Structured reporting for efficient epidemiological and in-hospital prevalence analysis of pulmonary embolisms

Strukturierte Befundung zur effizienten Erhebung von epidemiologischen Daten und Analyse der innerklinischen Prävalenz bei Lungenarterienembolien

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ABSTRACT

Purpose Structured reporting (SR) not only offers advantages regarding report quality but, as an IT-based method, also the opportunity to aggregate and analyze large, highly structured datasets (data mining). In this study, a data mining algorithm was used to calculate epidemiological data and in-hospital prevalence statistics of pulmonary embolism (PE) by analyzing structured CT reports.

Methods All structured reports for PE CT scans from the last 5 years (n = 2790) were extracted from the SR database and analyzed. The prevalence of PE was calculated for the entire cohort and stratified by referral type and clinical referrer. Distributions of the manifestation of PEs (central, lobar, segmental, subsegmental, as well as left-sided, right-sided, bilateral) were calculated, and the occurrence of right heart strain was correlated with the manifestation.

Results The prevalence of PE in the entire cohort was 24 % (n = 678). The median age of PE patients was 71 years (IQR 58–80), and the sex distribution was 1.2/1 (M/F). Outpatients showed a lower prevalence of 23 % compared to patients from regular wards (27 %) and intensive care units (30 %). Surgically referred patients had a higher prevalence than patients from internal medicine (34 % vs. 22 %). Patients with central and bilateral PEs had a significantly higher occurrence of right heart strain compared to patients with peripheral and unilateral embolisms.

Conclusion Data mining of structured reports is a simple method for obtaining prevalence statistics, epidemiological data, and the distribution of disease characteristics, as demonstrated by the PE use case. The generated data can be helpful for multiple purposes, such as for internal clinical quality assurance and scientific analyses. To benefit from this, consistent use of SR is required and is therefore recommended.

Key Points

- SR-based data mining allows simple epidemiologic analyses for PE.
- The prevalence of PE differs between outpatients and inpatients.
- Central and bilateral PEs have an increased risk of right heart strain.

Citation Format

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ZUSAMMENFASSUNG

Ziel Die strukturierte Befundung (Structured Reporting; SR) bietet neben Vorteilen hinsichtlich der Befundqualität als IT-basierte Methode auch die Möglichkeit umfangreiche, hochstrukturierte Datenmengen zu erheben und diese sekundär auszuwerten (Data-Mining). Im Rahmen dieser Studie wurde ein Data-Mining-Algorithmus genutzt, um epidemiologische Daten und innerklinische Prävalenzstatistiken der Lungenarterienembolie (LAE) durch Auswertung strukturierter CT-Befunde zu erheben.

Methoden Alle strukturierten Befunde zu LAE-CTs der letzten 5 Jahre (n = 2790) wurden aus der SR-Datenbank extrahiert und ausgewertet. Die Prävalenz einer LAE wurde für die Gesamtkohorte und in Abhängigkeit der Zuweisungsart und in Abhängigkeit des klinischen Zuweisers berechnet. Verteilungen der Lokalisationen der LAEs (zentral, lobär, segmental, subsegmental sowie linksseitig, rechtsseitig, beidseitig) wurden analysiert sowie das Auftreten einer Rechtsherzbelastung mit der Lokalisation korreliert.

Ergebnisse Die Prävalenz einer LAE in der Gesamtkohorte betrug 24 % (n = 678). Das mediane LAE-Patientenalter betrug 71 Jahre (IQR 58 – 80) und die Geschlechterverteilung 1,2/1 (M/F). Ambulante Patienten zeigten eine geringere Prävalenz (23 %) als Patienten von Normalstationen (27 %) oder Intensivpatienten (30 %). Chirurgisch zugewiesene Patienten zeigten eine höhere Prävalenz als internistisch zugewiesene (34 % vs. 22 %). Zentrale und beidseitige LAEs korrelierten mit einer signifikant höheren Rechtsherzbelastung im Vergleich zu peripheren und einseitigen Embolien.

Schlussfolgerung Data-Mining von strukturierten Befunden ist eine einfache Methode zur Erhebung von Prävalenzstatistiken, epidemiologischen Daten und Verteilung von Krankheitscharakteristika, wie am Beispiel der LAE gezeigt. Die so generierten Daten können in vielerlei Hinsicht hilfreich sein, wie beispielsweise zur internen klinischen Qualitätssicherung oder für wissenschaftliche Auswertungen. Um davon zu profitieren, ist die konsequente Nutzung von SR erforderlich und wird deshalb empfohlen.

Kernaussagen

- SR-basiertes Data-Mining ermöglicht einfache epidemiologische Auswertungen bei LAEs.
- Die Prävalenz der LAE ist bei ambulanten und stationären Patienten unterschiedlich.
- Zentrale und beidseitige LAEs haben ein erhöhtes Risiko für eine Rechtsherzbelastung.

