Abstract

Objective: To build a comprehensive corpus covering syntactic and semantic annotations of Chinese clinical texts with corresponding annotation guidelines and methods as well as to develop tools trained on the annotated corpus, which supplies baselines for research on Chinese texts in the clinical domain.

Materials and methods: An iterative annotation method was proposed to train annotators and to develop annotation guidelines. Then, by using annotation quality assurance measures, a comprehensive corpus was built, containing annotations of part-of-speech (POS) tags, syntactic tags, entities, assertions, and relations. Inter-annotator agreement (IAA) was calculated to evaluate the annotation quality and a Chinese clinical text processing and information extraction system (CCTPIES) was developed based on our annotated corpus.

Results: The syntactic corpus consists of 138 Chinese clinical documents with 47,424 tokens and 2553 full parsing trees, while the semantic corpus includes 992 documents that annotated 39,511 entities with their assertions and 7695 relations. IAA evaluation shows that this comprehensive corpus is of good quality, and the system modules are effective.

Discussion: The annotated corpus makes a considerable contribution to natural language processing (NLP) research into Chinese texts in the clinical domain. However, this corpus has a number of limitations. Some additional types of clinical text should be introduced to improve corpus coverage and active learning methods should be utilized to promote annotation efficiency.

Conclusions: In this study, several annotation guidelines and an annotation method for Chinese clinical texts were proposed, and a comprehensive corpus with its NLP modules were constructed, providing a foundation for further study of applying NLP techniques to Chinese texts in the clinical domain.

1. Introduction

Electronic medical records (EMRs) represent the storage of all healthcare data and information in electronic formats [1] and constitute core data in the implementation of health care services. These services are undergoing enormous changes with increasing health awareness and demand for medical services. The situation is becoming more urgent for China, a country with the largest population but limited medical resources. In facing these challenges, the Chinese
Ministry of Health (MOH) has issued a series of relevant regulations since 2010 to standardize EMR systems and their intelligent support [2-4]. With the rapid popularization of EMRs, the development of healthcare services has a solid data foundation.

Clinical texts, an important type of patient data within EMRs, are free-text documents that contain large amounts of information about patients’ medical activities. In recent years, natural language processing (NLP) techniques on English clinical texts have been widely used [5, 6] and many resources have been established for the development of these techniques. For example, the Unified Medical Language System (UMLS) [7], an integrated knowledge base of biomedical concepts, is widely applied in medical informatics research. Moreover, challenges organized by Informatics for Integrating Biology & the Bedside (i2b2) have released various kinds of annotated data for medical information extraction tasks, and enable clinical researchers to employ these clinical corpora for discovery research [8].

However, due to the lack of an annotated corpus, NLP research on Chinese clinical texts is still at a preliminary stage. Chinese clinical text has sublanguage features [9] that make it difficult for research on general-domain texts to be applied directly to clinical texts. In this study, we focus our efforts on conducting syntactic and semantic annotations of Chinese clinical texts, involving two resident physicians (P1 and P2) and eight annotators with backgrounds in computational linguistics (CL1-CL10). To our knowledge, this is the first comprehensive Chinese clinical corpus that includes several types of syntactic and semantic annotations, making it possible to develop effective NLP techniques for application to Chinese texts in the clinical domain.

This paper has six sections and is organized as follows: background on NLP research on clinical texts is summarized in Section 2. We then describe the development of annotation guidelines, annotation method, and annotation quality measurement in Section 3. Next, Section 4 presents inter-annotator agreement (IAA) scores, data analysis of the annotations, and system development based on this corpus. In Section 5, we describe the contributions of this work and identify further improvements for future work.

