A Constraint-based Approach to Medical Guidelines and Protocols

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Abstract. Medical guidelines and protocols are documents aimed at improving the quality of medical care by offering support in medical decision making in the form of management recommendations based on scientific evidence. Whereas medical guidelines are intended for nation-wide use, and thus omit medical management details that may differ among hospitals, medical protocols are aimed at local use within hospitals and, therefore, include detailed information. Although a medical guideline and protocol concerning the management of a particular disorder are related to each other, one question is to what extent they are different. Formal methods are applied to shed light on this issue. A Dutch medical guideline regarding the treatment of breast cancer, and a Dutch protocol based on it, are taken as an example.

1 Introduction

Medical management is increasingly based on recommendations from the medical scientific community, summarised in medical guidelines and protocols. Medical guidelines are systematically developed, structured documents, containing conclusions and recommendations, based on scientific evidence [7]. These documents are, therefore, called *evidence-based guidelines*. Medical protocols are local adaptations of medical guidelines.

The goal of the work described here was to better understand the differences and similarities between guidelines and protocols. A start of obtaining insight into these issues is yielded by an informal analysis, where the structure and content of a medical guideline and protocol concerning the medical management of one particular disorder, here breast cancer, are studied. Based on the results of this analysis, we have carried out a formal analysis of parts of both the guideline and protocol of breast cancer treatment. This is done by looking at both medical protocols and guidelines as defining (logical) constraints on the medical management of patients performed in practice. This approach was inspired by a statement by Wiersma and Burgers that "recommendations in guidelines should not only be based on evidence extracted from scientific literature, but take into account the context of daily medical practice as well".[3] In principle this approach would allow one to discover flaws or suboptimal management actions in the medical management in practice, assuming that a given protocol and guideline are correct, or to find incorrect or suboptimal medical management decisions in a protocol or guideline, assuming that the medical management in practice is correct

and optimal. In the research described in this document we investigate whether this is really possible using a combination of informal and formal, in particular model checking, methods.

2 Medical Guidelines and Protocols

A medical guideline is an extensive document, developed by a working group of professionals involved in the management of the disorder covered by the guideline. By definition, a protocol is seen as a local version of a guideline, meant to be useful as a guide for daily clinical care. The need for a protocol in conjunction with a guideline is twofold: firstly, a guideline is an extensive document (e.g., the breast-cancer guideline is 121 pages in A4 format), and, therefore, it is not easy to locate relevant information; secondly, detailed recommendations about duration, dose, or actual procedure have been omitted from the guideline, and, thus, are added in a protocol to complement the information that is in the guideline. Hence, basically, a medical protocol is a summary of the most important sections that are in the guideline, mostly recommendations, supplemented with hospital-specific details concerning the treatment. This implies that many sections in a protocol may be very similar to related sections in a guideline. However, there may also be differences, partly due to differences in opinion between the guideline designers and protocol designers, and partly due to the difference in purpose of a guideline and protocol. The guideline that we have used in this study was the 2004 version of the Dutch CBO guideline on the treatment of breast cancer. The protocol that we have used was the protocol of the Dutch Integral Cancer Centre East (IKO in Dutch), which was based on the CBO guideline; the principal protocol developer was fully aware of the context of the breast cancer guideline and was later included in the guideline development team. As a consequence, much of what is included in the guideline is also in the protocol.

To understand the differences between breast cancer treatment in the guideline and the protocol, we present a number of examples where the recommendations of the guideline and protocol differs.

1. In the IKO protocol, an ultrasound axilla is suggested as default during the sentinel node procedure to asses the stage of the disease. CBO does not provide such a default.
2. IKO recommends first radiotherapy, then chemotherapy; CBO specifically does not recommend any order.
3. In case of isolated tumour cells, sentinel node dissection can be omitted according the CBO guideline, in contrast to the IKO protocol where additional axillary treatment is recommended in any case.

The first difference is due to the fact that the protocol is more specific than the guideline. Such a difference is also referred to as 'cookbook'

difference indicating that the difference is no more than an insignificant refinement compared to the guideline. The second difference is also a 'cookbook' difference and is due to agreements with other regional hospitals. The guideline does not recommend any order and as a consequence, the hospitals may choose a specific order to gain, for example, efficiency. The third difference is not a cookbook difference as it is a significant change in advise and, assuming a closed world assumption on the interventions that may be performed, can be seen as a contradiction. However, the evidence underlying the guideline advice was based on retrospective studies and is therefore uncertain.

