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Evaluation of Reporting Based on Descriptional Knowledge

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Abstract **Objective:** In an attempt to enhance the completeness and clarity of clinical narratives, the authors developed a general formalism for the entry of structured data. The objective of this study was to gain insight into the expressive power of the formalism through its use for reporting in endoscopy.

Design: Each of ten endoscopists reported twice about eight endoscopy videotapes. They produced free-text reports first, and then structured reports using this formalism. Statements in the resulting reports were compared.

Results: In total, 6.8% of the endoscopists' statements could not be expressed in structured options. Most of these statements were not due to limitations of the formalism itself. Topics mentioned in the free-text reports were described more frequently in the structured reports and, in addition, the structured reports included a greater variety of topics. Overall, increases of 83% for topics not related to abnormal findings (366 in free-text reports and 671 in structured reports) and 45% for features of abnormal findings (406 in free-text reports and 586 in structured reports) were observed. Although there was an overall information gain, features of abnormal findings were, on average, described by only half of the endoscopists.

Conclusion: The expressive power of this formalism is promising, but general, multipurpose usage of the acquired data requires that topics be described by a larger percentage of physicians. Since this formalism led to more complete and more uniform data, additional research is justified to study how spontaneous reporting can be augmented further. The few subjects that occurred less often in structured reports suggest a possible negligence effect of structured reporting.

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Because data in paper-based patient records have limited suitability for formal analysis, computer-based patient records (CPRs) are increasingly gaining interest.[1] In early CPRs, coding was mainly confined to laboratory data, medications, and diagnoses, whereas the narratives, such as findings of history taking and physical examination, were recorded in free text.[2–6] Free-text data, even in electronic form, have drawbacks—spelling errors, ambiguity, and incompleteness. Although several efforts have been

undertaken to obtain coded data from free text, techniques such as natural language processing do not improve the quality of the recorded data. Formalisms that a priori try to collect data in a structured, coded format are more likely to increase the usefulness of the data for research, decision support, quality assessment, and clinical care itself.

When the domain of the data that are to be captured is small and well circumscribed, the use of paper-[7] or computer-based[8–13] forms has been shown to be feasible, particularly when the data elements that need to be captured are well defined. However, when the domain becomes large, forms become impractical to accommodate the flexibility to which the physician has become accustomed when using free text.[14] Furthermore, limiting data capture to essential elements restricts the expressive power.

To overcome these limitations, we have developed a formalism based on explicit descriptional knowledge.[15] Descriptional knowledge is general knowledge that describes where, when, and how concepts can be described. The aim of our formalism was to enable the capture of structured, coded data with an expressive power approaching that of free text, while maintaining flexibility and reducing ambiguity. To evaluate these objectives, we built a data-acquisition front end conforming to our formalism: the entry program. The behavior of this general entry program is determined by a combination of user input and domain-specific descriptional knowledge. This domain-specific descriptional knowledge is stored in a knowledge base. We have developed knowledge bases for general internal medicine (physical examination), gastrointestinal endoscopy, pathology (cutaneous lymphomas), and radiology (chest x-rays).

For formalisms aimed at capturing clinical data, a prime criterion for acceptability is the ability to express the clinical findings. In this study, we focus on the expressive power of a structured data entry formalism in a specific domain. This study does not assess the practical implication and feasibility of using structured data entry in a routine setting, nor does it demonstrate that a change in report practice results in better care. This study attempts to explore the limitations of our structured data entry formalism. We sought to answer the following questions:

- How good is the expressive power of our formalism? Can physicians freely and spontaneously express the concepts they need to when restricted to using our predefined structure and terminology?
- What happens to the quantity of acquired data when structured data entry is used? Other researchers[11–13] have shown that the "completeness" of small sets of items has increased using structured data entry compared with free-text reports. Is such an increase also feasible when the items that can be captured extend beyond such limited sets?
- What happens to the uniformity of the acquired data? Do reports by multiple observers, describing the same examination and produced with our formalism, resemble each other more than free-text reports resemble one another?

We chose to study the domain of endoscopy. A previous study had shown that the size and complexity of this domain were great enough to require an approach other than forms.[16] That study had also shown that endoscopists themseleves indicate that their currently produced free-text reports do not contain sufficient detail.