Background

Pulmonary embolism (PE) is the third most common cardiovascular disease after acute myocardial infarction and stroke [1]. Because of the risk of right heart failure due to obstruction of the pulmonary vessels, pulmonary embolism is associated with a high mortality rate of approx. 30 % if left untreated. Since the PE mortality risk is highest within the first hours of symptom onset, early diagnosis is essential [2]. CT angiography is the internationally recognized reference standard for diagnosing PE [3, 4]. CT is not only very sensitive for detecting thrombi in the pulmonary vessels but also allows simple quantification of possible right ventricular strain as a surrogate parameter for the risk of right heart failure [4, 5]. As a result of the described urgency, it is essential for radiology to provide quick and correct reports for these CT examinations.

A majority of radiology reports, including CT angiography reports in the case of suspicion of PE (PE CT), are still written as free text. Free-text reports are highly variable with respect to content and structure. In addition, free-text reports often lack relevant information for the clinical referring physician [6, 7]. Structured reporting (SR) has increasingly become a topic of interest in recent years. The advantages of SR compared to free-text reporting have been shown in dozens of studies. Structured reports are easier to read, easier to compare, more complete, and more detailed than free-text reports [6, 7, 8]. This could also be explicitly proven for PE CT examinations [9]. Both clinical referring physicians and radiologists prefer structured reports compared to free-text reports [10].

However, SR has not yet been able to become established in the clinical routine in spite of the numerous advantages. Usage is low in most radiology departments [10]. This is probably due to difficulties that can occur when implementing SR. The introduction of SR solutions in the clinical reporting workflow can be technically challenging and require significant effort. Moreover, implementation is highly dependent on the manufacturer of the *Picture Archiving and Communication System* (PACS) and *Radiology Information System* (RIS) [11]. The integration of voice recognition into SR is currently insufficient. In contrast to free-text reports, structured reports must be largely completed manually with mouse and keyboard, which is inconvenient and time-consuming and can distract from the actual image data [12].

In addition to the advantages regarding report quality, structured reporting as an IT-based method makes it possible to automatically add large amounts of highly structured data to databases and to perform secondary evaluation. Data mining of structured reports can be used to answer a variety of questions.

Thus, for example, data on the epidemiology of the disease including the setting-specific prevalence can be collected based on the report data. In 2017, our department conducted the first feasibility study on this topic. The study included just over 500 patients, who underwent CT examination for suspicion of PE. Since structured reporting of PE CT examinations had not yet been implemented in the clinical routine at this time, all corresponding free-text reports had to be manually retrospectively structured [13]. There is hardly any epidemiological data in the literature generated primarily from structured reports created in the clinical routine [14]. Moreover, data mining of structured reports is also suitable for scientific questions. Therefore, based on structured report data, a new system for evaluating clot burden in PE patients was able to be developed [15]. Structured report data is also ideally suited for the training and validation of artificial intelligence (AI) [16].

Building on the described feasibility study, the goal of this study was to use a data mining algorithm to analyze all structured PE CT reports created in the clinical routine in the last five years in our department's database. For internal quality assurance, epidemiological data and disease characteristics as well as insight regarding possible in-hospital differences in PE prevalence was acquired.

Methods

In 2016, a web-based SR platform compatible with *Integrating the Health Enterprise Management of Radiology Report Templates* (IHE MRRT) was developed and implemented for use in the clinical routine in our hospital [17]. Since then, numerous templates for various types of examinations in the ultrasound, CT, and MRI modalities have been able to be developed and implemented [10]. The reporting template for CT angiography to rule out pulmonary embolism was implemented in the clinical routine in the third quarter of 2018. ▶ **Fig. 1** shows the current version of the template. Data is typically entered in the template during reporting with the mouse and keyboard. The diameter of the right and left ventricles (RV/LV ratio) was determined for the quantification of possible right ventricular strain by measuring the maximum ventricular diameter in the axial view and is automatically calculated by the template after entry of the two values. The presence of right ventricular strain was defined as an RV/LV ratio > 1 in accordance with the guidelines of the European Society of Cardiology [18].

All reports generated and released in the clinical routine with the help of templates are automatically saved in the reporting platform and are thus accessible for secondary analyses. Reports can be systematically read out by the reporting platform with the help of the software RapidMiner Studio (RapidMiner, Cambridge, USA) for a predefined time period. Individual parts of reports (e. g., the presence of right ventricular strain) or the entire contents of reports can be read out. The results are output as a .csv file and can then be evaluated with the help of statistics software. ▶ **Fig. 2** shows a graphic of the workflow described here.

For the questions examined in this study, the following content was read out from the PE template: Patient age and sex, in-hospital referring physician, type of referral (outpatient, standard ward, intensive care unit), presence of a pulmonary embolism, type of possible pulmonary embolism (main pulmonary artery, lobar artery, segmental artery, subsegmental artery), side of the embolism (right, left, bilateral), presence of right ventricular strain (RV/LV ratio > 1), and date and time of the examination. All reports generated since implementation of the template from 8/2018 to 7/2023 were included.