There are some important observations that can be made on the basis of a more elaborate analysis that was performed. First, there are few real differences (i.e., differences that cannot be described in terms of a refinement) between the protocol and the guideline: most of them are 'cookbook differences'. The main reason for this is that this particular protocol is heavily based on the guideline and the writers are involved in both the guideline and the protocol. As a consequence, the evidence used is the same in both cases, and therefore the recommendations are very similar. Second, considering the level of evidence of studies supporting the differences, it was found that almost all differences are related to guideline pieces with a low level of evidence (level C/grade 4). In our findings, there was only one such case, which could be justified on the basis that strong evidence mentioned in the guideline was superseded by new evidence.

3 Medical Management in Breast Cancer

First, we give an informal description on the medical management as stated in the CBO guideline (and IKO protocol) that deals with locoregional treatment of operable breast cancer, i.e., T1-2 N0-1 M0 breast cancer according to the TNM classification system [9]. Thereafter, we discuss temporal logic as a means for formalizing the medical management of breast cancer.

3.1 Informal Description of Medical Management

According to the CBO guideline there are only two options for local treatment of operable invasive breast cancer: breast-conserving therapy (BCT) or modified radical mastectomy (MRM). BCT implies ample local excision of the tumour, an axillary staging procedure, and radiotherapy of the breast. MRM involves a total resection of the breast (mastectomy) and dissection of the axillary nodes (AD). The aim of BCT is to achieve a survival rate comparable to that following MRM with an optimal cosmetic result in terms of the treated breast. BCT is usually the preferred treatment unless the patient has a clear preference for MRM and there are no contra indications for BCT, i.e., there is no

- multicentricity (two or more tumour foci in different quadrants),
- diffuse malignant microcalcifications, or
- previous radiotherapy of the breast.

Another contra indication for BCT is obtained *during* surgery:

- the margins of the local excision remain tumour-positive after repeated local excision attempts.

In this case, local excision attempts are unsuccessful in removing the primary tumour and treatment therefore switches to MRM.

Treatment of the axillary nodes is also part of the treatment of breast cancer as the pathologic assessment of axillary lymph nodes remains the most important prognostic variable for the invasive breast cancer patient. An optimal assessment would be achievable by means of a complete axillary node dissection (AND). However, AND may lead to morbidity, e.g., pain, limited shoulder movement. An alternative for axillary staging is the sentinel node procedure (SNP), which only dissects the sentinel nodes, i.e., those nodes that drain the area of the breast where the primary tumour is located and thus are most likely to contain metastasis. The SNP is currently the standard procedure for axillary staging in breast cancer provided that the contra-indications do not hold, where contra-indications of SNP are defined as

- suspected or proven malignancy in the axillary nodes,
- tumour > T2,
- multiple tumour foci, and
- potentially disrupted lymph drainage due to recent axillary surgery or a large biopsy cavity following tumour excision.

When the SNP is not possible, complete axillary node dissection should be carried out. Furthermore, treatment of the axilla is indicated (i.e., dissection, radiotherapy) for all forms of lymph node metastasis.[4]

3.2 Temporal Logic Representation

The CBO guideline can be interpreted as (temporal) constraints on medical management. It has been shown in [12] that the step-wise, possibly iterative, execution of a guideline can be described precisely by means of temporal logic. The logic that we use here for specifying properties of medical guidelines is a combination of Computation Tree Logic (CTL) [3, 4, 6] and Linear Temporal Logic (LTL) [14].

CTL uses atomic propositions and Boolean connectives (e.g., $\neg, \vee, \wedge$) to build up more complicated expressions for describing properties of states. Furthermore, CTL formulas can be composed of *path quantifiers* and *temporal operators* for describing properties of *computation trees*, i.e., all paths that are possible from a certain state. The path quantifiers are $\mathbf{A}$ and $\mathbf{E}$ to specify that all of the paths or some of the paths starting at a specific state have some property. The temporal operators describe properties of a path through the tree. The four temporal operators used are $\mathbf{X}$, $\mathbf{G}$, $\mathbf{F}$, and $\mathbf{U}$. With $\mathbf{X}\varphi$ being true if φ holds in the next state, $\mathbf{G}\varphi$ if φ holds in the current state and all future states, $\mathbf{F}\varphi$ if φ holds in some state in the future (or is true in the current state), $\varphi\mathbf{U}\psi$ if φ holds until ψ holds, i.e., there is a state on the path where ψ holds and in every preceding state φ holds.

