Radiological structured report integrated with quantitative imaging biomarkers and qualitative scoring systems

Abstract

The benefits of structured reporting (SR) in radiology are well-known and have been widely described. However, there are limitations that must be overcome. Radiologists may be reluctant to change the conventional way of reporting. Error rates could potentially increase if SR is used improperly. Interruption of the visual search pattern by keeping the eyes focused on the report rather than the images may increase reporting time. Templates that include unnecessary or irrelevant information may undermine the consistency of the report. Last, the lack of support for multiple languages may hamper the adaptation of the report to the target audience. This work aims to mitigate these limitations with a web-based structured reporting system based on templates. By including field validators and logical rules, the system avoids reporting mistakes and allows to automatically calculating values and radiological qualitative scores. The system can manage quantitative information from imaging biomarkers, combining this with qualitative radiological information usually present in the structured report. It manages SR templates as plug-ins (IHE-MRRT compliant and compatible with RSNA's Radreport templates), ensures a seamless integration with PACS/RIS systems, and adapts the report to the target audience by means of natural language extracts generated in multiple languages. We describe a use case of SR template for prostate cancer including PI-RADS 2.1 scoring system and imaging biomarkers. For the time being, the system comprises 24 SR templates and provides service in 37 hospitals and healthcare institutions, endorsing the success of this contribution to mitigate some of the limitations of the SR.

Background

The structured report in radiology has demonstrated benefits for radiological reporting [1]–[8]: (I) disease-specific report templates can improve clarity and quality in reporting, and ensure consistent use of terminologies in practice. (II) Checklist-based reports can reduce errors in diagnosis, as well as reduce grammatical errors of digital speech recognition systems. (III) Structured reporting ensures complete documentation of the radiological report, and has a positive impact on radiologic research by facilitating data mining. (IV) Structured reporting can help to promote evidence-based medicine by integrating results from decision-support tools within radiology reports. (V) In the context of patient-centered healthcare, there is a need for reports that can be read by healthcare professionals from different specialties and even non-healthcare professionals (the patient and his/her caregivers). The structured report can be used to generate natural language contents in accordance with the level of understanding of the reader to whom it is addressed. To achieve these benefits, current solutions implementing templates for radiological reporting are focused on promoting structured reports beyond conventional speech recognition [9][10], integrating radiological qualitative scoring systems in structured reporting [11]–[13], and ensuring seamless integration of the structured report with the EHR using EHR standards, DICOM standard and the IHE MRRT (Management of Radiology Reporting Templates) integration profile [14]–[17].

The structured reporting has evolved from common templates, defined by committees of experts like the Templates Library Advisory Panel (TLAP) [18], to sophisticated actionable forms that include validations, calculators and links to key images [19]. It is expected that in the near future additional information from Big Data, Artificial Intelligence (AI) or Decision Support Systems (DSS) will be incorporated to the structured report [20]. Imaging biomarkers are DSS defined as anatomic, physiologic, biochemical, or molecular quantitative parameters detectable with imaging methods used to establish the presence or severity of diseases. Imaging biomarkers are playing an increasingly pivotal role in medical research and clinical practice in the era of precision medicine [21]. Procedures to integrate imaging biomarkers into radiological reports bring the paradigm of personal medicine closer to radiological workflow. The results of quantification can complement radiological diagnosis, improving the accuracy on diagnosis and the evaluation of the efficacy of treatments. A structured radiological report complementing conventional qualitative reporting with quantitative analyses encourages the adoption of personalized medicine [22].

Despite the described benefits, there are limitations that must be overcome for the widespread adoption of structured reporting [3]. (I) Radiologists may be reluctant to change the conventional way of reporting, as the learning curve of the new reporting style may negatively impact radiology workflow and productivity.

(II) Error rates could potentially increase if used improperly (for example, if the default values of certain fields in the template have not been confirmed by the user). (III) Interruption of the visual search pattern by keeping the eyes focused on the report rather than the images may increase reporting time. (IV) Templates that include unnecessary or irrelevant information may undermine the consistency of the report and the interpretation of the report by referring physicians. Last, (V) the lack of support for multiple languages may hamper the adaptation of the report to the target audience.

The goal of this work is to mitigate some of the mentioned limitations of structured reporting, by means of a structured reporting system integrated with annotation capabilities from imaging biomarkers. The system facilitates the transition from conventional reporting to the electronic form filling in a fast and agile checklist approach. It provides functionalities to generate natural language extracts from report contents, ensuring a uniform diagnosis text adapted to the audience (usually the referring physician or the patient and his/her caregivers) and, at the same time, facilitating the integration with the PACS/RIS similarly to conventional speech recognition systems. To avoid the overlooking of relevant information and minimize reporting errors, the system allows defining field validators and logical rules to automatically calculate relevant values (e.g., lesion volume) and ensure the compliance with radiological qualitative scoring systems (e.g., PI-RADS scoring). In addition, logical rules serve to dynamically hide or show report fields, which reduces the interruption of the visual search pattern along the report form. This work introduces a use case of the system with TLAP-approved structured report templates, which has been validated by committees of experts ensuring that templates include only relevant information for each clinical scenario. In the use case, a structured report template including radiological qualitative scoring systems and imaging biomarkers is presented in a prostate report template. It implements assessment tools for the PI-RADS 2.1 scoring system and fields to hold relevant information from imaging biomarkers for multi-parametric prostate MRI: potential prostate lesions and its Apparent Diffusion Coefficient (ADC) and vascular permeability (K^{trans}) values. The Discussion section describes how this work mitigates some limitations of structured reporting in contrast to existing solutions.

