metafile. The checklist system then automatically loads the checklist items. Therefore, expert interviews are to be conducted with various hospitals to gather requirements from other application areas and demonstrate the approach for different use cases.

In order to use the intraoperative checklist in clinical routine, the system needs to be improved. The implementation of missing interfaces for administration and clinical integration is required. Furthermore, the checklist's usability must be slightly optimized depending on the feedback received during the evaluation. For optimal clinical use, other input modalities, such as speech recognition, could be implemented. By extending the system and integrating further use cases, test scenarios in a realistic setting including different roles can be enabled.

5 Conclusion

This work demonstrates the proof of concept of multi-role checklists to provide targeted support and improved collaboration of the surgical team during cochlea implantations. By depicting multiple roles and different additional information within one BPMN model, role-specific intraoperative checklists can automatically be generated. The evaluation based on requirements and clinical feedback shows promising results. Within further steps, the checklist can be optimized to enable tests in a realistic setting and with several use cases.

Author Statement

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