LTL provides operators for describing events along a single computation path. Each formula is of the form $\mathbf{A}f$, with f being a path formula, which is either an atomic proposition or inductively defined as $\neg f$, $f \vee g$, $f \wedge g$, $\mathbf{X}f$, $\mathbf{F}f$, $\mathbf{G}f$, or $f\mathbf{R}g$ with f, g path formulas.

The language we use for atomic propositions consists of medical actions $Actions$, medical plans $Plans$, and data structures $Data$:

$Actions$: {tumour-excision, mastectomy, axilla-dissection, sentinel-node}
$Plans$: {TREATMENT, BCT, MRM, AXILLA-STAGING}
$Data$: {CI-BCT, CI-SN, TF, SN, ITC}

with CI-BCT, CI-SN $\in \{\top, \bot\}$ denoting the contra indications for BCT and SN respectively, SN $\in \{unknown, neg, pos\}$ denotes whether there is a metastasis found in the lymph nodes after performing the SN procedure, TF $\in \{unknown, \top, \bot\}$ denotes whether the re-section margins are tumour free, and ITC $\in \{\top, \bot\}$ denotes whether there are isolated tumour cells.

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[4] The CBO guideline differs at this point with the IKO protocol as it makes an exception for isolated tumour cells.

4 Formalisation of Medical Management

Here, we give a constrained-based representation of the CBO guideline using the temporal logic representation discussed in the previous section. Furthermore, we interpret the recommendations in the IKO protocol and represent this in a more or less executable model. The goal is to verify whether the model of the protocol complies with the recommendations of the CBO guideline, or if there are differences, using a model checking approach [5].

4.1 Constrained-Based Represention Guideline

The final representation in temporal logic of the medical management in the CBO guideline is shown in Figure 1.

Constraints related to control structure
(1) $\mathbf{AG}(\text{TREATMENT} \rightarrow \mathbf{AF}(\text{BCT} \vee \text{MRM}))$
(2) $\mathbf{AG}(\text{CI-BCT} \rightarrow \neg\text{BCT})$
(3) $\mathbf{AG}(\text{BCT} \rightarrow \mathbf{AF}(\text{AXILLA-STAGING} \vee \text{MRM}) \wedge$ $\mathbf{AF}\text{ tumour-excision})$
(4) $\mathbf{AG}(\text{MRM} \rightarrow \mathbf{AF}\text{ axilla-dissection} \wedge \mathbf{AF}\text{ mastectomy})$
(5) $\mathbf{AG}(\text{AXILLA-STAGING} \rightarrow$ $\mathbf{AF}\text{ (axilla-dissection} \vee \text{sentinel-node}))$
(6) $\mathbf{AG}(\text{CI-SN} \rightarrow \neg\text{sentinel-node})$
(7) $\mathbf{AG}(\text{tumour-excision} \rightarrow$ $((\text{TF} = \bot \rightarrow \mathbf{AF}\text{ MRM}) \wedge (\text{TF} = \top \rightarrow \mathbf{AG} \neg\text{MRM}))$
(8) $\mathbf{AG}(\text{sentinel-node} \rightarrow$ $(\text{SN} = pos \wedge \neg\text{ITC} \rightarrow \mathbf{AF}\text{ axilla-dissection}))$
(9) $(\mathbf{G}\neg\text{MRM}) \rightarrow \mathbf{AG}(\text{sentinel-node} \rightarrow$ $\mathbf{AG}(\text{ITC} \rightarrow \mathbf{AG}\neg\text{axilla-dissection}))$
(10) $\mathbf{AG}(\text{TREATMENT} \rightarrow (\text{CI-SN} \rightarrow \mathbf{AF}\text{ axilla-dissection}))$
Constraints related to data
(11) $(\text{CI-BCT} \rightarrow \mathbf{AG}\text{ CI-BCT}) \wedge (\neg\text{CI-BCT} \rightarrow \mathbf{AG} \neg\text{CI-BCT})$
(12) $(\text{CI-SN} \rightarrow \mathbf{AG}\text{ CI-SN}) \wedge (\neg\text{CI-SN} \rightarrow \mathbf{AG} \neg\text{CI-SN})$

Figure 1. Constraint-based representation of the CBO guideline. BCT = breast conserving treatment, MRM = modified radical mastectomy, CI-BCT = contra indications for BCT, SN = result of sentinel node procedure, CI-SN = contra indications for SN, tumour-excision = segmental tumour excision, TF = tumour free resection margins.