Methods

This section describes the structured reporting system from a conceptual point of view, whereas the Results section provides detail on how to build this system and suggests specific programming languages for the implementation. The system has been designed following a modular approach, which allows the creation of new structured report templates that can be imported as plugins in the system. Requirements have been collected from the literature [1]-[8] and validated by early-adopter radiologists from the "Hospital Universitari i Politècnic La Fe de Valencia" Hospital (Valencia, Spain). Specifically, system requirements are: To provide a structured reporting system integrable with annotation capabilities from imaging biomarkers. To encourage the structured reporting through a fast and agile checklist approach. to provide functionalities to generate natural language extracts from radiological report contents in different languages. To ease the integration with the PACS/RIS similarly to conventional speech recognition systems. To allow defining field validators and logical rules, that automatically calculate relevant values and/or dynamically hide or show report fields. To be compatible with Radreport templates from RSNA. To be compliant with the IHE MRRT integration profile.

Among the available structured report templates in the system, the user (usually the radiologist) may choose a reporting template for the examination to be evaluated. The selected structured report will be displayed in a form-like structure with its specific fields and validators. Its modular approach provides flexibility for report template customization according to the necessities of each radiology department. Allowing the creation of highly specialized templates. It is possible to design a specific template for each pathology, even combining the diagnosis of several pathologies in a single template. This is especially useful to report cases of patients with multiple problems. Last, the examination time can take between five and ninety minutes on average. It depends on the pathology, the anatomical area, the complexity of the structured report template, and the expertise of the radiologist reporting the case.

A template implementation consists of:

(I) A template layout defining the report structure and including form fields to be filled in.

(II) Field validators and logical rules defining the behavior of the report template. It establishes when to show or hide specific fields according to the information provided (e.g., if a finding is stated, then additional fields to include finding details are shown to the user), when to automatically calculate a specific value (e.g., the lesion volume can be calculated starting from the delimitation of the region of interest) or when to warn users in case wrong information is provided (e.g. values out of range or incorrect data types) or required information is missing.

(III) Natural language specifications to convert report content into natural language extracts. They consist of a set of sentences in different languages related to each field in the report template. As the radiologist fills in the report, the system embeds the information of each field into these sentences and combines them to build the natural language extract.

The template layout includes a set of variables called "binding variables" that are used by the logical rules to identify data from each original source. The logical rules manage the template behavior depending on the values in the binding variables. When the user enters data in the report, the data is stored in a binding variable. The logical rules evaluate the data and dynamically modify the template if required. The binding variables are wrapped in a parent object containing three main sections: qualitative information, quantitative information and natural language sentences. The radiologist manually enters the qualitative information by typing on the keyboard during the case reporting. The process consists of filling in a form built according to a template. The form contains the fields specified in the template definition and applies logical rules and validations in real time during the reporting. Radiological qualitative scores and automatically calculated values in the template are stored in the qualitative information section. When results from imaging biomarkers are available, the system automatically embeds them in the template, in variables of the quantitative information section. These variables are also in the reporting form and the radiologist may remove or modify the quantitative information if he/she does not agree with the results. During the case reporting, natural language sentences are generated each time the radiologist enters or modifies data in the report form. These sentences are stored in the binding variables, in the section for natural language sentences of the wrapper object. At the end of the case reporting, these sentences are combined to build the natural language extract of the structured report.

The system includes a DICOM SCP interface to receive imaging studies (i.e., native sequences) and quantification results (i.e. parametric maps including imaging quantification) as DICOM objects from PACS and/or modalities. It serves to automatically extract patient data from the DICOM objects and embed them in the report. The whole process is summarized in Figure 1. Qualitative and quantitative data are provided to the template layout (step 1), whose binding variables are bound to the wrapper object (step 2). Value changes in these variables trigger the evaluation of field validators and logical rules (step 3). The evaluation could lead to changes in current values of the binding variables (e.g., automatically calculated values. Step 4a) or changes in the template (e.g., hide or show specific fields. Step 4b). Then, natural language specifications are loaded (step 5) and natural language sentences are generated according to the current values of the binding variables (step 6). Finally, the natural language sentences are combined to generate the natural language extract (step 7).

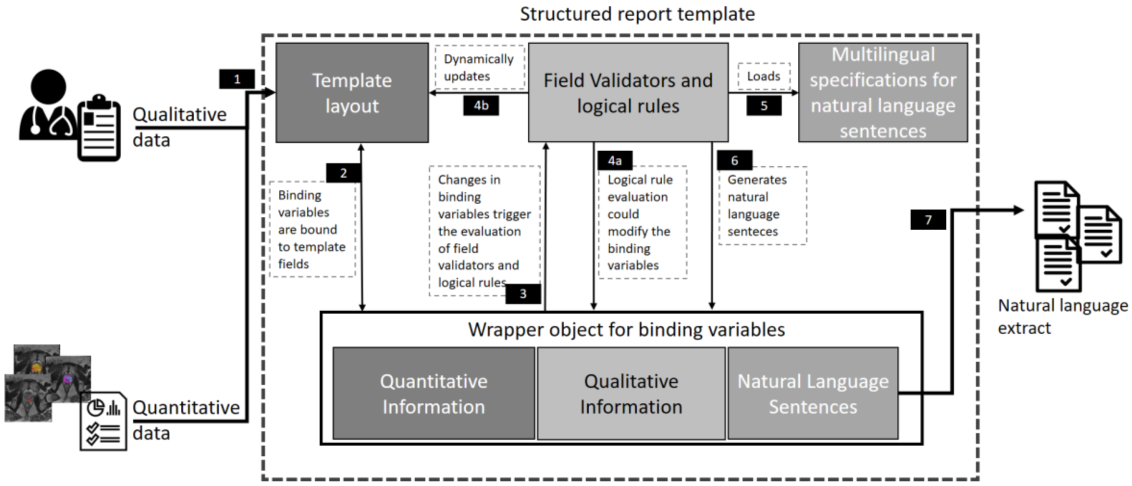

Fig. 1 Architecture of structured report template together with the process of structured report generation. The process is described in terms of the components of the structured report template (template layout, field validators, logical rules and natural language specifications), and the wrapper object that holds values for the binding variables in the template layout.