Methods

Study Design, Participants, and Study Material

For this evaluation, we chose an experimental setting in which esophago–gastro–duodenoscopy videotapes were described, both in free text and with the entry program, by ten endoscopists. Two of the endoscopists worked in our university hospital, and each of the other eight worked in a hospital affiliated with our university hospital. All participated voluntarily.

Since the objective of this study was to investigate the endoscopy reports as a whole, not solely descriptions of abnormal findings, we videotaped the *complete* examination of each patient who would be undergoing an esophago–gastro–duodenoscopy. The first eight videos that contained at least one abnormality were selected. In total, the eight videos showed 14 abnormal findings.

For each video, each endoscopist prepared a free-text report in his usual fashion (nine dictated their reports and one wrote his). Two to four weeks later, the endoscopists prepared the reports using the entry program, after the videos had been shown again. The endoscopists had never used or seen the program before, and were given a short introduction (about ten minutes) on the use of the program. Any observation that could not be expressed in structured options was noted.

Throughout the study no constraints were placed on

the amount of time the physician spent on recording the findings.

Short Description of the Entry Program

The entry program is menu driven, and its behavior is determined by a combination of user input and the content of the descriptional knowledge base used. The endoscopy knowledge base basically consists of concepts, each of which exists only once in the knowledge base. Concepts have relations with other concepts, and the entry program uses these relations to show the descriptors for each selected concept: all concepts describing that concept in a given context. This process is repeated after a selection by the user. Furthermore, the knowledge base represents whether concepts may occur multiple times in a context, and whether a physician may state that a concept is absent. A physician may also use "normal definitions" in our formalism, that is, a physician needs to define only once what he or she means when using a statement such as "no abnormal findings in the esophagus." When used in reporting, the explicit, physician-specific meaning of such a statement is then incorporated in the report. Moorman et al.[15] provide a detailed description of the formalism. We use the term structured report when referring to reports made with the entry program.

Three types of data cannot be expressed with the current prototype and knowledge base: uncertainties, performed actions (e.g., biopsies), and relations between described findings (e.g., it can be stated that there is an ulcer and a polyp, but it is not possible to formally state that the ulcer is located on or near the polyp).

Analysis of Reports

In this study, we restricted ourselves to the description of findings; other components of reports, such as indications and conclusions, were not included.

Free-text Reports

To enable comparison of the reports, we first made an inventory of the contents of the free-text reports by identifying all statements. A statement is defined as each combination of a subject and a described feature. In Table 1, we provide an example of a free-text report and its statements.

Every statement from the free-text reports was assigned to one of the following categories:

- General statements. These are statements that appeared in each group of reports. The term group refers to all reports describing the same video. Hence, general statements are abnormality independent. Examples of these statements are the position of the Z-line with respect to the diaphragm impression, and the shape of the pylorus.
- Features. For each of the 14 abnormal findings, a list of features describing that finding was made. Examples of these features are the size and shape of an ulcer.
- Unclear feature descriptions. Features were placed in this category when it was unclear to which feature a description referred. In the example of Table 1, the expression "irregular ulcer" is considered

Table 1 ■

Example of a Free-text Report and Its Statements

	Statements	
Free-text	Subject	Described Feature
The esophagus is covered with normal mucosa.	Esophagus mucosa	Aspect
The Z-line is situated directly above the hiatus.	Z-line and hiatal impression of diaphragm	Position with respect to each other
In inversion, we see that the hiatus closes around the scope.	Hiatus	Closure around scope
The gastric mucosa is intact everywhere.	Gastric mucosa	Aspect
The pylorus has an oval shape, and can easily be passed.	Pylorus	Shape Passage
In the anterior wall of the bulb, we see a deep, more or less regular,* round-shaped ulcer, covered with fibrous exudate. The border is regular. The diameter is 5 to 6 mm.	Ulcer	Location site Anatomic location Depth Base/shape*—regularity Shape Type/color of exudate Border—regularity Numeric size
In the descending duodenum, we see intact mucosa.	Descending duodenum mucosa	Aspect

*From the free-text description it remains unclear to what feature "regular" refers.

unclear because it may refer to the regularity of the base or to the regularity of the shape.