### 2. Background

NLP tasks can be divided into low-level tasks and higher-level tasks: low-level tasks include sentence boundary detection, tokenization, word segmentation, part-of-speech (POS) tagging, shallow parsing, and so on; based on low-level tasks, higher-level tasks include named entity recognition (NER), negation identification, relationship extraction, etc. [10] As a bridge for adapting existing techniques into the clinical domain, annotated corpora in the clinical domain are needed. Table 1 summarizes some major clinical text corpora for NLP tasks, and is discussed in the following sub-sections.

| Author          | Year | Language | Scale         | Chinese word segmentation | POS tagging | Shallow parsing | Full parsing |
|-----------------|------|----------|---------------|---------------------------|-------------|----------------|--------------|
| Savova et al.   | 2010 | English  | 273 documents | –                         | √           | √              | –            |
| Albright et al. | 2013 | English  | 13,091 sentences | –                         | √           | √              | √            |
| Fan et al.      | 2013 | English  | 1100 sentences | –                         | √           | √              | √            |
| Xu et al.       | 2014 | Chinese  | 336 documents  | √                         | –           | –              | –            |
| Author          | Year | Language | Scale              | Entities | Assertions | Relations |
|-----------------|------|----------|--------------------|----------|------------|-----------|
| Meystre et al.  | 2006 | English  | 160 documents      | √        | √          | –         |
| Meystre et al.  | 2009 | English  | 150 documents      | √        | √          | –         |
| Meystre et al.  | 2010 | English  | 160 documents      | √        | √          | –         |
| Uzuner et al.   | 2011 | English  | 826 documents      | √        | √          | –         |
| Albright et al. | 2013 | English  | 13,091 sentences   | √        | √          | –         |
| Elhadad et al.  | 2015 | English  | 531 documents      | √        | √          | –         |
| Xu et al. [13]  | 2014 | Chinese  | 336 documents      | √        | –          | –         |
| Lei et al. [19] | 2014 | Chinese  | 800 documents      | √        | –          | –         |
| Wang et al. [20]| 2014 | Chinese  | 11,613 CCs         | √        | –          | –         |
| Wang et al. [21]| 2014 | Chinese  | 115 documents      | √        | –          | –         |
| Jia et al. [22] | 2014 | Chinese  | 30 documents       | √        | √          | –         |
| Xu et al. [23]  | 2015 | Chinese  | 500 HPIs           | √        | √          | –         |
| Li et al. [24]  | 2015 | Chinese  | 1000 documents     | √        | –          | √         |

“√” means annotated, and “–” means unannotated. POS, part-of-speech; CC, chief complaint; HPI, history of present illness.

2.1. Annotated clinical text corpus for low-level tasks

2.1.1. Current status in English clinical texts

The Mayo Clinic’s cTAKES system aims at comprehensive processing of clinical texts and covers various NLP techniques [6]. In this work, a linguistic corpus annotated for POS tagging and shallow parsing was accomplished by three linguistic experts via extending the Penn TreeBank (PTB) annotation guidelines [25, 26] to the clinical domain. Additionally, Albright et al. [11] constructed a corpus involving annotations of POS tags and syntactic trees, and its advantage is that multilayer annotations are carried out in each sentence, which is beneficial in training joint models. As Albright et al. pointed out, the sentences in clinical texts contain numerous patterns that do not appear in the bracketing guidelines for the PTB [26], and clinical texts have sublanguage properties [27, 28]. Therefore, Fan et al. [12] developed annotation guidelines for parsing clinical texts and annotated a syntactic corpus of progress notes from the University of Pittsburgh Medical Center (UPMC).

2.1.2. Current status in Chinese clinical texts

Word segmentation is an initial processing step in low-level tasks on Chinese texts. Xu et al. [13] found that out-of-vocabulary words and resolving ambiguities in clinical texts brought great challenges to word segmentation and that a state-of-the-art Chinese word segmenter trained by a general corpus would have poor performance in the clinical domain. Therefore, they manually annotated a corpus of segmented words in discharge summaries to improve the performance of word segmenters in Chinese clinical texts. Analogously, Zhang et al. [14] constructed similar corpus to achieve better word embedding features.