The presented design is focused on increasing the integration capabilities of the structured reporting system with health IT systems using standards. According to the MRRT IHE profile specifications [23], the modular approach of the system allows the definition of structured report templates using an extension of Hypertext Mark-up Language version 5 (HTML5) for the template layout, and establishes transportation mechanisms to query, retrieve and store the structured report templates. In addition, the structured reports (specifically, the wrapper object for binding variables) can be directly converted to DICOM SR in reporting time to include the reporting information into a minable format for PACS and RIS. Last, the natural language extract generated for each report serves to send the reporting information as plain text in a HL7 v2 message, similar to conventional speech recognition systems. Note that the system only supports outbound HL7 messages but supports both inbound and outbound DICOM communications. Figure 2 shows an example of our structured reporting solution where information from different sources (radiologist diagnosis, imaging biomarkers, radiological qualitative scoring systems and automatically calculated values) is combined into a natural language extract.

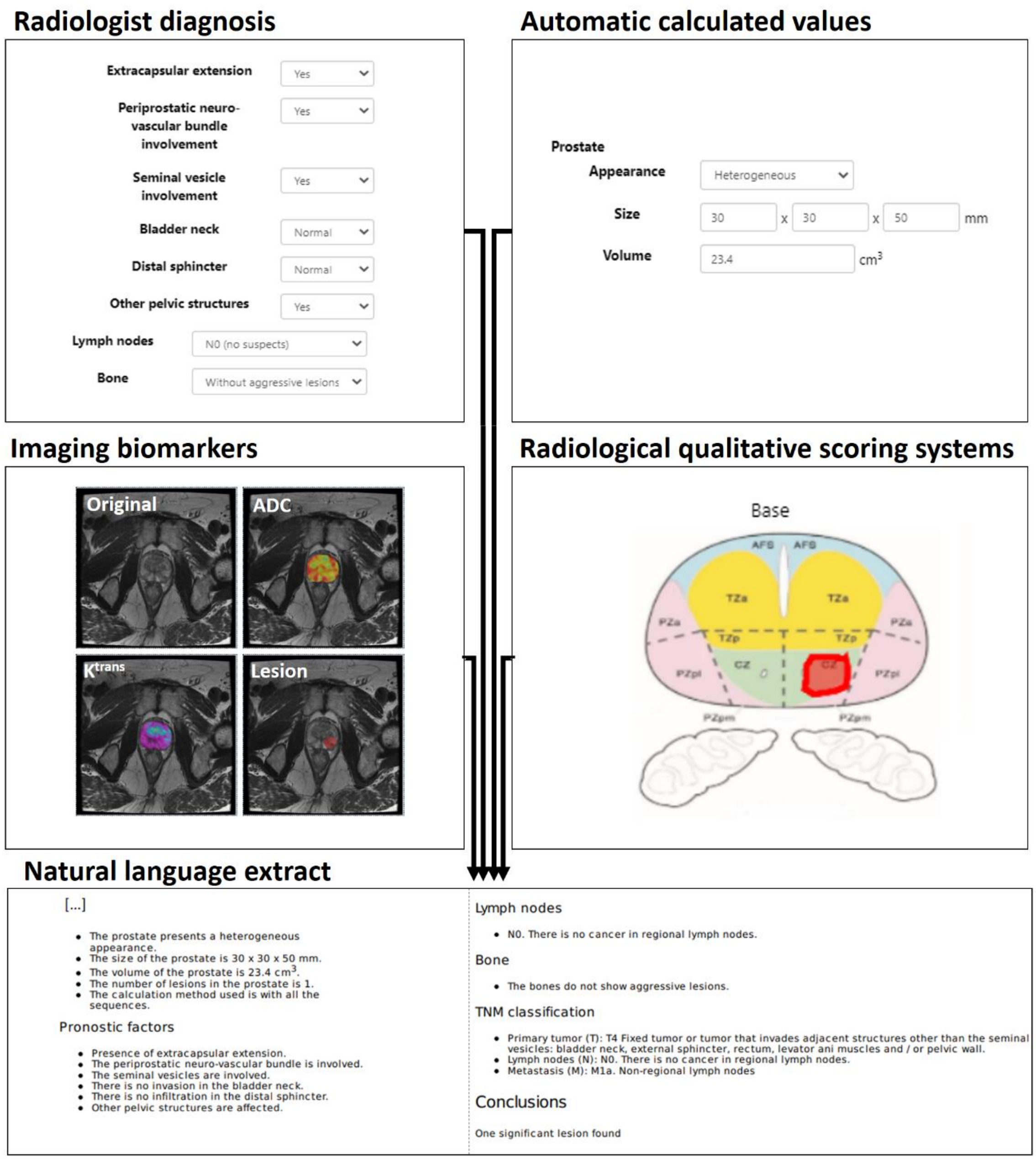

Fig. 2 Relevant reporting information (radiologist diagnosis, imaging biomarkers, radiological qualitative scoring systems and automatically calculated values) is combined by the structured report into a natural language extract.

Results

A web-based system has been developed to facilitate the integration of structured reports into the radiological workflow while allowing the interaction with DSS algorithms. The system has been developed using the MEAN stack [24], consisting of the MongoDB database for the persistence layer, ExpressJS web application server to hold the backend services, the Angular framework for the web interface, and NodeJS for the implementation of the backend services. In addition, Java-based tools have been employed for operations related to DICOM and HL7 standards. Specifically, dcm4che toolkit has been used for DICOM management (i.e., to convert the report to DICOM SR object and send it to the PACS), and utilities from the HAPI library have been used to build and send the report through HL7 v2 messages.

The system allows importing structured report templates as plugins. Each structured report template must be implemented using HTML5 for the template layout, JavaScript for the field validators and logical rules, and JSON objects to define the natural language specifications in several languages. Figure 3 illustrates an example of these files for a portion of a prostate MRI structured report template, as well as the corresponding structured report form and the generated natural language extract. The methodology employed to generate field validators, logical rules and natural language extracts is also applied for the implementation of radiological qualitative scoring systems in structured report templates.