Some constraints given by the guideline are not easily expressible in temporal logic, as they are not one to one related to the order of the protocol but involve other modalities except for time, such as the preference for BCT over MRM and the preference for the SNP over axilla-dissection for staging the axilla. Other assumptions regarding the patient data are implicit in the guideline, e.g., the status of the resection margins, i.e., whether they are tumour free (TF) or not ($\neg$TF), only becomes known after excision of the tumour and the existence of metastasis (SN=pos or SN=neg) only becomes known after the SNP. Here we have chosen not to consider these more implicit constraints.

4.2 Asbru Representation of the IKO Protocol

Much research has already been devoted to the development of representation languages for medical guidelines. Most of them consider guidelines as a composition of actions, controlled by conditions. However, many languages are not formal enough for the purpose of our research as they often incorporate free-text elements which do not have a clear semantics. Exceptions to this are PRO*forma* [8] and Asbru [16]. Here we use Asbru, because in previous research its semantics has been defined precisely [1] and can be translated automatically into SMV for model checking purposes [2].[5]

The overall structure of the Asbru model is given in Figure 2. It consists of nine plans ordered in a hierarchy. The top level plan 'treatment' will start by selecting the BCT plan, which may be rejected in case there are contra indications against doing breast conserving therapy. In that case, treatment will continue with a modified radical mastectomy (MRM). In case BCT is successfully completed, the treatment also completes and the MRM plan will not be started. The 'BCT surgery' plan consists of axillary staging and tumour excision, which are modelled as unordered plans, as the protocol does not explicitly state an order. To allow for a specific ordering of these two sub-plans we include a manual activation, but assume that the activation will be performed by a doctor eventually. In case of BCT, the axillary staging starts with an investigation of the sentinel nodes provided that there are no contra indications for doing this. In case it is rejected or, because the sentinel nodes are positive, the plan is aborted, and an axillary dissection has to be performed. Furthermore, it is possible that the excision aborts because the margins are not tumour free. Since BCT surgery waits for this sub-plan, in that case BCT surgery has to be aborted and therefore it is mandatory to do a MRM. Finally, we model that the MRM consists of a dissection of the axilla and a mastectomy as defined by the protocol. No particular order between the two is given.

The formal semantics of the Asbru model in Figure 2 is based on the plan state model described in [1], of which an SMV model was constructed using the method and tool described in [2]. Most variables dealing with patient data are initialised as *unknown* and receive an indeterministic value in the second step to make sure there is only one root of the model. Furthermore, we assume that they do not change during the treatment. The only variables that are initialised at a later stage are the status of the sentinel node, which becomes known during the SNP and whether or not the tumour margins that have been resected are tumour free, which becomes known at the excision of the tumour. Furthermore, fairness constraints have been added to ensure that the manual activation of both the axilla surgery and the tumour excision eventually occurs. In other words, the patient will not wait indefinitely for the treatments to start.

Using the above formalisation, the IKO protocol can be verified using the constraints of the CBO guideline using standard model checking techniques. However, guidelines and protocols are usually under-constrained, thereby allowing many treatment paths not occurring in medical practice. We therefore look at the inclusion of medical management in practice in the following section.