- Other statements. Any statement not falling into one of the above three categories.

In addition, we constituted, per abnormal finding, a list with the type labels that the endoscopists used to name an abnormal finding. For example, one endoscopist would use the term erosion while another endoscopist would use the term ulcer to describe the same lesion.

Structured Reports

The same inventory of statements and lists was made for the contents of the structured reports. An additional list was made containing all statements that the endoscopists could not express using structured options in the entry program.

Comparison of Reports

We compared the following topics:

- General statements: number of different general statements, and number of times that they were mentioned.
- Features: number of different features per abnormal finding, and number of endoscopists who mentioned each finding.
- Other statements: total number of mentioned statements in this category.
- Type labels: number of different type labels per abnormal finding.

To gain insight into the nature of the unclear statements, we asked the endoscopists to attempt to express their statements in our formalism, after they had made their structured reports.

Results

Quantity of the Data

In total, the free-text reports contained 871 statements: 366 general statements, 406 features, 60 other, and 39 unclear statements. The structured reports contained 1,297 statements: 671 general statements, 586 features, and 40 other. In total, 88 statements could not be expressed with the entry program.

The occurrence of general statements and features in the reports is summarized in Table 2.

Table 2 ■

Numbers of Different General Statements and Features, and Numbers of Times They Were Described in Free-text Reports and in Structured Reports

	No. Different	No. Times Described	
		In Free-text Reports	In Structured Reports
General statements			
In free-text and in structured reports	8	366	448
New in structured reports	11	—	223
Features			
In free-text and in structured reports	101	406	526
New in structured reports	22	—	64

General Statements

In the free-text reports, we identified eight different general statements; these were mentioned 366 times. These same eight general statements were mentioned 448 times in the structured reports. In the structured reports, 11 additional statements fell into the category of general statements. These were mentioned 223 times. Thus, the total number of mentioned general statements increased 83%, from 366 in the free-text reports to 671 in the structured reports.

Features

In the eight videos, 14 abnormalities were present. In free text, an abnormality was described by, on average, 7.2 features (in total, 101 features), and every mentioned feature was described, on average, by 4.0 endoscopists (in total, 406 described features). These same features were described by, on average, 5.2 endoscopists in structured reports (an increase of 30%). Of the 101 free-text features, 22 were described by as many endoscopists in structured reports, 25 were described by fewer endoscopists in structured reports, and 54 were described by more endoscopists in structured reports. Furthermore, on average, 1.6 more features per abnormality were described in the structured reports (in total, 22 more features; an increase of 22%), which were, on average, described by 2.8 endoscopists. Overall, the 123 structured features were, on average, described by 4.8 endoscopists (in total, 590 described features).

Of the statements that were described less often in the structured reports, the most striking decrease concerned a video in which esophageal varices were

present. In free text, eight endoscopists made the statement "varices in the fundus are not present" (i.e., no varices in the stomach), while only one endoscopist made this statement in the structured reports.

Expressive Power of the Model and the Knowledge Base

During data entry, the endoscopists felt that 88 statements could not be expressed in structured options. As a statement was sometimes made by different endoscopists, or by the same endoscopist in different reports, 51 different statements were identified. As shown in Table 3, we grouped these statements according to the modification that would be required to allow their expression in structured options.

Modification of the Knowledge Base: 46 of the 51 Different Statements

Four of the statements would be resolved by changing a concept. For example, the term "circular," used in the knowledge base to denote a "shape," should be changed to "round" because some of the endoscopists preserved the term "circular" to denote "covering the complete circumference of (e.g.) the esophagus"; and the concept "signs of previous bleeding" should be changed to "signs of recent bleeding."

Thirteen of the statements would be resolved by adding relations between existing concepts in the knowledge base. For example, some of the endoscopists wanted to describe the "surrounding mucosa" of a "scar," the "peristalsis" in the duodenum, and the "part" (e.g., "distal," "middle," or "proximal") of the location "bulb."