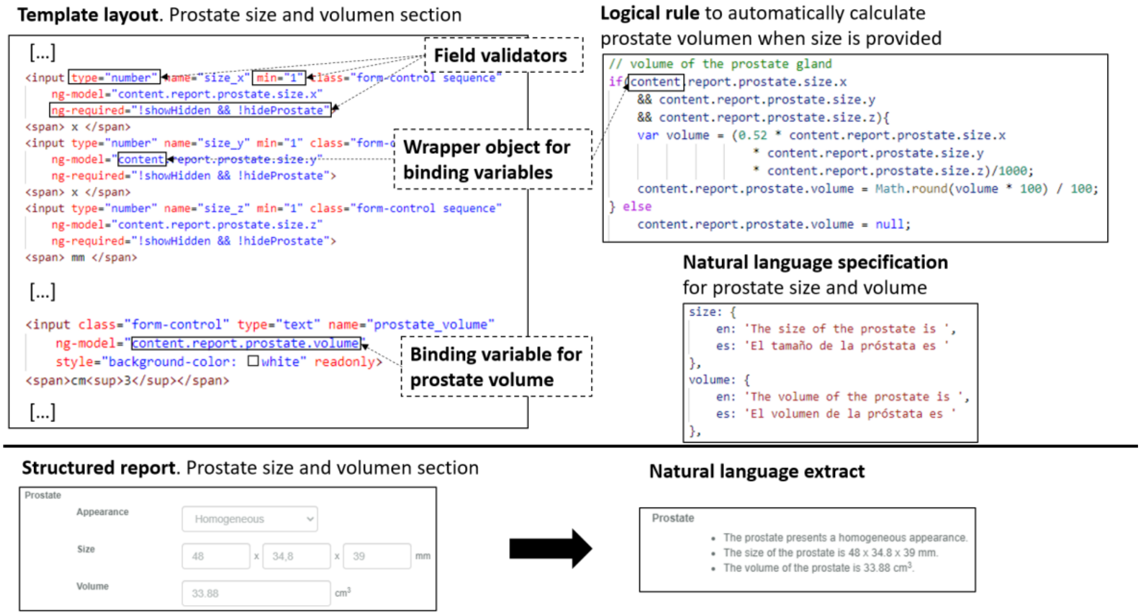

Fig. 3 A portion of the prostate MRI structured report template related to the prostate size and volume. At the top of the figure, the template layout, field validators, a logical rule and the natural language specifications are shown. At the bottom, the resulting structured report form, and the generated natural language extract are displayed. The prostate volume is automatically calculated by the logical rule according to the prostate size.

Field values can be defined as mandatory or optional, and can be constrained to a specific data type and/or range of values using field validators and logical rules. These are useful for warning users when incorrect values are provided, or required information is missing. Moreover, logical rules can be employed to hide or show report fields according to the information provided by the user. Figure 4 shows examples of how field validators and logical rules constrain possible values, warn users when incorrect values are introduced, and hide or show fields depending on provided values.

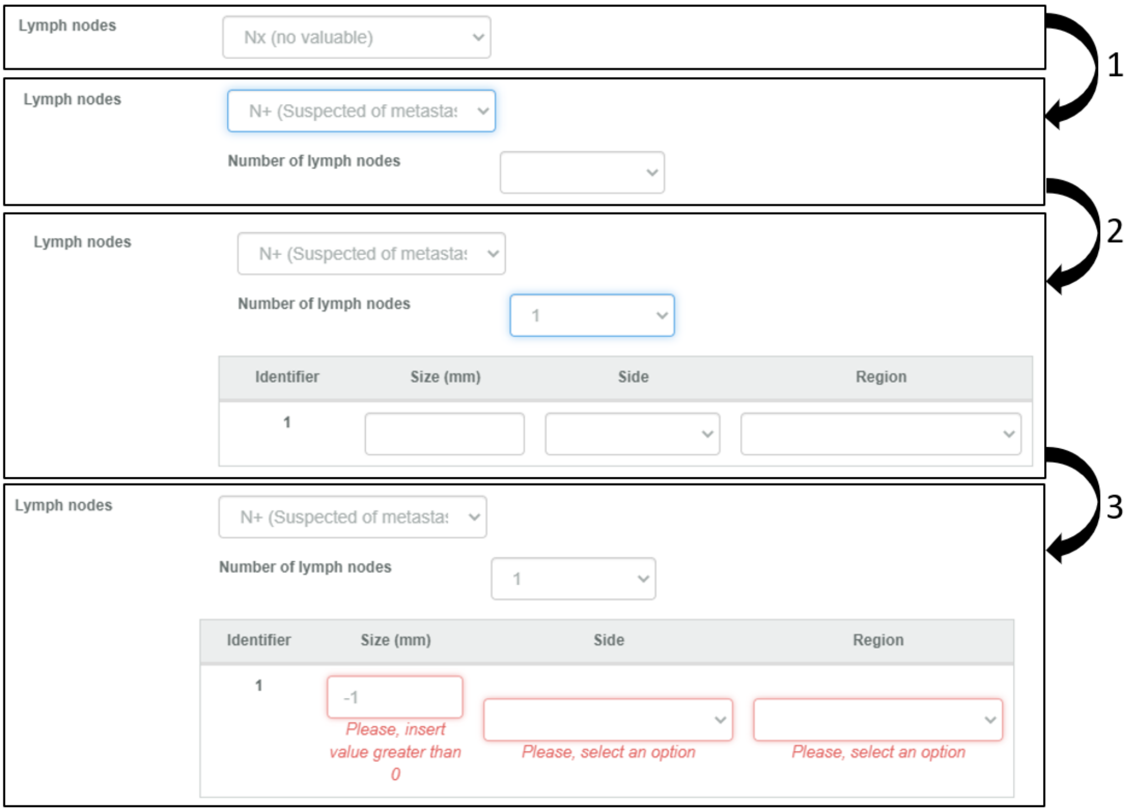

Fig. 4 Field validators and logical rules dynamically changing the report form and showing or hiding fields according to user inputs. Transition 1: "Number of lymph nodes" field appears when selecting "N+ (Suspected of metastasis)" for "Lymph nodes" field. Transition 2: A table for lymph node details appears when selecting "1" for "Number of lymph nodes" field. Transition 3: User warnings are shown when trying to store the report with missing and incorrect values.