2.2. Annotated clinical text corpus for higher-level tasks
2.2.1. Current status in English clinical texts

In 2006, Meystre et al. [15] constructed an entity corpus involving 80 different medical problems with their assertions to judge whether a medical problem is present or absent, and 10 clinical document types were annotated. However, this corpus was somewhat limited in that only medical problems and two kinds of entity assertions were annotated. To extract further information from clinical texts automatically, Roberts et al. [16] randomly chose 50 clinical narratives, 50 histopathology reports, and 50 imaging reports to annotate entities, relations, modifiers, co-references, and temporal information in the CLinear E-Science Framework (CLEF) project [29]. This was the first corpus that extended the number of entity types to six, and was the first attempt at annotating relations and temporal information in clinical texts. Moreover, an iterative approach was used to develop annotation guidelines, and this greatly inspired subsequent work to build high-quality corpora in the clinical domain. Besides, Savova et al. built a named entity corpus [6] that included disorder entities with attached UMLS concept unique identifiers (CUI) and assertions that are of the types negated, current, history of, family history of, and possible. This corpus has contributed towards the development of cTAKES system, which brings enormous benefits to subsequent clinical text studies. In 2010, Uzuner et al. [30] released a corpus that annotated concepts, assertions, and relations. Based on semantic types defined in UMLS, concepts are classified into medical problems, tests, and treatments; meanwhile, there are six types of assertions for medical problems and three groups of relations between concepts. Furthermore, the annotation guidelines [31-33] in this corpus are of great importance for corpus construction in the clinical domain. However, diseases and symptoms, which are treated differently in medical practice, are not subdivided in this corpus but are merged into medical problems. In fact, Uzuner et al. [34] split medical problems into diseases and symptoms in a study before the i2b2 2010 challenge. Considering the differences between disorders and symptoms in many medical applications, Albright et al. [11] annotated disorders as a semantic type independent of signs or symptoms, and built a corpus that annotated entities and their assertions. In 2015, to enhance NLP research in the clinical domain, Elhadad et al. [18] released a corpus that annotated disorders with various attributes in SemEval-2015 Task 14. The attributes of the disorders are beneficial for extracting deeper patient information in the clinical texts.

2.2.2. Current status in Chinese clinical texts

Referring to the concept annotation guidelines in the 2010 i2b2/VA challenge, Xu et al. [13] labeled medical problems, treatments, and tests in Chinese discharge summaries and added two more entity types, namely medication and anatomy. Medication is divided from treatment for further analysis on the usage and effectiveness of medications, and anatomy can help to locate positions of symptoms or tests. Similar to Xu et al.’s corpus on entities, Lei et al. [19] developed an entity corpus of discharge summaries and admission notes from Peking Union Medical College Hospital. Their entity categories differ from the 2010 i2b2/VA concept guidelines in that treatments are divided into procedures and medications. Moreover, Xu et al. [23] annotated medical terms on “history of present illness” section in clinical texts, and proposed an effective rule-based method. Differ from the above research on Chinese clinical texts, Jia et al. [22] manually marked up negated information of medical terms. To our knowledge, this is the first entity corpus with assertion information annotated in Chinese clinical texts.
Moreover, research into clinical texts of traditional Chinese medicine has gradually been taken into account. Wang et al. [20] conducted research in recognizing symptoms from the chief complaints, but the text types and entity categories in their corpus were relatively few. Li et al. [24] proposed a network-based correlation analysis method to detect the herb-symptom associations, and built a dataset of herb-symptom records that annotated correlations between symptoms and herbs. This study is meaningful to research of relation extraction from Chinese clinical texts.

However, for the clinical texts on a particular disease, the existing classification standards of medical entities are too rough, and some important information has not been distinguished effectively. In order to identify tumor-related information from Chinese operation notes, Wang et al. [21] manually annotated 12 entity types on operations, which revealed operation details and correlated strongly with patients' pathological status. This study provides a good reference for research on information extraction for specific diseases.

2.3. Shortcomings of research on Chinese clinical texts

Corpus construction on English clinical texts is a mature field, and its annotation scheme and evaluation method are of great significance for Chinese clinical texts. Considering the research status described above, research on Chinese clinical texts has three shortcomings: first, research on low-level tasks is quite limited, and this may cause performance improvement of higher-level tasks to encounter a bottleneck; second, as far as we know, only negated assertion and symptom-herb correlation have been annotated, other types of assertions or relations have not been annotated systematically; and third, guideline tuning and annotator training are needed in corpus construction, but descriptions of previous research efforts have not described these processing procedures. Based upon the above three points, along with the fact that no clinical corpus written in Chinese has been released to the public, it is imperative to build a comprehensive corpus that follows a complete annotation scheme.

By referring to the existing research on English clinical texts, we constructed a comprehensive corpus of Chinese clinical texts. In our annotation method, some existing well-developed guidelines were used and adapted into Chinese clinical texts in the process of annotation guideline tuning. Next, annotator training and various measures were conducted to ensure the quality of this corpus. Furthermore, according to the annotations in this corpus, corresponding automatic system modules were developed.

