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Utilizing Natural Language Processing to Improve Research and Clinical Management of Thyroid Disorders through Electronic Health Record Analysis: A Comprehensive Review

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Abstract

Background: Natural Language Processing (NLP) has become an essential tool in healthcare, particularly for analyzing Electronic Health Records (EHRs) to improve research and patient care. Despite the abundance of unstructured data in EHRs, extracting relevant information for clinical decision-making remains a challenge. This review examines the application of NLP in the understanding and management of thyroid disorders, which are common yet often inadequately researched.

Methods: A systematic review was carried out, sourcing studies published from 2012 to 2023 across databases such as MEDLINE, EMBASE, and Scopus. The search strategy, developed by an experienced librarian, focused on studies utilizing NLP to analyze EHR data related to thyroid disorders, including thyroid nodules and cancer.

Results: The review identified various NLP algorithms used to classify thyroid nodules and predict cancer outcomes, achieving accuracy rates ranging from 77% to 100%. Noteworthy studies demonstrated the capacity of NLP to extract valuable data from radiology and pathology reports, enhancing the understanding of patient quality of life and treatment responses. Despite these advancements, the integration of NLP into clinical practice remains limited, with only one study utilizing a prospective design.

Conclusion: NLP shows considerable potential for revolutionizing the management of thyroid disorders by enabling the extraction and analysis of unstructured EHR data.

However, challenges such as methodological variability, data representation issues, and the need for extensive validation impede broader adoption. Future research should aim to refine NLP techniques and address these challenges to improve clinical application.

Keywords: Natural Language Processing, Electronic Health Records, Thyroid Disorders, Machine Learning, Clinical Decision-Making

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1. Introduction

Artificial intelligence (AI) aspires to replicate human-like intelligence in entities (e.g., machines) that can process information and execute actions similar to human behavior. Furthermore, machine learning is a swiftly advancing domain within computer science that endeavors to train machines with data sets to undertake laborious tasks that usually necessitate human cognitive capabilities [1,2]. The capacity to address tangible challenges across multiple sectors, including healthcare, has prompted heightened investigation into its applications. By incorporating diverse AI modalities into physicians' decision-making processes, this technology could advance the medical field by augmenting diagnostic test accuracy, optimizing provider workflows, facilitating improved disease and therapeutic monitoring, and ultimately yielding superior patient outcomes [3].

Natural language processing (NLP) constitutes the convergence of linguistics and artificial intelligence, facilitating the analysis of text and speech to attain human-like comprehension of language. Despite its extensive history exceeding 50 years, the increasing relevance in medicine has generated considerable interest in these technologies, particularly by surmounting prior limitations through advancements in machine and deep learning [4,5]. In healthcare, NLP models have predominantly been employed to identify and extract information from unstructured data within electronic health records (EHRs). The adoption of EHRs has resulted in a dramatic increase in the volume of healthcare data over the last two decades. Approximately 20% of Electronic Health Record (EHR) data is projected to be formatted as diagnostic or billing codes, along with basic clinical variables such as vital signs or laboratory findings [6].

Conversely, the majority of data in Electronic Health Records (EHRs) is unstructured, presented as free text, such as clinical notes or diagnostic reports, rendering their utilization in research laborious and complex [7]. To mitigate this issue, Natural Language Processing (NLP) techniques have been developed to effectively extract and standardize varied medical data from textual sources, including elements such as medical history, physical examinations, laboratory results, diagnostic reports, and treatment documentation. For instance, in radiology, NLP has been employed to identify specific features of interest within imaging reports. Likewise, in oncology, it has been utilized to extract and categorize information from pathology reports, thereby facilitating the staging and prediction of outcomes for different cancer types [8,9].

Thyroid diseases are frequent in the general population. Recent studies have evidenced the efficacy of diverse NLP systems in extracting pertinent information from EHRs in thyroidology. These NLP-driven methodologies have exhibited potential in augmenting and validating diagnostic and prognostic instruments for various thyroid pathologies, including functional thyroid disorders, thyroid nodules, and thyroid cancer [20,21]. Notwithstanding these encouraging advancements, the current literature is deficient in a thorough overview. This review might be essential for physicians, researchers, and other stakeholders seeking to comprehend the use of NLP in enhancing the treatment of patients with thyroid disorders. This research aimed to address this gap by thoroughly examining the uses of natural language processing in thyroid-related disorders. We sought to encapsulate the existing issues and provide insights into future prospects in this emerging subject.