Statistical analyses were performed with the help of the software R (The R Foundation for Statistical Computing, Vienna, Austria). Binary and categorical data were expressed as absolute values and percentages. Continuous data were presented as mean and standard deviation (SD). Not normally distributed data were presented as median and interquartile range (IQR). The Kruskal-Wallis test was used to check for statistical significance. The level of significance was set to $\alpha = 0.05$.

Results

In total, 2790 structured reports for patients who underwent PE CT examination were included.

A pulmonary embolism was detected in 24 % (n = 678) of the total patient population. The median patient age was 71 years (IQR: 58–80). The ratio of men to women was 1.2:1 (▶ **Fig. 3**).

There were some significant differences in PE prevalence depending on the type of referral. Among the patients referred by outpatient providers who comprised 69 % (n = 1913) of the total cohort, only 23 % (n = 441) had a positive finding. Among the 678 patients referred from a standard ward, 27 % (n = 182) had a PE. A higher rate of positive findings (30 %, n = 59) was seen In the relatively small patient population referred from the ICU (n = 199) (▶ **Fig. 4A**). Differences in PE prevalence were also seen depending on the referring clinical discipline. In total, 75 % (n = 2104) of patients were referred by internal medicine departments. A PE was detected in 22 % (n = 470) of these patients. 34 % of the 453 surgically referred patients (n = 155) were diagnosed with a PE. The remaining departments collectively designated here as "other" referred 233 patients. 24 % (n = 57) of these patients were diagnosed with a PE (▶ **Fig. 4B**).

Of the 678 patients with PE, 32 % (n = 215) were diagnosed with a central embolism, 25 % (n = 172) with a lobar embolism, 33 % (n = 228) with a segmental embolism, and 10 % (n = 69) with a subsegmental embolism. 65 % of all PEs were bilateral (n = 444), 10 % (n = 71) were left-sided, and 35 % were right-sided. Right ventricular strain was seen in 43 % (n = 292) of PE patients.

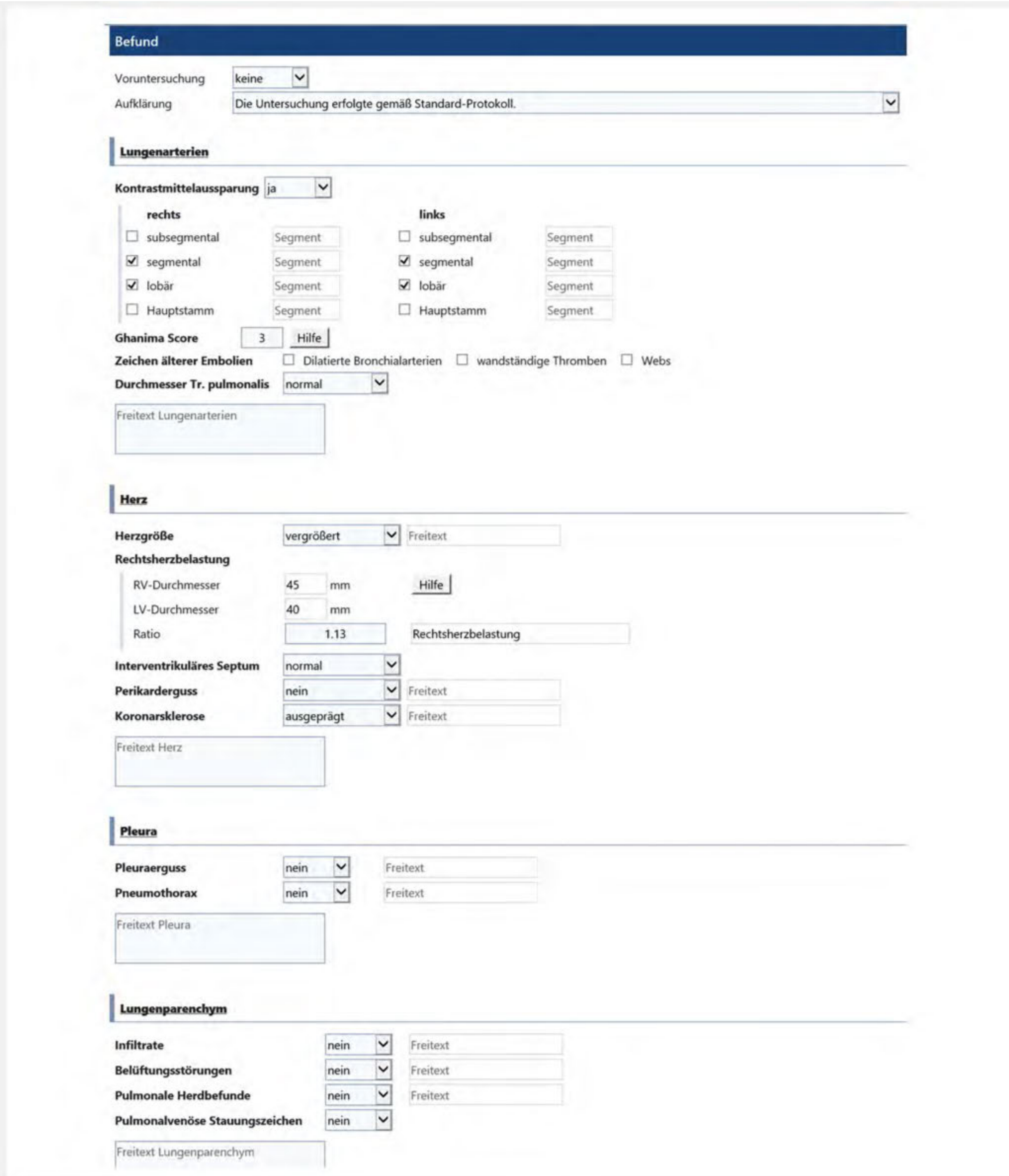
Further evaluation showed that central embolisms are associated with a higher RV/LV ratio than lobar, segmental, or subsegmental embolisms (▶ **Fig. 5A**). In addition, right ventricular strain occurred significantly more frequently (73 %) in central embolisms than in lobar (38 %), segmental (26 %), and subsegmental embolisms (13 %) (▶ **Fig. 5B**).

