

Mining peripheral arterial disease cases from narrative clinical notes using natural language processing

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ABSTRACT

Objective: Lower extremity peripheral arterial disease (PAD) is highly prevalent and affects millions of individuals worldwide. We developed a natural language processing (NLP) system for automated ascertainment of PAD cases from clinical narrative notes and compared the performance of the NLP algorithm with billing code algorithms, using ankle-brachial index test results as the gold standard.

Methods: We compared the performance of the NLP algorithm to (1) results of gold standard ankle-brachial index; (2) previously validated algorithms based on relevant International Classification of Diseases, Ninth Revision diagnostic codes (simple model); and (3) a combination of International Classification of Diseases, Ninth Revision codes with procedural codes (full model). A dataset of 1569 patients with PAD and controls was randomly divided into training (n = 935) and testing (n = 634) subsets.

Results: We iteratively refined the NLP algorithm in the training set including narrative note sections, note types, and service types, to maximize its accuracy. In the testing dataset, when compared with both simple and full models, the NLP algorithm had better accuracy (NLP, 91.8%; full model, 81.8%; simple model, 83%; $P < .001$), positive predictive value (NLP, 92.9%; full model, 74.3%; simple model, 79.9%; $P < .001$), and specificity (NLP, 92.5%; full model, 64.2%; simple model, 75.9%; $P < .001$).

Conclusions: A knowledge-driven NLP algorithm for automatic ascertainment of PAD cases from clinical notes had greater accuracy than billing code algorithms. Our findings highlight the potential of NLP tools for rapid and efficient ascertainment of PAD cases from electronic health records to facilitate clinical investigation and eventually improve care by clinical decision support. (J Vasc Surg 2017;■:1-9.)

Peripheral arterial disease (PAD) is a chronic disease associated with high morbidity and mortality.¹⁻³ PAD affects at least 8.5 million people in the United States and in excess of 200 million people worldwide.⁴ PAD is associated with increased risk for death, myocardial infarction, and stroke with annual risk for adverse cardiovascular events exceeding 5%.^{1-3,5-7} Despite high prevalence and associated mortality, morbidity, and cost, PAD has received relatively little attention from clinical researchers, health systems, and government agencies.^{2,8,9} The diagnosis of PAD is based on abnormal ankle-brachial index (ABI). However, not all PAD cases have ABI results available in their electronic health records (EHRs). In the absence of ABI results,

time-consuming and laborious manual abstraction of narrative clinical notes is needed to ascertain PAD status.

Previously, we used billing code algorithms composed of PAD-related International Classification of Diseases, Ninth Revision (ICD-9) codes (simple model) or a combination of PAD-related ICD-9 codes with procedural codes (full model) to identify patients with PAD.¹⁰ When applied to a community-based sample, these billing algorithms had limited performance.¹⁰ In another prior study, we successfully developed and applied a natural language processing (NLP) algorithm to ascertain PAD status from radiology reports; however, radiology reports describe the results of radiology tests and

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do not contain the key components of the clinical notes such as impression, report, and plan of care.¹¹ To address these shortcomings, we tested the hypothesis that NLP of narrative clinical notes would improve accuracy of PAD ascertainment over billing code algorithms using ABI test results as the gold standard. In this study, we develop a NLP algorithm for automated ascertainment of PAD cases from clinical narrative notes and compare the performance of the NLP algorithm to billing code algorithms and gold standard ABI test results.

METHODS

Study setting and population. The study was conducted at Mayo Clinic, Rochester Minnesota and used the resources of the Rochester Epidemiology Project (REP) to assemble a community-based PAD case-control cohort from Olmsted County.¹² The REP consists of Mayo Clinic and the Mayo Clinic Hospitals, Olmsted Medical Center, and its affiliated hospitals. The REP is an integrated health information system that links medical records of all Olmsted County residents regardless of their ethnicity, socioeconomic, or insurance status.¹² In the present study, we applied this NLP algorithm to the Mayo clinical data warehouse. For this study, we obtained patient informed consent, and this study was approved by the institutional review boards of participating medical centers.

Gold standard. All patients from both datasets had undergone ABI testing in the Mayo noninvasive vascular laboratory using standardized protocols.⁴ The ABI results were reported in pdf format and were not part of the narrative clinical notes. In brief, the systolic blood pressure was measured in each arm and dorsalis pedis and posterior tibial arteries bilaterally using a hand-held 8.3-MHz Doppler probe. The higher of the two-arm pressures and lower of the two-ankle pressures were used to calculate the ABI for each leg.³ Normal ABI was defined as 1.0-1.3. PAD was defined as an ABI ≤ 0.9 at rest or 1 minute after exercise; or by the presence of poorly compressible arteries (ABI ≥ 1.40 or ankle systolic blood pressure >255 mm Hg).⁴ These criteria were used to classify all subjects into case or control categories.

Dataset. The dataset consisted of 1569 patients (806 cases and 763 controls) (Fig 1). We randomly divided this dataset into two subsets: training and testing. The training dataset consisted of 935 patients and 300,364 clinical notes; there were 479 PAD cases (abnormal ABI) and 456 controls (normal ABI). The testing dataset comprised 634 patients, 212,047 clinical notes, and included 327 PAD cases and 307 controls.

Study design. We retrieved all clinical notes of the subjects participating in this study from the Mayo data warehouse created through June 2015. We applied the NLP

ARTICLE HIGHLIGHTS

- **Significance:** The authors describe the development of a natural language processing (NLP) algorithm for the extraction of the diagnosis of peripheral arterial disease (PAD) from clinical notes, which may enhance detection.
- **Type of Research:** Retrospective case-control study
- **Take Home Message:** A knowledge-driven NLP algorithm for automatic ascertainment of PAD cases from clinical notes had greater accuracy than billing code algorithms.
- **Recommendation:** The authors recommend that NLP extraction algorithms continue to be explored to enhance the detection of PAD from large sets of clinical notes.
- **Strength of Recommendation:** 2. Weak
- **Level of Evidence:** C. Low or very low

algorithm to these retrieved clinical notes to ascertain PAD status as an output for each patient (Fig 2). We developed and conducted iterative refinement of an NLP algorithm in the training dataset. For subsequent validation, we applied the best version of the refined NLP algorithm to the testing dataset. For each dataset, we compared the performance of NLP algorithm with each billing code algorithm (simple model, full model) and NLP algorithm with the gold standard. The simple model was composed of PAD-related ICD-9 codes, whereas the full model was a combination of both PAD-related ICD-9 codes and procedural codes.¹⁰

NLP algorithm. The NLP algorithm was knowledge-driven and had two main components: text processing and patient classification (Fig 2). The text processing component found PAD-related concepts (the keywords listed in Table 1) in the text using MedTagger, an open source clinical NLP pipeline that analyzed text and identified PAD-related medical concepts.¹³ The NLP algorithm extracted PAD-related concepts from clinical notes and mapped them to the specific categories. For example, NLP algorithm identified a concept "lower extremity" from clinical notes and then mapped it to the category "Disease location III" (Table 1). The NLP algorithm also checked assertion status of each concept that included certainty (ie, positive, negative, and possible), temporality (historical or current) along with experiencer (ie, associated with the patient or someone else). For example, if the NLP algorithm came across a sentence: "noninvasive studies are consistent with severe arterial occlusive disease of bilateral lower extremities," the system identifies the concepts "arterial occlusive disease" and "lower extremities" along with the corresponding assertion status (ie, arterial occlusive disease) is stated positively (certainty = positive), present

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