2. Methods

A thorough search was performed across several scientific databases for publications published from 2012 to 2023. The databases used were MEDLINE, EMBASE, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, and Scopus. An experienced librarian (L.P.) devised and executed the search strategy for references using NLP in patients with thyroid disorders.

3. Applications of Natural Language Processing in Thyroid Nodules

Numerous NLP algorithms were created and trained on extensive datasets to categorize nodules as benign or malignant based on documented radiologic features (accuracy, 86%-88%; sensitivity, 84%-92%; and positive predictive value, 94%). Additionally, other NLP models focused on extracting detailed radiology characteristics from ultrasound reports (accuracy, 77%-98%; sensitivity, 85%-98%; and positive predictive value, 74%-98%) [22,23].

Incidental thyroid abnormalities often occur in nonthyroid-related imaging, resulting in heightened identification of nodules and a possible diagnosis of thyroid cancer. Drake et al. used a natural language processing method to assess the incidence of incidental observations across several imaging modalities [24-29]. Canton et al. [15] created a very precise model for identifying thyroid lesions in imaging investigations often used in trauma evaluations within emergency department contexts (sensitivity, 90%; specificity, 95.3%).

The Thyroid Imaging, Reporting, and Data System (TI-RADS) is often used to standardize reporting methods for thyroid nodule attributes [30]. Chen et al. [19] created a model to address the essential deficiencies of TI-RADS. Furthermore, Short et al. [31] developed a natural language processing pipeline designed to identify radiologic reports that meet the requirements for follow-up evaluations. Their model demonstrated notable accuracy (96.5%), sensitivity (92.1%), and specificity (96%). Additionally, Santos et al. [30] created a methodology intended to amalgamate TI-RADS findings with patient demographic data and concomitant conditions. This model achieved prospective validation (accuracy, 0.89; F1 score, 0.99) and was tested at an external facility (accuracy, 0.85; F1 score, 0.94). Additionally, Zhang et al [32-34] developed a multistep model that integrates data from thyroid images, pathology reports, and radiology reports, attaining an accuracy rate of 83%.

4. Applications of Natural Language Processing in Thyroid Cancer

Lian et al [24] developed an NLP pipeline to measure and categorize health-related quality of life based on narrative interviews with patients who underwent surgical treatment (area under the curve, 0.76; accuracy, 70.09; SN, 70.02%; and PPV, 70.20%).25 In addition, Yoo et al [12] developed an NLP algorithm to determine thyroid cancer diagnosis and stage based on retrospective information from medical records, specifically using surgical pathology and whole-body scan reports (SN, 100%; PPV, 100%). Another application successfully extracted information from internet papers and genomic databases to discover genes associated with nonmedullary thyroid cancer, which accounts for 95%-97% of all thyroid malignancies [35]. Zhou et al. [36] used a natural language processing system to extract genes associated with nonmedullary thyroid carcinoma from web resources.

5. Applications of NLP in Functional and Autoimmune Disorders

Grani et al. [22] used a natural language processing pipeline to gather data from text conversations in an online open medical forum to examine patient experiences with hypothyroidism and their worries about treatment. Park and Hong [27] sought to elucidate patients' viewpoints on thyroid hormone replacement therapy using online health forums (WebMD) and assess its influence on treatment satisfaction. In a separate study, Zheng et al. [35] developed an NLP-based tool that extracts clinical characteristics of hypothyroid patients from EHRs, utilizing phenotypes gathered from various medical resources, achieving an accuracy rate exceeding 97%. Additionally, Luft et al. [25] employed NLP to extract clinical features from EHRs of pediatric patients with mood and anxiety disorders, correlating these features with abnormal thyroid-stimulating hormone levels.