Analogously, bilateral embolisms were also associated with a higher RV/LV ratio compared to unilateral embolisms (▶ **Fig. 5C**). 54 % of all bilateral embolisms included right ventricular strain, while this was the case in only 27 % of left-sided embolisms and in 19 % of right-sided embolisms (▶ **Fig. 5D**).

Discussion

The data show that consistent use of SR allows prevalence statistics and epidemiological data to be acquired without significant effort as shown here using pulmonary embolism as an example. The data provide a valuable overview of the patient population and the distribution of disease features and disease presentation. In addition, it provides important feedback for clinical referring physicians and radiologists.

The age and sex distribution of PE in the examined cohorts (median patient age 71, ratio of men to women 1.2 to 1) is in agreement with multiple other epidemiological studies on PE [19, 20, 21]. The calculated PE prevalence of 24 % in the total


Befund
Voruntersuchung keine
Aufklärung Die Untersuchung erfolgte gemäß Standard-Protokoll.

Lungenarterien
Kontrastmittelaussparung ja
rechts
☐ subsegmental Segment
☑ segmental Segment
☑ lobär Segment
☐ Hauptstamm Segment
links
☐ subsegmental Segment
☑ segmental Segment
☑ lobär Segment
☐ Hauptstamm Segment
Ghanima Score 3 Hilfe
Zeichen älterer Embolien ☐ Dilatierte Bronchialarterien ☐ wandständige Thromben ☐ Webs
Durchmesser Tr. pulmonalis normal
Freitext Lungenarterien

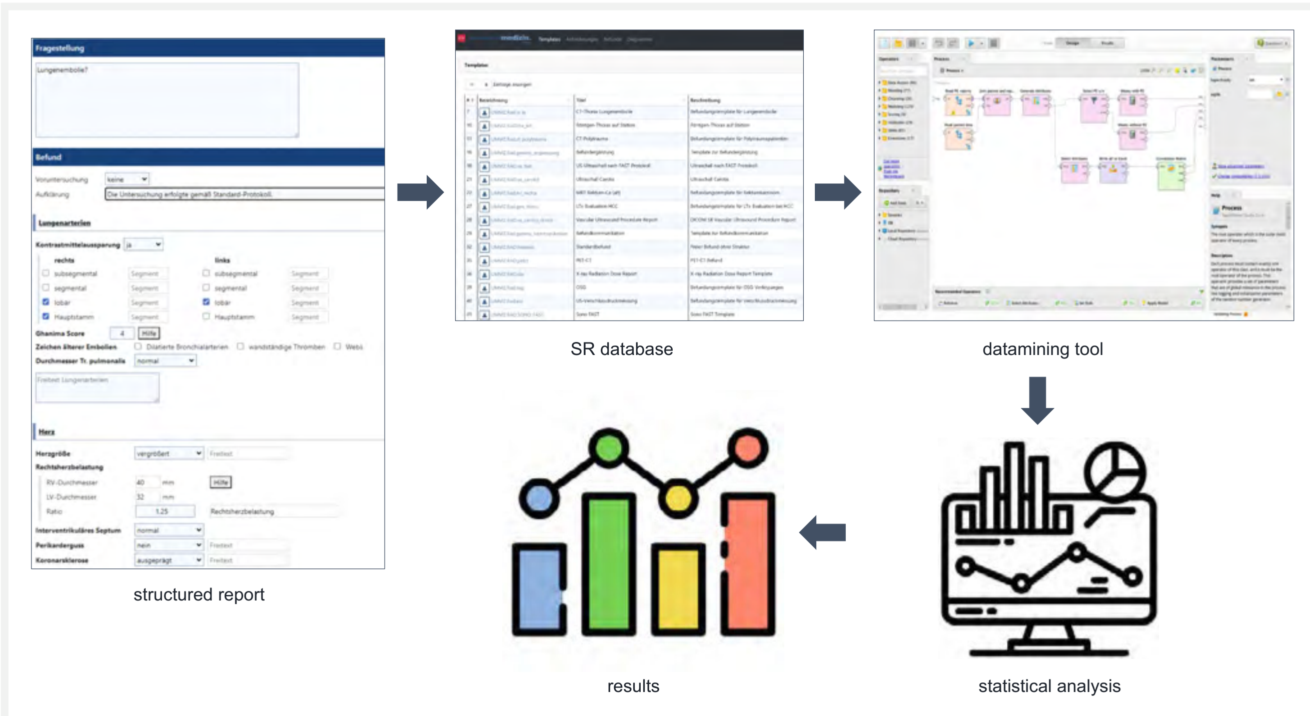
Herz
Herzgröße vergrößert Freitext
Rechtsherzbelastung
RV-Durchmesser 45 mm Hilfe
LV-Durchmesser 40 mm
Ratio 1.13 Rechtsherzbelastung
Interventrikuläres Septum normal
Perikarderguss nein Freitext
Koronarsklerose ausgeprägt Freitext
Freitext Herz