The time required to code a structured report template varies greatly depending on the complexity of the template. It is possible to implement a simple template in less than an hour, or to spend several days defining a complex template. Templates can be registered in the system through an administration panel, which also serves to enable or disable existing templates. To register a new structured report template, it is required to provide the template layout definition, the field validators and logical rules, and the natural language specifications. These components can be provided in a unique HTML file to be compliant with the MRRT IHE profile, or as separated files bundled into a zip file. The system requires additional information to register a new template: title, description and clinical application. It serves for final users to search into the system for specific templates. Figure 5 shows the web components developed to support the structured report template lifecycle, which meets the specifications of the MRRT IHE profile providing functionalities to store, query and retrieve HTML5 structured report templates. To be compliant with the IHE MRRT profile [23], the system uses HTTP protocol as defined in the MRRT Technical Framework to retrieve ("4.103 Retrieve Imaging Report Template [RAD-103]"), store ("4.104 Store Imaging Report Template [RAD-104]") and query ("4.105 Query Imaging Report Template [RAD-105]") templates. To ease the integration with PACS/RIS systems, the template form allows exporting the report as DICOM SR or as plain text (through an HL7 v2 message) to the PACS/RIS.

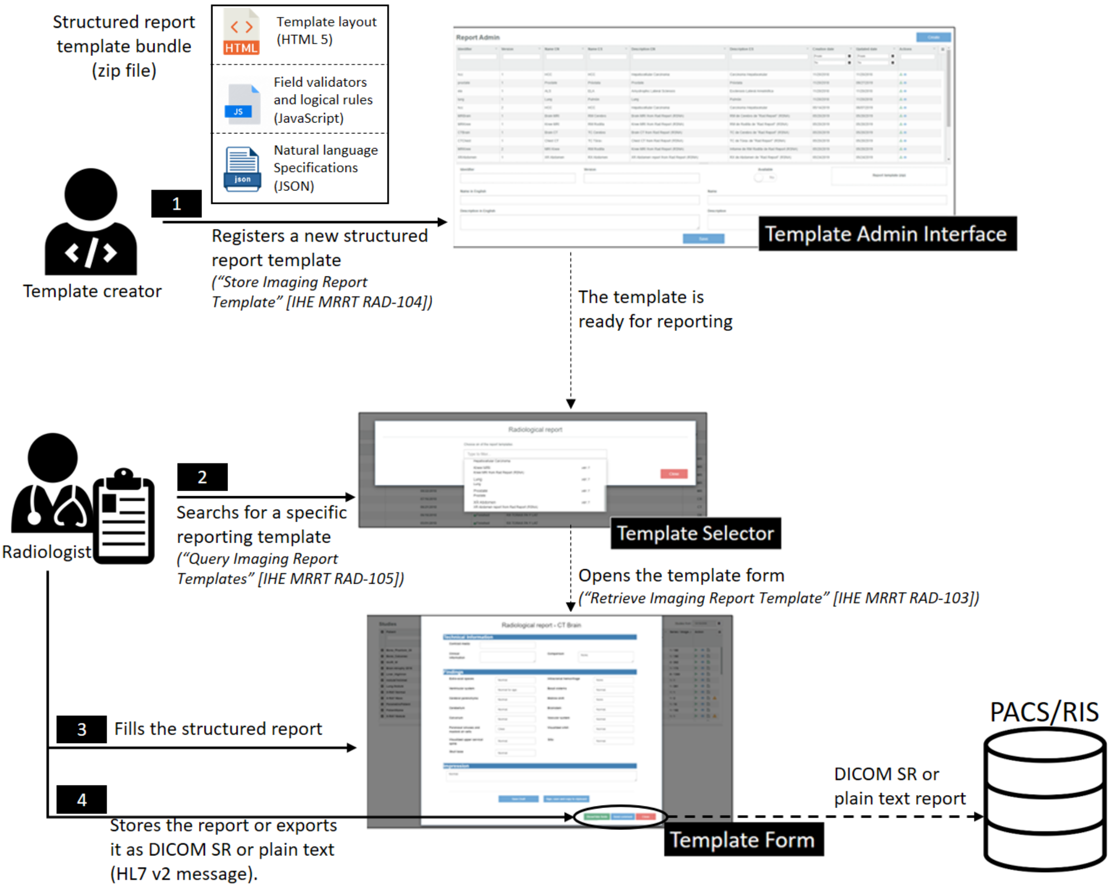

Fig. 5 Structured reporting template lifecycle compliant with MRRT IHE profile. First, the template creator registers the structured report template in the template administration interface. Contextual information of the template (title, description and clinical application) is provided at this point. Then, the template is available for reporting. A radiologist can search for the template and fill in the form with the diagnosis information. Finally, the radiologist can store the report and export it as DICOM SR and as plain text similar to conventional speech recognition systems.

The structured reporting system stores information from imaging biomarkers into the binding variables. It serves to integrate the system with imaging biomarkers platforms and embed quantitative data in the report content. An implementation of this approach has been carried out integrating the structured reporting system with the imaging biomarkers platform QUIBIM Precision® (QUIBIM, Valencia, Spain), resulting in an advanced radiological reporting tool that combines qualitative and quantitative information for reporting. The binding variables for imaging biomarkers are bound to the outputs from the imaging biomarkers platform, to dynamically embed quantitative results in the report form. This provides decision support for radiologists at the time of reporting.