5 Comparison Using Background Knowledge

In this section, we use the textbook of Roses [15] to create a precise model of medical management in practice. This model will be formalized into a decision tree, referred to as *background knowledge*, which will be used to select that part of the IKO protocol that is consistent with [15] and then verify for only this selected part whether it complies with the constrained based representation of the CBO guideline.
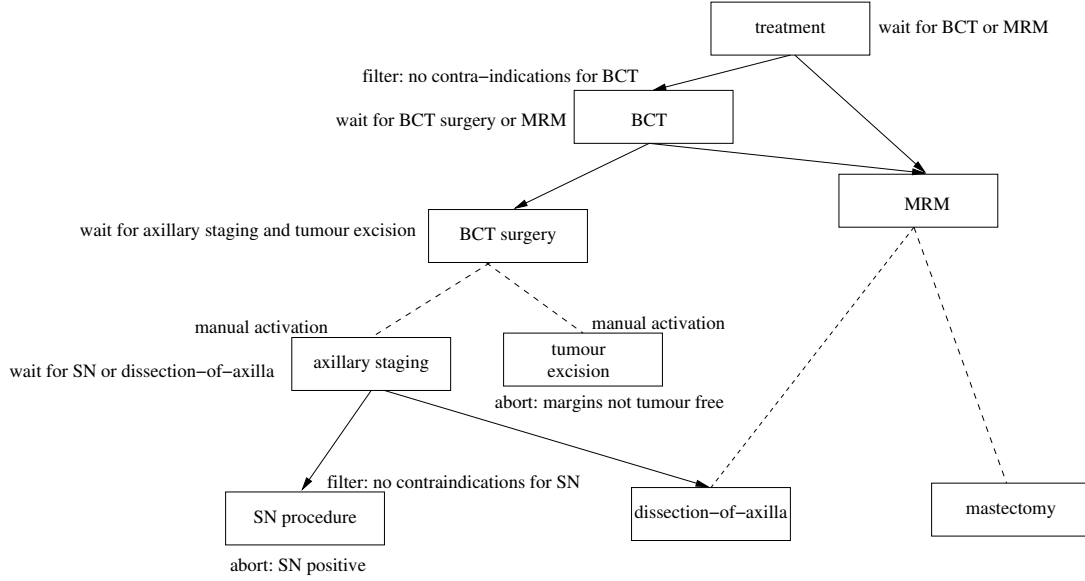
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[5] http://www.cis.ksu.edu/santos/smv-doc/

Figure 2. Asbru interpretation of IKO protocol. Arrows represent sequential plans, dotted lines represent unordered sub-plans

5.1 Medical Management in Practice

According to [15], the sentinel node procedure (SNP) is started before segmental excision (i.e., used in BCT) or mastectomy. The sentinel nodes (SNs) are then immediately sent to the pathology lab, where they are examined during surgery. If the SLNs are found to be positive, axillary dissection can be completed during the primary breast surgery in one setting.

Furthermore, [15] differs with the CBO guideline and IKO protocol in the case of recurrent tumour positive re-section margins in the BCT treatment. Whereas CBO and IKO recommend to switch the treatment to MRM, which includes axillary dissection, [15] only recommends a mastectomy with axillary dissection dependent on sentinel node histopathology.
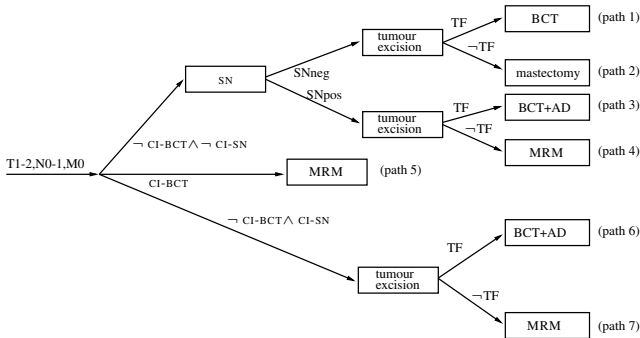

Figure 3. Background knowledge: possible treatment paths for surgery of operable invasive breast cancer. CI-BCT = contra indications BCT, CI-SN = contra indications SNP, TF = tumour free resection margins, AD = axillary dissection.

Information from [15] can be represented in a decision tree as shown in Figure 3, which deals with the ordering of medical actions treating the primary tumour (BCT and MRM) and the axilla (SN

and/or AD).[6] Nodes represent medical actions or plans, arcs represent constraints. A path from the root node to a leaf node represents a treatment path, which defines the order of medical actions when the constraints on the path are satisfied.