Pleura
Pleuraerguss nein Freitext
Pneumothorax nein Freitext
Freitext Pleura

Lungenparenchym
Infiltrate nein Freitext
Belüftungsstörungen nein Freitext
Pulmonale Herdbefunde nein Freitext
Pulmonalvenöse Stauungszeichen nein
Freitext Lungenparenchym

▶ **Fig. 1** Structured reporting template for CT angiography of pulmonary embolism.

cohort coincides with the feasibility study performed in 2017 in which free-text reports from a smaller cohort (n = 500) were retrospectively structured [13]. An American study in which free-text reports for over 500 PE CT scans were manually evaluated describes a significantly lower PE prevalence of 9 % but only includes patients referred by an emergency department [22]. It must also be taken into consideration that the indication for CT sometimes has a lower threshold in the USA due to the different legal regulations.

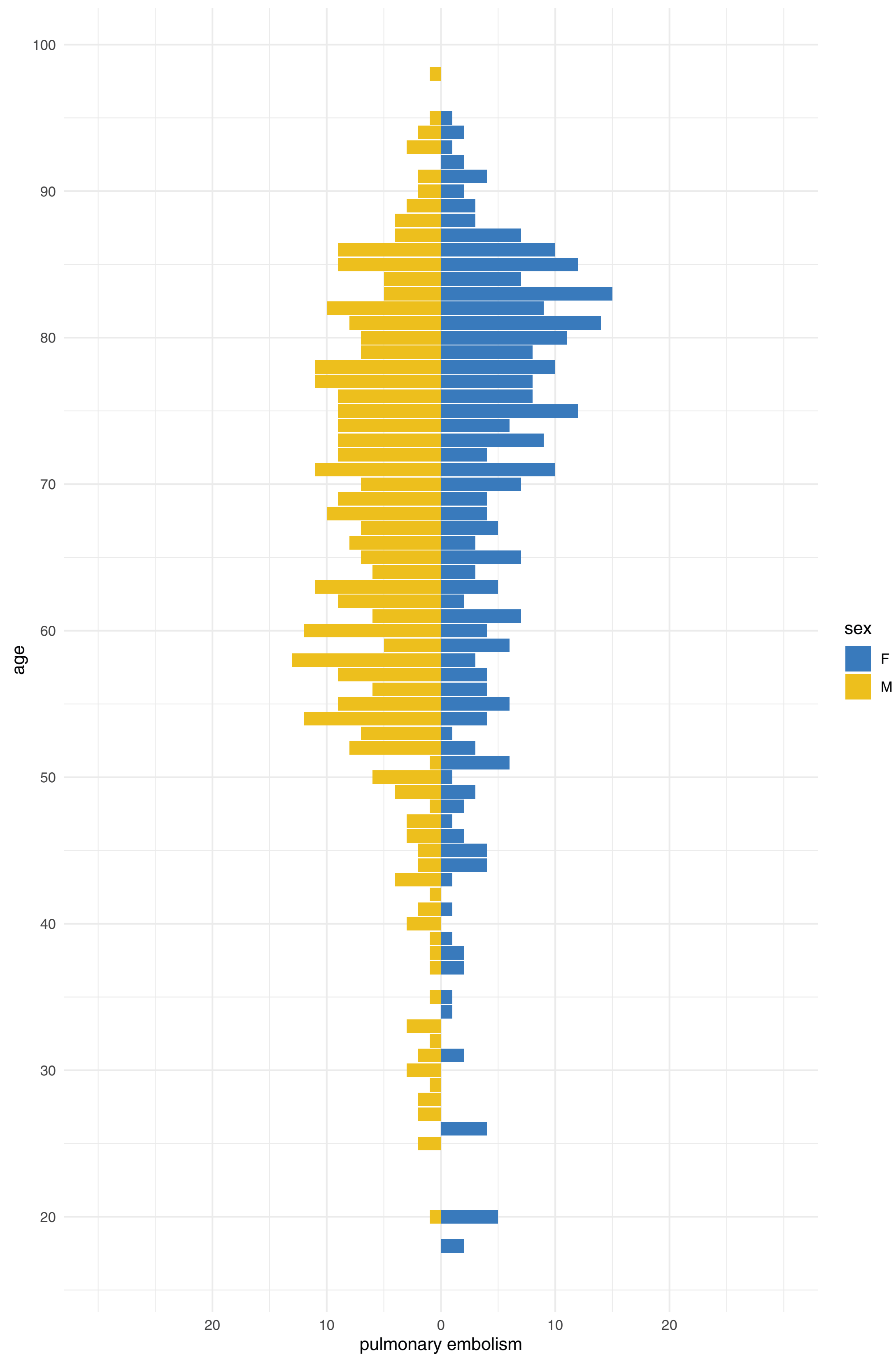


▶ **Fig. 2** Graphic of the workflow for secondary evaluation of structured reports (data mining).

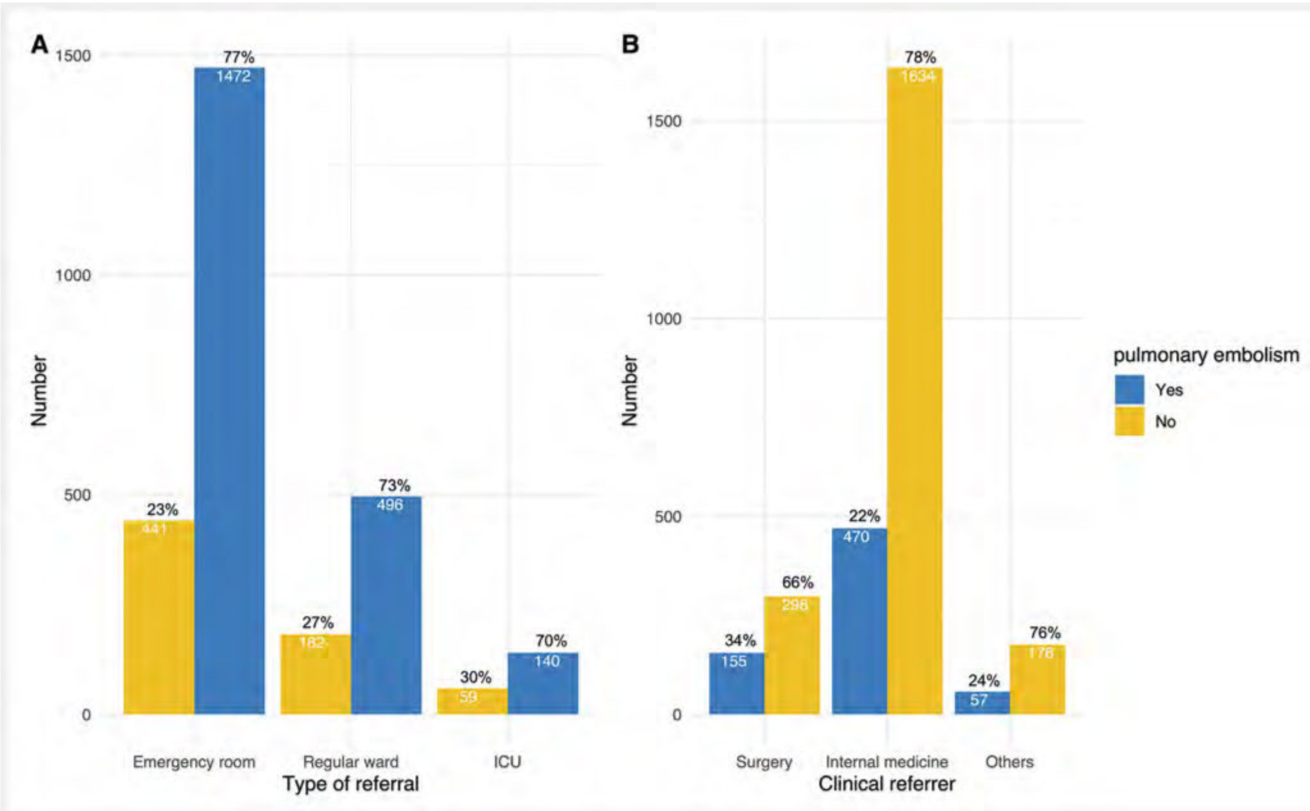
Differences in the probability of a positive finding depending on the type of referral could also be identified in this study. The lower rate of 23 % in the outpatient setting compared to 27 % in standard wards and 30 % in the ICU can be primarily explained by the fact that the diagnosis of a PE is more evident in the inpatient setting in the case of the onset typical symptoms, e. g. after an operation or longer period of immobilization, than in the outpatient setting. In the latter case, PE CT examination is more often used to rule out PE than to confirm the diagnosis in the case of unclear symptoms and a positive D-dimer on laboratory tests. This is also supported by the lower rate of positive findings in patients referred by internal medicine departments (22 %) compared to surgically referred patients (34 %). Hahiharan et al. were able to show a significant increase in right ventricular strain in central embolisms compared to peripheral embolisms for a smaller cohort of patients for whom image and report data was evaluated manually [23]. This connection was able to be proven with the help of the SR-based data mining approach performed here in a cohort that was more than twice the size.