The digitalization of health care seeks to enhance patient care, optimize health care processes, and transform clinical and health care delivery research [37-40]. Natural Language Processing (NLP) can extract extensive narrative data and convert it into computable elements for subsequent analyses, a task that was formerly constrained by labor-intensive and time-consuming manual extraction by human annotators. As in all sectors of health care, the potential applications and advantages of NLP in thyroid diseases are substantial. We observed a rising quantity of NLP-focused thyroid papers, particularly in the last three years, with over fifty percent of the included articles published during this period. This seems to be the first systematic review of NLP applications within the realm of thyroidology [41-44]. Our comprehensive analysis revealed that, while still constrained, NLP is now used to investigate thyroid illnesses, namely thyroid nodules and thyroid cancer, which constituted 54% and 29% of the papers in our review, respectively.

Research has utilized natural language processing to extract features of thyroid nodules from radiology reports by employing advanced deep learning models. Moreover, while certain models concentrated on fundamental tasks, such as identifying the presence of thyroid incidentalomas in computed tomography, magnetic resonance imaging, or ultrasound reports, others demonstrated the capability to ascertain whether the reported incidentaloma warranted further ultrasound evaluation and monitored the completion of such assessments. In comparison to traditional manual extraction of unstructured data, these models effectively leveraged extensive datasets, thereby facilitating observational research, enhancing quality improvement initiatives, standardizing unstructured documentation, and developing real-time predictive tools for clinical practice. NLP models successfully constructed extensive data sets by extracting features from various unstructured text sources, such as diagnostic and pathology reports and clinician documentation. Additionally, certain models standardized unstructured data from multiple institutions to create multicenter data sets.

While the majority of models used EHR data, other important data sources have also been investigated. Zheng et al. [35] used phenotypes derived using NLP from several web sites. Others employed NLP tools to streamline abstract screening for systematic literature reviews concerning genetic associations in thyroid cancer, as well as to automate the analysis and integration of findings from previously published studies. These initiatives enabled researchers to utilize data more efficiently and comprehensively from the rapidly expanding corpus of literature and genetic repositories. Moreover, Park and Hong used natural language processing on social media postings to discern concerns pertaining to thyroid hormone replacement from patient medication evaluations. This tool can offer a comprehensive understanding of the patient experience, encompassing their emotional and social reactions to their condition and treatments, which may not be adequately documented in clinical records. This facilitates the identification of themes for discussion during shared decision-making sessions and delineates factors to be considered in future treatment or quality-of-life research.

Despite the encouraging outcomes of NLP, none of the applications examined in this study are now accessible for use in clinical practice. Among the 24 studies identified, only one employed a prospective design, and two validated their NLP models in an external healthcare setting. The integration of these NLP interventions into standard research or clinical practice faces numerous challenges that require meticulous consideration and collaborative efforts to overcome. Specifically in the thyroid field, we hypothesize that the uptake of NLP methods is associated with the complexity of the thyroid-related domains, variations in language expression and reporting styles, completeness and accuracy of clinical documentation (ie, data on patient-specific concerns, complaints, or severity of symptoms depends on the accuracy of providers' documentation), semantic (ie, misspellings, abbreviations, acronyms, or synonyms), and context (ie, it is challenging to create algorithms that can appropriately extract chronologic descriptions or simultaneous references in situations like a thyroid ultrasound report that includes several nodules), which can affect the NLP outcome, decrease the performance of the algorithm when applied to different institutions, and limit the portability and scalability of the interventions [7,21,34,43]. In addition, data sources need to be representative of the population to avoid the incorporation of inequities and social bias into the models [44]. Finally, using NLP methods requires high optimization for the local environment and extensive domain knowledge, which can be expensive, and stakeholders' lack of financial resources or prioritization could halt their implementation. Consequently, efficacy and cost-effectiveness studies are essential to validate the intervention's usefulness and promote its adoption.

This research highlights a significant variation in NLP methodologies within the field of thyroidology. Deep learning has been the predominant technique in natural language processing, with several research use pretrained big language models, followed by rule-based methodologies. It is important to note that several research did not provide detailed details about the NLP approaches used.

In considering the future of NLP in thyroid nodule and cancer care, it is clear that improving reporting systems and integrating models, especially via big language models, would greatly enhance the importance of NLP. This integration signifies a transition towards more advanced, efficient, and adaptable uses of NLP in the treatment of thyroid nodules and cancer.