Eight of the statements would require the introduction of new concepts. For example, two endoscopists wanted to describe a shape using the term "triangular," and preferred to use "hours" to describe the site of findings in tubular organs instead of the options "left," "right," "front," and "back."

Twenty-one statements would require careful consideration before they could be added to the knowledge base because they would possibly introduce redundancy or ambiguity, or would add no "relevant" detail. Two types of statements that introduce redundancy can be distinguished: the statement is inherent to a concept, or the statement can be formulated using concepts in the knowledge base. An example of the first type is that some of the endoscopists wanted to state that an erosion was "superficial" or was "red." However, by definition, an erosion is superficial, and when an erosion is not covered by exudate (which is one of the options by which to describe an erosion), it is always red. It is therefore unclear whether such statements add relevant detail. An example of the second type is that the endoscopists were looking for words such as "particularly" or "most pronounced," e.g., to state that the mucosa was red in the fundus and antrum, but most pronounced in the antrum. Although it would be possible to add the possibility of such statements to the knowledge base, we feel that the endoscopists probably meant something such as "there is mild redness in the fundus, and severe redness in the antrum." Therefore, addition of concepts as "particularly" would introduce not only redundancy, but also ambiguity.

Table 3 ■

Statements That the Endoscopists Could Not Make in Structured Options, Grouped According to Required Modification

	No. Different Statements	No. Times Mentioned
Knowledge-base modification	46	77
Concept change	4	5
Addition of relations	13	30
Addition of concepts and relations	8	10
Debatable	21	32
Model adjustment	5	11
TOTAL	51	88

Model Adjustment: 5 of the 51 Different Statements

Five of the statements would require an extension of the model. Although all fall into the category "relations between findings" (e.g., the pylorus is asymmetrically deformed by an ulcer in the bulb), it will also be necessary to support statements about the arrangement of an abnormality when it occurs many times (e.g., erosions occur throughout the stomach, but are arranged in groups or in rows).

Uniformity and Ambiguity

In free text, we found, on average, 5.0 different type labels to name a given abnormal finding; in the structured reports, this had decreased to 2.2. Whereas in free text none of the abnormalities had been named with the same type label by all of the endoscopists, in the structured reports all ten endoscopists used the same type label for five of the 14 abnormalities.

In the free-text descriptions of the abnormal findings, we encountered 39 unclear feature descriptions. When asked to do so, the endoscopists had no trouble translating those statements into knowledge-base concepts. All unclear feature descriptions that we

Table 4

Unclear Feature Descriptions of Ulcers, and Their Translations into Knowledge-base Concepts

Expression in Free Text	Translated into Knowledge-base Concepts
Ulcer is "punched out"	Ulcer is deep, sharply demarcated, and surrounding mucosa has normal color
Exudate of ulcer is elevated	Border is elevated
Ulcer in local thickening	Border is elevated
Base is messy	Base is irregular
Base is clean	Base contains white exudate
Base is smooth	Base is regular
Irregular ulcer	Shape and base are irregular
Border is quiet	Border is regular
Surrounding mucosa is quiet	Surrounding mucosa has normal color, and is not swollen
Border is sharp	Ulcer is sharply demarcated
Border is red and swollen	Surrounding mucosa is red and swollen

encountered in the free-text descriptions of ulcers, together with their knowledge-base translations, are listed in Table 4.

Discussion

The main objective of this study was to gain insight into the differences between reports expressed in free text and reports expressed in our formalism. Ten endoscopists reported about eight videotapes of complete endoscopic examinations using both methods. We studied the expressive limitations of our formalism and the quantity of the data and assessed differences in uniformity.

Although several evaluations of programs for structured data entry have been reported, only a few describe more than user acceptance and/or time requirements alone. The main focus of our research was the expressiveness of our structured data entry formalism; we did not attempt to assess practical feasibility or time requirements.

Kuhn et al.,[11] Bell and Greenes,[12] and Gouveia-Oliveira et al.[13] have studied the completeness of free-text and structured reports in the domains of upper abdominal ultrasound, pelvic ultrasound, and endoscopy, respectively. These three studies differ from our study with respect to study design. The three studies evaluated reports produced in a clinical setting, whereas our study was done in an experimental setting. This allowed us to study reports describing the same examination.