Finally, the results of this study are within the range of expected results. The actual innovation is the method used to generate the results. This method makes it possible to acquire data from imaging quickly and without significant personnel requirements. Arduous review of individual reports would be needed to obtain the same results from free-text reports. However, it must be taken into consideration that the primary generation of structured reports in the clinical routine can be more time-consuming than conventional free-text reporting. There are also many uses for the data. It is essential for both clinical referring physicians and radiologists to identify probabilities for a positive finding in radiology examinations. Particularly in the case of examinations involving radiation, like CT, quality assurance measures in the sense of radiation protection would be required in the case of low probabilities. Imaging-based structured data continues to be ideally suited for data enrichment of registry databases as are already available for PE patients in various European countries [24]. These databases typically primarily include clinical data and could be additionally optimized with image parameters. This could allow the development of AI models, e. g., to predict the risk of relapse. Moreover, in the future, the data could also be included in data integration centers set up at university hospitals as part of medical information initiatives, which would allow site-independent use for research purposes.

In addition to the structured report data mining approach shown here, free-text reports can also be retrospectively evaluated for secondary data use by using natural language processing (NLP) [25, 26, 27]. NLP as an AI-related technology is capable of automatically analyzing free text and extracting and structuring relevant content [27]. However, on the one hand, the method is limited by the fact that the free-text reports used for this do not always contain all necessary information [6, 7]. On the other hand, although NLP algorithms have improved significantly in recent years, completely correct detection of free-text report content is still not guaranteed [26]. Moreover, large language models like Chat GPT-4 are capable of retrospectively converting entire free-text reports into a structured report [28]. Finally, the SR-based approach used here is more suitable since complete datasets can be generated in a highly structured form and directly evaluated without the need for an additional conversion step.



▸ **Fig. 3** Age and sex distribution for pulmonary embolism based on a tree diagram.



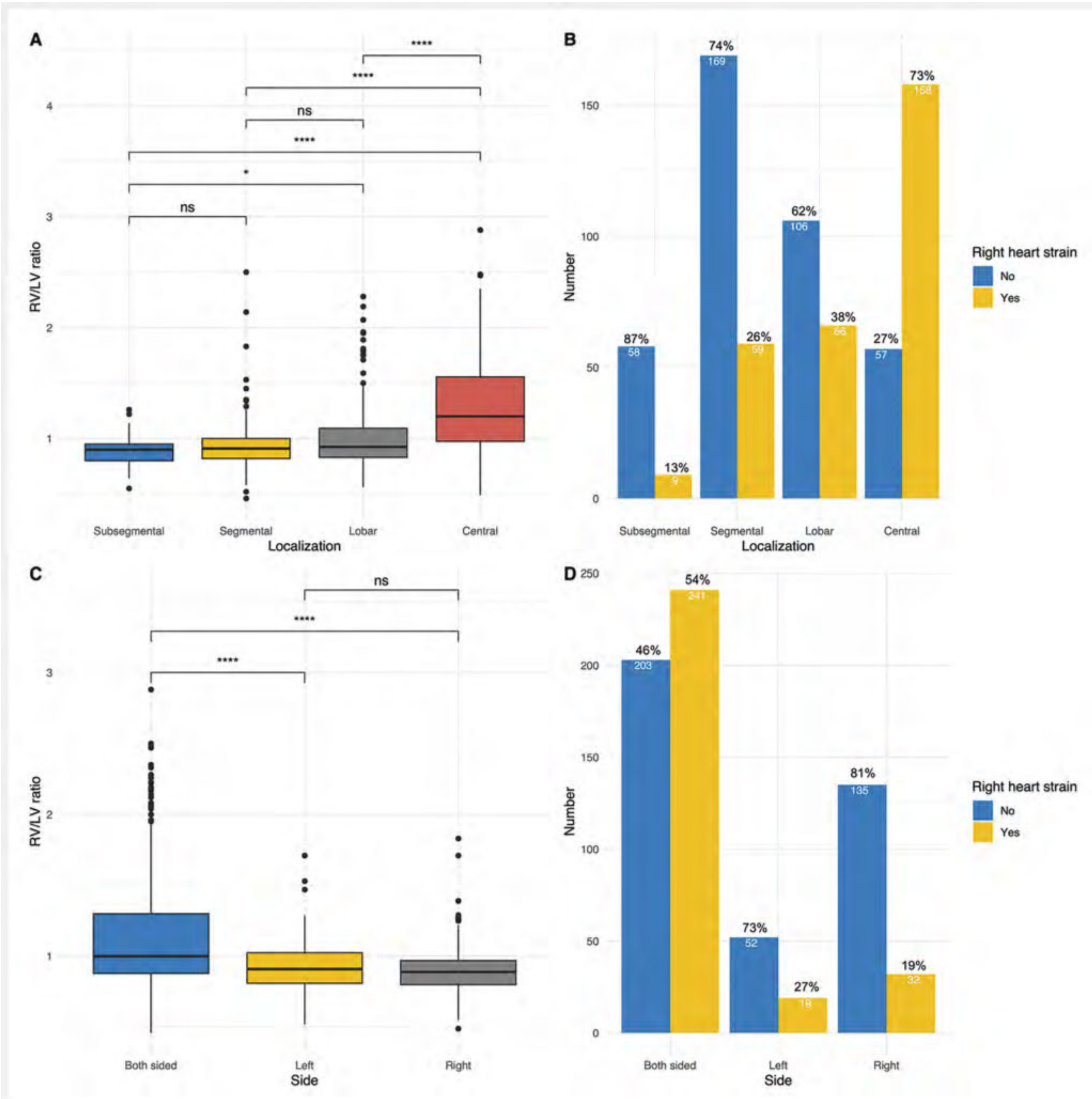
▶ **Fig. 4** Frequency of PE depending on the type of referral (outpatient, regular ward, intensive care unit (**A**)) and as a function of the referring clinical department (**B**).