Figure 6 shows an example of a prostate MRI structured report template integrated in the imaging biomarkers platform. A prostate case with one dominant lesion is shown in the example. The biomarker platform quantified ADC and K^{trans} values for the prostate MRI and detected one potential dominant lesion (DL 1) in the acquisition. The system embedded the ADC and K^{trans} values for the potential lesion region in the quantitative information section of the binding variables (as described in the Methods section), making the quantitative data available for the user in the template form. The radiologist can modify or remove a misidentified lesion by manipulating or deleting it on the left side. In addition, the structured report template in the example includes a section for PI-RADS 2.1 scoring, which is a radiological qualitative scoring system for prostate cancer assessment. Input values for PI-RADS scoring (T2, DWI, DCE, diameter and lesion zone) must be established manually by the radiologist, but the template contains drop-down lists with the available scoring values to constraint the inputs and avoid mistakes. PI-RADS 2.1 score is automatically calculated according to the provided input values. The Prostate MRI structured report template manages a number of dominant lesions limited up to four findings with the highest PI-RADS assessment, as specified by the radiologic guideline PI-RADS 2.1. The template allows the radiology to add, edit or remove the dominant lesions through drop down lists and a table form (Figure 6). Specifically, the drop-down list “Lesions and PI-RADS rating” serves to set the number of dominant lesions and “Dominant lesion” is used to choose the dominant lesion shown in the PI-RADS schema. On the other hand, the table form contains constrained fields to enter the PI-RADS 2.1 scores. Last, the structured report template for prostate MRI shown in the example also allows embedding key images from quantification algorithms, which could be useful for the referring physician as part of the radiological report. Figure 7 shows how the key images that are focused on the quantification and the dominant lesions can be attached to the structured report. Key images must be manually selected by the radiologist according to the potential interest for the diagnosis.

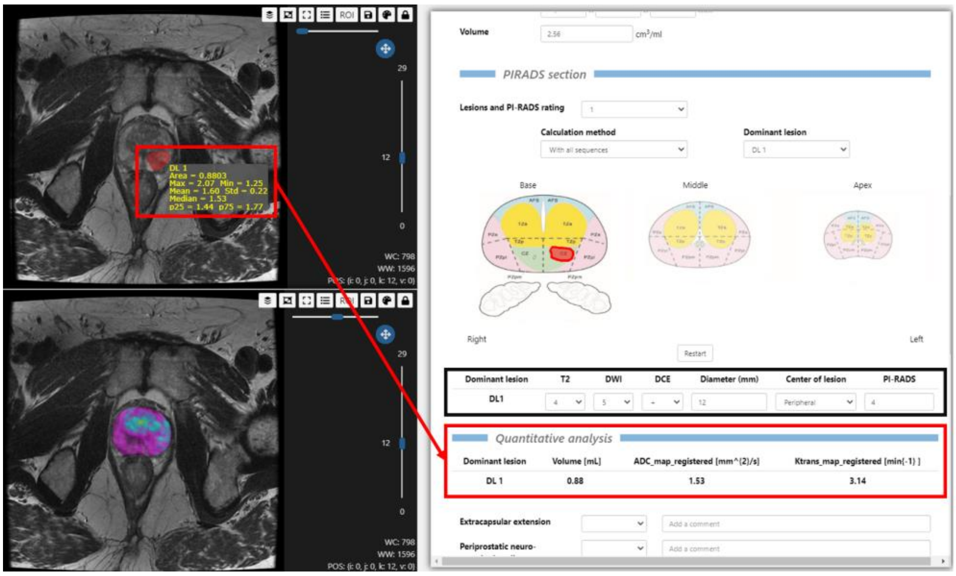

Fig. 6 Advanced structured report for prostate MRI integrated with an imaging biomarkers platform. The template includes tools for prostate lesion assessment according to the PI-RADS 2.1 scoring system (highlighted in black), and binding variables for quantitative data from imaging biomarkers (highlighted in red). The system detected a potential dominant lesion (DL 1) and its ADC and K^{trans} values has been automatically embedded in the report form.

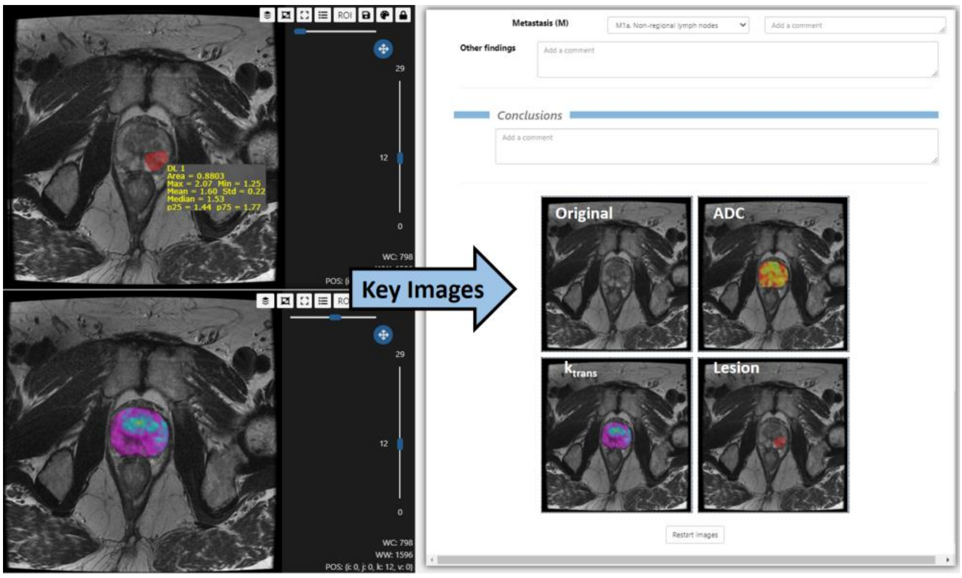

Fig. 7 Advanced structured report for prostate MRI integrated with an imaging biomarkers platform. The structured report template for prostate MRI includes binding variables to hold key images. At reporting time, the radiologist may add a set of key images to the report to illustrate the findings.