5.2 Comparing Medical Management with the IKO Protocol

Clearly, the medical management stated by the IKO protocol is less precise than the medical management performed in practice. Typically, one would expect the medical management in the protocol to be under constrained when compared to the medical management in practice. To verify this for the IKO protocol, we have transformed the 7 possible treatment paths in Figure 3 into a number of CTL properties (2 shown below) and verified whether these paths occur in the protocol.

$$(1) \quad \mathbf{EX}(\neg \text{CI-BCT} \land \neg \text{CI-SN} \land$$
$$\mathbf{EF}(\text{sentinel-node} \land \text{SN} = neg \land$$
$$\mathbf{EF}(\text{tumour-excision} \land \text{TF} \land$$
$$\mathbf{AG}(\neg \text{mastectomy} \land \neg \text{AD}))))$$
$$(2) \quad \mathbf{EX}(\neg \text{CI-BCT} \land \neg \text{CI-SN} \land$$
$$\mathbf{EF}(\text{sentinel-node} \land \text{SN} = neg \land$$
$$\mathbf{EF}(\text{tumour-excision} \land \neg \text{TF} \land$$
$$\mathbf{EF}(\text{mastectomy}) \land \mathbf{AG}(\neg \text{AD}))))$$

With the SMV model checker we were able to verify that all paths, except (2), can occur in the IKO protocol. Path (2) does not hold in the IKO protocol because it recommends a MRM whereas [15] recommends a mastectomy, i.e., axillary dissection is included in the medical management according to the protocol, but not according to [15]. Whether the protocol or the textbook is incomplete or incorrect should be discussed with medical experts.

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[6] We abstract from radiotherapy and isolated tumour cells.

5.3 Selective Comparison of Guideline Constraints and Protocol

Clearly medical management is much less precisely defined in the CBO guideline and the IKO protocol than in the medical textbook of Roses [15]. Hence, any model that is only based on a written document of a guideline or protocol without the inclusion of background knowledge, will include many paths in which medical actions are unrealistically ordered. Many rightful properties of medical management may therefore not hold for the model constructed. Either one can choose to improve the model such that it adheres to medical practice (but not to the guideline document), or one can select only those paths in the model that also occur in medical practice for which then the property needs to be proven.

One approach to accomplish this is by including assertions to the model of the protocol or guideline. Assertions are statements that should hold in every execution path of the protocol, which, in Cadence SMV, are written down in the form of linear time logic (LTL) properties. This makes it possible to state properties about the relation of medical actions in time. In order to do this, the background knowledge formalised in terms of a decision tree, needs to be interpreted in terms of such LTL assertions. It is obvious to guarantee that such statements are sound with respect to the decision tree. Here, we consider the following LTL assertions.

(1) $(\neg\text{CI-BCT} \wedge \neg\text{CI-SN}) \leftrightarrow \mathbf{F}$ sentinel-node
(2) $(\mathbf{F}$ sentinel-node$) \rightarrow$
$\quad((\neg\text{tumour-excision} \ \mathbf{U} \ \text{sentinel-node}) \wedge$
$\quad\mathbf{F}$ tumour-excision$)$
(3) $((\mathbf{F}$ sentinel-node$) \wedge \text{SN} = neg \wedge$
$\quad(\mathbf{F} \ \text{TF})) \rightarrow (\neg(\mathbf{F} \ \text{AD}) \wedge \neg(\mathbf{F} \ \text{MRM}))$
(4) $((\mathbf{F}$ sentinel-node$) \wedge \text{SN} = neg \wedge (\mathbf{F} \ \neg\text{TF})) \rightarrow$
$\quad((\mathbf{F}$ mastectomy$) \wedge \neg\mathbf{F} \ \text{AD})$
(5) $((\mathbf{F}$ sentinel-node$) \wedge \text{SN} = pos \wedge (\mathbf{F} \ \text{TF})) \rightarrow$
$\quad((\mathbf{F} \ \text{AD}) \wedge \neg(\mathbf{F} \ \text{MRM}))$
(6) $((\mathbf{F}$ sentinel-node$) \wedge \text{SN} = pos \wedge (\mathbf{F} \ \neg\text{TF})) \rightarrow \mathbf{F} \ \text{MRM}$
(7) $(\text{CI-BCT} \rightarrow (\neg(\mathbf{F}$ tumour-excision$) \wedge \mathbf{F} \ \text{MRM}))$
(8) $(\neg\text{CI-BCT} \wedge \text{CI-SN}) \rightarrow \mathbf{F}$ tumour-excision
(9) $(\neg\text{CI-BCT} \wedge \text{CI-SN} \wedge (\mathbf{F} \ \text{TF})) \rightarrow ((\mathbf{F} \ \text{AD}) \wedge \neg(\mathbf{F} \ \text{MRM}))$
(10) $(\neg\text{CI-BCT} \wedge \text{CI-SN} \wedge (\mathbf{F} \ \neg\text{TF})) \rightarrow \mathbf{F} \ \text{MRM}$