We recognize many limitations that must be taken into account while assessing our findings. The variability in methodology, outcomes, and performance criteria across the included research rendered it impractical to uniformly summarize individual study findings and to do a meta-analysis. Furthermore, we must acknowledge the possibility of publication bias, which may result in an overrepresentation of positive outcomes. Nonetheless, despite these constraints, it is essential to emphasize the merits of our systematic study. Our results provide a thorough and strong definition of the current state of NLP in thyroidology, presenting significant implications for doctors, researchers, and other stakeholders involved in this area of inquiry.

6. Conclusion

The use of NLP in thyroidology has increasing interest and has the potential to enhance research and patient treatment, while alleviating the strain on healthcare system stakeholders. It is important to note that the areas of focus in thyroidology and the used NLP approaches are fairly limited. Thus, significant opportunities remain for additional investigation into the unexplored potential of NLP applications in many thyroid disorders that have not previously been examined.

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استخدام معالجة اللغة الطبيعية لتحسين البحث والإدارة السريرية لاضطرابات الغدة الدرقية من خلال تحليل السجلات الصحية الإلكترونية: استعراض شامل

الملخص

الخلفية :أصبحت معالجة اللغة الطبيعية (NLP) أداة أساسية في الرعاية الصحية، وخاصة لتحليل السجلات الصحية الإلكترونية (EHRs) من أجل تحسين البحث ورعاية المرضى. على الرغم من وفرة البيانات غير المنظمة في السجلات الصحية الإلكترونية، إلا أن استخراج المعلومات ذات الصلة لاتخاذ القرارات السريرية لا يزال يمثل تحديًا. يستعرض هذا البحث تطبيق معالجة اللغة الطبيعية في فهم وإدارة اضطرابات الغدة الدرقية، التي تعد شائعة لكنها غالبًا ما تكون غير موضوعة بما فيه الكفاية في البحث العلمي.

الطرق :تم إجراء مراجعة منهجية، استهدفت الدراسات المنشورة من 2012 إلى 2023 عبر قواعد بيانات مثل MEDLINE و EMBASEو .Scopusركزت استراتيجية البحث، التي تم تطويرها بواسطة أمين مكتبة ذو خبرة، على الدراسات التي تستخدم معالجة اللغة الطبيعية لتحليل بيانات السجلات الصحية الإلكترونية المتعلقة باضطرابات الغدة الدرقية، بما في ذلك العقيدات والسرطان.

النتائج :حددت المراجعة العديد من الخوارزميات الخاصة بمعالجة اللغة الطبيعية المستخدمة لتصنيف العقيدات الدرقية وتوقع نتائج السرطان، مع تحقيق معدلات دقة تتراوح بين 77% إلى 100%. أظهرت الدراسات البارزة قدرة معالجة اللغة الطبيعية على استخراج بيانات قيمة من تقارير الأشعة وعلم الأمراض، مما يعزز الفهم لجودة حياة المرضى واستجاباتهم للعلاج. على الرغم من هذه التقدمات، لا تزال إدماج معالجة اللغة الطبيعية في الممارسة السريرية محدودة، حيث استخدمتها دراسة واحدة فقط بتصميم استشرافي.

الخاتمة :تظهر معالجة اللغة الطبيعية إمكانات كبيرة لتحويل إدارة اضطرابات الغدة الدرقية من خلال تمكين استخراج وتحليل البيانات غير المنظمة من السجلات الصحية الإلكترونية. ومع ذلك، فإن التحديات مثل تنوع المنهجيات، وقضايا تمثيل البيانات، والحاجة إلى التحقق الموسع، تعيق التبني الأوسع لها. يجب أن تركز الأبحاث المستقبلية على تحسين تقنيات معالجة اللغة الطبيعية ومعالجة هذه التحديات لتعزيز التطبيق السريري.

الكلمات المفتاحية :معالجة اللغة الطبيعية، السجلات الصحية الإلكترونية، اضطرابات الغدة الدرقية، التعلم الآلي، اتخاذ القرارات السريرية