At the time of this writing, 24 structured report templates have been implemented and integrated into the structured reporting system. Among them, 17 are TLAP-approved templates, and 7 are advanced customized templates, including imaging biomarkers and calculators for BI-RADS, LI-RADS, and PI-

RADS scoring systems. Advanced templates have been developed and tailored to specific requirements of radiology departments using this system. For the time being, The system has been deployed in 37 hospitals and healthcare institutions to guide the reporting process and to homogenize radiological reports. A total of 949 registered radiologists from different centers have reported 21853 imaging studies.

Discussion

Several publications show the benefits of structured reporting in radiology [1], [2]. Nevertheless, there are limitations that must be overcome to widely implement structured reporting [3]. This paper introduces a structured reporting system where TLAP-approved structured report templates have been enriched with field validators, logical rules, radiological qualitative scoring systems, quantitative information from imaging biomarkers and functionalities to generate natural language extracts in different languages. These features provide multiple advantages over existing solutions. They serve to avoid mistakes and assist the reporting by automatically calculating values and evaluating value constraints. Logical rules and field validators can be useful to reduce error rates due to improper use of the template, as they can be programmed to warn users if there are missing or incorrect values. As logical rules are directly implemented in JavaScript language, sophisticated algorithms such as PI-RADS scoring calculation or natural language extract generation can be embedded in templates to assist the reporting, in contrast with common dictation systems incorporating logical rules to allow for basic if/then logic. Existing solutions providing consensus-based templates [10], [16], [17] lack logical rules to avoid mistakes and enforce report consistency. Moreover, advanced solutions providing calculators for radiological scoring systems [12] and frameworks for computer-assisted reporting and decision support [11], [13] lack imaging biomarkers integration capabilities to combine quantitative and qualitative data in the same report at reporting time. Our methodology overcomes such limitations, by combining quantitative data from imaging biomarkers with qualitative data from radiological reporting in a unique report at reporting time. In addition, it can generate natural language extracts from report contents in different languages. Natural language extracts serve to adapt the report language and contents to the target audience that will receive the radiologic report (typically, the referring physician or the patient and his/her caregivers). The procedure to create a template for a specific target audience, for multiple languages, or for a specific target audience in multiple languages is similar. It depends on the intended use of the template. This work introduces an example of a template supporting multiple languages. The template contains a variable holding the preferred language and generates the natural language extract by indexing natural language sentences, from the natural language specifications of the template, with the value of the language variable. This method can be applied to other specific intended uses. For example, a template including an input field to choose the target audience (e.g., patient or physician), can use the value of this input to index the natural language sentences from the natural language specifications of the template. In this example, the natural language extract will change accordingly to the selected target audience.

Although the learning curve of the new reporting style may negatively impact radiology workflow and productivity [3], the inclusion of radiological qualitative scoring systems and imaging biomarkers may save time in the decision-making process, encouraging radiologists to start using structured reports for their reporting. On the other hand, the interruption of the visual search pattern can be mitigated by showing and hiding report fields dynamically according to provided values, focusing the user attention on the relevant sections of the report form. In addition, these limitations may be further mitigated in future works integrating voice dictation and speech recognition technologies with reporting forms, allowing radiologists to fill in the report by directly dictating values to the template.

The software design and implementation has been addressed by the first author of this work as a PhD student from the “Universitat Politècnica de València” University (Valencia, Spain), in collaboration with the company Quibim SL. The system is based on HTML5 templates, which contain JSON objects and JavaScript code in a unique html file, being compliant with the IHE MRRT profile and, at the same time, leveraging the advantages of scripting languages for interactive and dynamic forms. Furthermore, the system can import MRRT-compliant HTML5 templates from RSNA’s radreport.org website and new templates can be drafted using the RSNA’s T-Rex Report Template Editor. HTML and JavaScript programming skills are required to enrich templates with logical rules, field validators, scoring systems and/or results from imaging biomarkers. Template creators are usually multidisciplinary teams, with expertise in radiological practice and programming languages. Logical rules and field validators in templates should be defined to guide and assist the radiological reporting, constraining field values to avoid mistakes but also avoiding excessive field constraints that could hinder the reporting of outlier cases. Once defined, templates can be used for reporting without knowledge on these programming languages. They only require a web browser to be rendered and filled in by users.

To ensure that relevant and required information is included in reporting forms, structured report templates in the system have been developed starting from TLAP-approved templates and/or following specifications from a committee of experts in radiology. The structured reporting system is ready for clinical routines and reporting workflow. As mentioned before, it has been deployed in 37 hospitals and healthcare institutions and is currently being used for radiological reporting. Hospitals and healthcare institutions develop their own templates combined with imaging biomarkers using this system. At the time of this writing, 21853 reported imaging studies have been managed in this system by a total of 949 registered users from different centers. Note the difference between templates (24) and reported cases (21853). Templates serve to define the relevant data to be reported, whereas a reported case is the result of filling in a template and issuing a report with the diagnosis for a specific case. By default, the system includes 17 TLAP-approved templates and 7 advanced templates integrating imaging biomarkers and automatic calculators for BI-RADS, LI-RADS and PI-RADS scoring systems. Its modular design allows the system to be installed in isolation or otherwise integrated with an imaging biomarker platform.

The administration interface serves radiologists or institutions to customize the portfolio of structured report templates that they want to use for each clinical scenario, and includes a versioning mechanism useful to track the evolution of the structured report templates. Once cases are reported, reports are stored in a MongoDB database, which provides flexibility to store any kind of data formatted as a JSON object (i.e., the wrapper object for binding variables). It encourages secondary uses of radiological reports for research and radiomics [25], facilitating the use of big data and AI tools by exploiting the reporting data. This can be done either through MongoDB queries against the database, or by means of data mining tools that may render reporting information in searchable tables and may calculate statistics on reporting data, or by just exporting the reporting information in a structured data sheet for further research. Additional advantages of the presented structured reporting system are authentication mechanisms, role management (from read-only users to administrators), structured report template metadata to search and classify templates, audit trail system to track the activity of users in the system, the ability to export structured reports as DICOM SR or plain text and the integration with PACS/RIS systems using DICOM communication protocols and HL7 v2 messages. The versioning mechanism and the template search form assist the user to identify the suitable template for each pathology and anatomical area in large sets of templates.