Assumption (1) and (2) deals with the use of sentinel node procedure and the order between this and the excision of the tumour. Assumptions (3) to (6) are concerned with paths (1) to (4). Assumption (7) deals with path (5). Finally assumptions (8) and (9) deals with path (6) and (7). However, we have seen in the previous section that (4) is not coherent with the model (i.e., from (4) it follows the antecedent of (4) is false), so in this form it is not usable. We could therefore either adapt the assumption so that it corresponds to the guideline or omit it. Here, we have omitted it.

Verifying the guideline constraints with SMV on the Asbru model of the IKO protocol using these assumptions, shows that, consistent with the description in Section 5.2, constraint (9) does not hold in the Asbru model of the IKO protocol, indicating a difference between protocol and guideline with respect to medical management in practice. Although, in this case the difference between protocol and guideline is clear and could also have more easily been found through an informal analysis, this is largely because the protocol and guideline have a very similar structure and their recommendations are almost identical. However, the approach taken is independent of the underlying structure of the protocol and guideline. Therefore, this case study shows that formal techniques can be used to compare guideline and protocol independent of their underlying document structure.

6 Related Work

Researchers in AI acknowledge that medical guidelines are good real-world examples of highly structured documents that are amenable for formalization. Much research has already focused on designing computer-oriented languages and developing tools for their employment. However, not many researchers seem to note that guidelines may exist at different levels of abstraction, which we designated here as 'guideline' and 'protocol' with protocol being a less abstract version of a guideline. Taking this view on guidelines raises a nummer of issues currently not addressed in literature.

First, guidelines are typically under-constrained thereby omitting many details about treatment order. Our work contrasts on this point with [17] for example, in which guidelines are more viewed as programs, but in which no execution paths are excluded that are illogical for medical management in practice. Clearly, additional medical background knowledge is needed to supplement the knowledge in the guideline document as was already acknowledged in previous work [11, 10]. Whereas in previous work we incorporated background knowledge into the model, here we have used background knowledge to restrain the number of possible execution paths.

Second, researchers have focused on the verification of the quality of medical guidelines. However, verification of guidelines still takes a lot of effort. By using formal methods to find differences between a protocol and a guideline, one could reuse verification results of the guideline for the protocol and only focus on those parts that are different. Current work on verification of guidelines only consider guidelines to be solitary objects. No reference is made to verifying adaptations of guidelines.

Third, locating differences between guidelines and protocols is a novel topic, which has previously only been looked at from an informal angle [13]. The formal techniques used in our research extends previous work on model checking medical guidelines [2] and complements the techniques used in earlier work on quality checking medical guidelines [17, 11, 10].

7 Discussion

The aim of this work was to obtain insight into the differences and similarities between guidelines and protocols, based on the assumption that protocols should be looked upon as local modifications of guidelines. As a guideline is a starting point for drafting a protocol concerning the same topic, the development of a protocol based on a guideline can been seen as a transformation process. In the project, we have only been able to find end point protocols; as a consequence, the transformation process could only be described as consisting of a single step. In reality, it may be a more iterative process to design a protocol on the basis of an available guideline.

With the help of an expert clinical oncologist, a preliminary informal analysis of the protocol about management of breast cancer was carried out, which yielded insights into differences and similarities that were valuable as a starting point for a more in-depth analysis using formal methods.

One of the questions that emerged in the course of the research was whether the guideline or protocol ought to be adopted as the gold standard for comparison. Based on insights obtained by consulting literature on guideline development, we decided to take neither

the guideline nor the protocol as the gold standard, but medical management in practice up to the point where it is consistent with the guideline and/or protocol. Using model-checking as principal tool, the guideline and protocol, now seen as defining logical constraints to medical management, were compared to a decision tree describing the medical management. Some of the outcomes of this research cast doubts on the content of both guideline and protocol, in the sense that at least some sort of explanation is needed in order to understand why there are differences between the decision tree, on the one hand, and guideline and protocol, on the other hand. We believe that these results give a promising starting point for further investigating the relations between guidelines, protocols, and medical management in practice.

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