Furthermore, in assessing the completeness of reports, the studies took as a starting point elements considered essential and/or of great clinical importance. In other words, they were restricted to elements that always need to be described in a report, or in the description of a given finding. This is what we refer to as the form-based approach. However, in a previous inventory,[16] we found that in endoscopy reporting, such essential elements hardly exist, and that the presence of a description of an element depends on the circumstances in which it is found. The inclusion of the complete descriptive contents of reports in our evaluation allowed us insight beyond essential elements alone.

Moreover, how often a statement is regarded as present will depend on the level of detail that is studied. Gouveia-Oliveira et al., for example, studied whether the border of an ulcer was described, whereas we studied whether the regularity, elevation, etc., of the border of an ulcer was described.

Finally, Kuhn et al.[11] and Bell and Greenes[12] took the percentage of structured reports with free-text annotations as a parameter for expressiveness. We feel that such a parameter is less informative because it gives no insight into the proportion of information formulated in free text.

In our experimental setting, the endoscopists may have been more motivated to describe features than they would have been in a clinical setting. This is, for example, illustrated by the fact that in the free-text reports of this study, the numeric size of abnormalities was described in almost 90% of the cases, whereas it was described in only 30% of the cases in an earlier report inventory.[16] However, since circumstances for the two methods of reporting were equal in our study, over-motivation would hardly have effected comparison of the two methods.

With regard to the expressive power of our formalism, we conclude that relatively few statements could not be expressed. If we compare the 88 statements that could not be made with the 1,297 statements that the endoscopists made in their 80 structured reports, then 6.8% of their statements could not be expressed with the current model and endoscopy knowledge base. Moreover, half of these 88 state-

ments would require only minor additions to or modifications of the knowledge base.

It remains debatable whether one-third of the 88 statements should be added as structured options. Reasons for not adding these to the knowledge base would be that they would possibly introduce unnecessary ambiguity or redundancy, or that they would add no relevant detail. This will require extensive debate, as shown by the following example. From the knowledge-base developer's point of view, adding concepts to describe "depth" to the descriptors of erosion would not add any information because an erosion is, by definition, superficial. It may be that the endoscopist who wanted to make such a statement would agree that it was indeed self-explanatory. However, the endoscopist may possibly want to add "superficial" on purpose to accentuate this for the physician who had referred the patient and who may not have sufficient endoscopic knowledge to appreciate the terms used.

Because the five statements that would require extension of the model all dealt with relations between findings, adding such expressiveness to our formalism has high priority.

With regard to the quantity of collected data, we first want to discuss whether it is a relevant parameter. In a previous study,[16] we showed that endoscopists are dissatisfied with currently produced free-text reports, and concluded that these reports do not report what endoscopists think should be reported. This finding led to our assumption that any increase in the quantity of the reported data should be regarded as a gain. The question of whether a newly described item has clinical significance is virtually impossible to answer, particularly since the previous study also showed that consensus among endoscopists was nearly absent regarding the question of whether an item should be included in a given report. Therefore, we took as a starting point that what an endoscopist wants to state must be possible to state, as long as it does not cause redundancy or ambiguity.

In the discussion of change in the quantity of collected data, we distinguish the general statements from the statements about features of findings.

An increase of 83% was seen in the documentation of general statements. Particularly, the increase in the number of different general statements (eight vs 19) accounted for this. The reason for this increase probably lies in the substitutions of normal definitions in our formalism.

With regard to features, we noted that features that had been described in the free-text reports were described 30% more often with our formalism. Furthermore, there was an increase of 22% in the number of described features per abnormal finding.

Because our comparison extended beyond essential elements, we were able to demonstrate that new elements also appeared in the structured reports, and that the occurrence of elements in the structured reports was associated with the a priori occurrence in the free-text reports. For example, new features were, on average, described by only 2.8 endoscopists, whereas the features that had already been present in the free-text reports were described by 5.2.