A use case of a structured report template including radiological qualitative scoring systems and imaging biomarkers is presented in a prostate report template. It implements assessment tools for the PI-RADS 2.1 scoring system and includes fields to hold relevant information from imaging biomarkers for prostate MRI: potential prostate lesions and its Apparent Diffusion Coefficient (ADC) and capillary permeability (K^{trans}) values. The success of this work is the implementation of the system meeting the proposed requirements, as well as its installation and use in radiology departments of 37 hospitals and healthcare institutions, where has shown an impact on the radiological reporting allowing the sending of reports in natural language while storing the data in a structured format. Future work is to evaluate the performance of this system in clinical practice, the time required for case reporting in comparison with conventional speech recognition systems, and the satisfaction of users. Also, to identify possible uses of speech recognition technologies for structured reporting. To investigate how this methodology for structured reporting promotes radiomics, in contrast with natural language reporting, by leveraging the advantages of structured data integrated with radiological qualitative scoring systems and imaging biomarkers. And last, to research how to combine information from multidisciplinary clinical sources into a structured clinical data hub, by applying the presented method to clinical domains other than radiology (such as reporting in pathology or genetics), which is potentially relevant for data mining or training of AI-based DSS for clinical diagnosis.

Conclusion

This paper has introduced a web-based structured reporting system that overcomes some of the current limitations of structured reporting, homogenizes the reporting and may help to minimize error rate. Note that minimizing error rate also depends on the quality of the template. A well-organized template helps to reduce the error rate, while a poorly defined template (with incorrect logical rules, or with fields for irrelevant information) can make reporting difficult and increase the error rate. Structured reports in this system are enriched with imaging biomarkers, radiological qualitative scoring systems, field validators, logical rules and natural language extracts. This system is compliant with the IHE MRRT profile and compatible with TLAP templates from RSNA's radreport.org website. Its modular design based on binding variables allows the integration of imaging biomarkers quantification in the structured report, facilitating the integration with third-party imaging biomarkers providers and the creation of advanced templates, customized for the requirements of each radiology department. In addition to these features, the main contribution of this work is a structured reporting system able to combine quantitative and qualitative information in the report, and to generate natural language extracts of the report, in different languages, tailored to the target audience. Additional market analysis to compare this system with commercial solutions can help to evaluate the real impact of this work. However, at the time of writing, we have not found solutions in the literature that provide all the features described above together.

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Annex I. Healthcare and research institutions

The structured reporting system introduced in this work is available at the following healthcare and research institutions:

"Equipo Juana Crespo". Fertility clinic in Valencia, Spain.
"Hospital Clínic de Barcelona". University Hospital in Barcelona, Spain.
"Fundación Clínic de Barcelona". Research Foundation in Barcelona, Spain.
"Fundación Biomédica Galicia Sur". Biomedical Research Foundation in Galicia, Spain.
"Instituto de Resonancia Magnética Dra. Guirado". MRI imaging institute in Barcelona, Spain.
"Instituto de Investigación Sanitaria La Fe". Health research institute in Valencia, Spain.
"Institut Català de la Salut (ICS)". Health institute in Barcelona, Spain.
"Fundación de Investigación HM Hospitales". Research foundation in Madrid, Spain.
"MRIcons", MRI Imaging centre in Nicosia, Cyprus
"Champalimaud Foundation". Biomedical research foundation in Lisbon, Portugal.
"SALUS, Medicina y Gestión Sanitaria". Imaging diagnosis centres in Murcia, Spain.
"Hospital Universitario de Canarias". University hospital in Canarias, Spain.
"RadiewCare". Imaging diagnosis centre in Madrid, Spain.
"Hospital Germans Trias i Pujol". Hospital in Barcelona, Spain.
"Hospital Ramón y Cajal". Hospital in Madrid, Spain.
"Instituto Ramón y Cajal de Investigación Sanitaria". Healthcare research institute in Madrid, Spain.
"Clínica DKF". Healthcare clinic in Madrid, Spain.
"Fundación Del Hospital Provincial De Castellón". Healthcare research foundation in Castellón, Sapin.
"Hospital Sant Joan de Deu". Hospital in Barcelona, Spain.
"Kurume University". University hospital in Kurume, Japan.
"Universitat de Girona". University in Girona, Spain.
"Laboratorio Clínico Diagnomed, S.A.". Clinical laboratory in Concepción, Chile.
"Molecular Oncology Institute FIRC – IFOM". Research institute in Milano, Italy.
"Centro Uruguayo de Imagenología Molecular". Imaging center in Montevideo, Uruguay.
"Centro de Medicina Comparativa y Bioimagen de Cataluña". Research centre in Barcelona, Spain.
"Fundació Privada per a la Recerca Sant Joan de Dèu". Research foundation in Barcelona, Spain.
"Wanfang Hospital". Hospital in Taipei, Taiwan.
"Mackay Memorial Hospital". Hospital in Taipei, Taiwan.
"Azienda USL di Reggio Emilia, IRCCS". Hospital in Reggio Emilia, Italy.
"Hospital Universitari i Politècnic La Fe". University Hospital in Valencia, Spain.
"Kaohsiung Veteran General Hospital". Hospital in Kaohsiung, Taiwan.
"IEC Core Lab". Imaging core lab for clinical trials in Barcelona, Spain.
"Imaging Endpoints". Imaging core lab for clinical trials in Massachusetts, United States.
"Ferring Pharmaceuticals". Pharmaceutical company in København, Denmark.
"Complejo Hospitalario Universitario de Vigo". University hospital in Vigo, Spain.
"Global Institute for Research". Research institute for clinical trials in Arizona, United States.
"Highlight Therapeutics". Research company for clinical trials in Valencia, Spain.