The present study has limitations. A high clinical usage rate of SR is needed to ensure the high quality of epidemiological data and prevalence statistics acquired via the SR-based data mining approach. High usage rates could be shown in our hospital for most structured reporting templates (e. g., polytrauma CT 97 %, prostate MRI 92 %, and urolithiasis CT 91 % in the year 2022). In contrast, the usage rate of the PE template (58 % in 2022) since implementation of the template in the 2018 (18 %) was relatively lower but has increased steadily [10]. Finally, SR is not equally suited for all examination types and its use at our hospital is not mandatory. In the case of PE CT scans, there are alternative diagnoses in up to 33 % of examinations [22]. When providing an exact description of alternative diagnoses and in highly complex cases, radiologists could find the reporting template unsuitable and therefore not use it. Based on this, it can be assumed that the actual probability of a positive PE CT finding is lower than in the evaluated patient population. Regardless of the applicability in individual types of examinations, there is still potential to optimize SR and to further promote clinical use. This could be achieved with improved integration of voice recognition in structured reporting templates with the help of NLP, which is the subject of current research studies [29].

Moreover, this imaging-based study only analyzes the disease only at a defined point in time. Therefore, it is not possible to draw any conclusions about the course of the disease. Finally, patients who underwent an examination other than CT, e. g., MRI or scintigraphy, for diagnosis or exclusion were not included. However, in the specific case of PE, this percentage of patients is to be considered relatively low [30].

Conclusion

SR makes it possible to collect epidemiological data and prevalence statistics without the need for additional time or resources by performing data mining of reports. For example, differences in the in-hospital PE prevalence could be shown as a function of the clinical referring physician and the type of referral. The generated data can be used in various areas, e. g., for internal quality assurance, scientific analyses, and for data enrichment of registry databases. To benefit from these advantages, implementation and consistent use of SR are essential and recommended.



▸ **Fig. 5** RV/LV ratio depending on the highest location of an embolism in the pulmonary artery system (**A**) and frequency of right ventricular strain as a function of the highest location of an embolism in the pulmonary artery system (**B**). RV/LV ratio depending on the PE side (**C**) and the occurrence of right ventricular strain as a function of the PE side (D). RHB = right ventricular strain.

Clinical relevance

- Consistent clinical use of SR makes it possible to obtain epidemiological data and in-hospital prevalence statistics without the need for significant resources by performing data mining.
- Using pulmonary embolism as an example, differences in in-hospital prevalence can be calculated as a function of the referring physician and the type of referral and probabilities for the presence of right ventricular strain can be determined as a function of the type of embolism.
- Knowledge of the probability of a positive finding in radiology examinations provides important feedback for radiologists as well as for clinical referring physicians.
- The generated data can also be used in various areas, e.g., for internal quality assurance, radiation protection, scientific analyses, and for data enrichment of registry databases.

Abbreviations

CT Computed tomography
PE Pulmonary embolism
SR Structured reporting
IHE MRRT Integrating the Health Enterprise Management of Radiology Report Templates
AI Artificial intelligence
NLP *Natural language processing*
RV/LV ratio Right ventricular to left ventricular ratio

Conflict of Interest

The authors declare that they have no conflict of interest.

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