A peculiar observation was that in the reports concerning the video in which esophageal varices were described, the absence of varices in the gastric fundus was no longer reported in the structured reports. In our descriptional knowledge base, the option to describe varices in the gastric fundus is not offered when esophageal varices have been selected. Thus, varices in the gastric fundus are not brought to the attention when describing esophageal varices. The low description rate of the varices in the gastric fundus may be explained by the fact that the endoscopists were so preoccupied with the offered options for description, they forgot their normal clinical thinking. Of course, this may be a transient issue that wears off as endoscopists gain more experience in using structured reporting, but it may also point to a potential danger of structured reporting: topics that are not brought to the attention may be neglected. This observation stresses the fact that programs using structured data entry should be as complete as possible because structured data entry may have not only a reminder effect, but also a negligence effect. In our descriptional knowledge model, a solution is already provided: options can be added to a menu that do not really describe the preceding concepts, but are cross-references to other concepts.

Furthermore, we noted that 25 features were described by fewer endoscopists in the structured reports. These features were so miscellaneous that a structural mechanism is difficult to pinpoint. It may be that because the physicians could not express uncertainties, they preferred not to describe a feature of which they were not completely convinced.

Inherent to the use of structured reporting is that reports become more uniform. In this study, this was shown by 1) increases in the number and the description rate of general statements, 2) an increase in the number of endoscopists describing a feature, 3) a decrease in the number of type labels used to name an abnormal finding, and 4) the fact that unclear

statements could be translated into knowledge-base statements.

Despite these promising results, conclusions regarding the suitability of the acquired data for general, multipurpose use are less positive. For formal analysis, it would be ideal if endoscopists would use the same type labels to name abnormal findings, and would describe the same topics for a given examination. However, in this study, all of the endoscopists used the same type label for only five of the 14 abnormal findings, and features were, on average, described by only 4.8 endoscopists. Furthermore, one has to consider that we took the fact that a feature *was* described as a parameter for uniformity, and not *how* it was described (e.g., whether every endoscopist used the same option when he described border regularity). Such interobserver variability was the subject of a previous study.[17]

Limitations

We performed this study for the endoscopy domain, and in an experimental setting. Although our formalism is general and was developed to enable the capture of many types of medical descriptive information, it remains to be seen whether the results of this study will also apply in other medical domains. Therefore, we tried as explicitly as possible to distinguish, in the discussion of the results, model shortcomings from shortcomings of the endoscopy knowledge base studied. Although the model cannot yet represent complex temporal relationships, it looks promising for other domains involving momentary observations, as mentioned earlier.

In this study, we did not attempt to mimic a clinical environment. Therefore, the results are difficult to generalize to settings where clinicians are under time pressures. We considered an experimental setting more suitable to study practical feasibility, namely, expressive power. If the endoscopists had refrained from describing certain findings due to time pressure, we would not have gained insight into whether those findings could have been expressed. If the experimental setting had not yielded a gain in reported facts, the need for an evaluation under clinical time pressure would have been eliminated.

Furthermore, it may be argued that more reporting is not necessarily better reporting. Although endoscopists indicate that more detailed reporting is useful, the study does not provide a clinical evaluation of the generally shared opinion. Also, the study does not take into account that more reported facts may decrease the subsequent readability of a report.

Conclusions and Recommendations

Our formalism offers a promising expressive power. The underlying descriptional knowledge model needs to be extended with the possibility to represent relations between findings to further increase the expressive power.

We demonstrated that with structured reporting the quantity of recorded data increased. The amount of increase, however, depended on the type and the a priori presence of data in the free-text reports. In the structured reports, subjects were described more often and new subjects were described. This indicates that an increase of data is also possible beyond the form-based, essential-elements-only approach.

Despite the increase in the completeness and uniformity of the structured reports, we conclude that the suitability of the acquired data for general, multipurpose usage is suboptimal. Recent studies, however, indicate that physicians may record more data in a formal way, once it is to their benefit.[18,19] Furthermore, the participants in this study were all experienced physicians. Therefore, we believe that, besides additional research to improve the quantity of spontaneously reported data, it will be valuable to study the educational effects of formal reporting by physicians who are just starting the reporting routine. Finally, further evaluations of our formalism are needed to assess whether the results of this study also apply to other domains.

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