3. Materials and methods

3.1. Types of clinical text

Discharge summaries and progress notes employed in this work were randomly selected from clinical texts of the Second Affiliated Hospital of Harbin Medical University (a general hospital in China), and all identifying information was removed manually to protect patient privacy. These two types of clinical text are semi-structured documents, and free text in the document is divided into several sections, as listed in Fig. 1.
3.2. Annotation guidelines

Due to the diversity of clinical texts, there is no existing annotation schema widely applicable in the clinical domain [11]. Owing to different language features between Chinese and English, annotation guidelines for CTB [35-37] were chosen to develop guidelines for low-level tasks on Chinese clinical texts; meanwhile, annotation guidelines in the 2010 i2b2/VA challenge [31-33] were consulted to develop guidelines for higher-level tasks. According to the characteristics of Chinese clinical texts, we developed several modified annotation guidelines [38-41] for four low-level and three higher-level tasks. Fig. 2 shows an example of the annotations in a sentence from the case characteristics section of a progress note.
A sentence from the case characteristics section of a progress note:

Eight years ago, the patient had discomforts such as chest congestion and palpitation without any obvious causes, and was diagnosed with hyperthyroid heart disease.

Annotations for low-level NLP tasks

![Sentence with annotations](image)

Annotations for higher-level NLP tasks

Entities
- [胸闷]: type=symptoms
- [心悸]: type=symptoms
- [甲状腺功能减退]: type=diseases

Assertions
- [胸闷]: type=present
- [心悸]: type=present
- [甲状腺功能减退]: type=present

Relations
- [胸闷, 心悸]: 甲状腺功能减退, type=SID)

Fig. 2. An example of the annotations in a sentence from a progress note. NLP, natural language processing; DT, determiner; NN, common nouns; P, prepositions; CD, cardinal numbers; M, measure word; LC, localizer; VE, you3 as the main verb; JJ, noun-modifier other than nouns; VV, other verbs; ETC, tags for deng3 and deng3deng3 in coordination phrases; PU, punctuation; DP, determiner phrase; NP, noun phrase; CLP, classifier phrase; ADJP, adjective phrase; QP, quantifier phrase; LCP, phrase formed by "phrase + LC"; VP, verb phrase; PP, preposition phrase; IP, simple clause; POS, part-of-speech; SID, symptom indicates disease.

3.2.1. Guideline development for low-level tasks

3.2.1.1. Word segmentation

The segmentation guidelines for the Penn Chinese TreeBank (CTB) [35] cannot cover all the segmentation ambiguities in clinical texts, especially the segmentation of medical terms, abbreviations, and their combinations. In order to address these segmentation ambiguities, three word attributes were utilized in the word segmentation guidelines:

1. **Combinability** [42], which means that a word can be separated into two sub-words and that each sub-word has its independent POS;
2. **Reducibility**, which indicates that, if a word is an abbreviation, then it can be reverted to its complete expanded form to clarify its description;
3. **Replaceability**, which denotes that one sub-word in a combined word can be replaced by another word with the same POS, and that the new combined word may still appear in clinical texts.

Obviously, medical terms, if they are nouns or do not have the combinability attribute, are not normally split, such as “糖尿病 (diabetes)”. Therefore, the main problems are segmentation...
ambiguities existing in non-nominal terms that have the combinability attribute. For these terms, a word segmentation method was developed, as shown in Fig. 3a, and Fig. 3b illustrates this method using the segmentation of “抗凝 (anti-coagulation)”.

![Fig. 3. A word segmentation method for non-nominal terms that have the combinability attribute.](image)

**3.2.1.2. POS tagging and Parsing**

For the POS tagging task in Chinese clinical texts, the POS guidelines for CTB [36] also have some degree of incompleteness. Three main problems and their solutions are described as follows:

1. Some specific symbols that do not exist in CTB are used as abbreviations of certain words in clinical texts. For example, “+” in “肌力 4+级 (myodynamia level is 4+)” means “stronger”. Moreover, we tagged the POS of the specific symbol based on its meaning in the context; hence, “+” in this example should be tagged as a VA (predicative adjective).

2. A verb-complement phrase is commonly utilized as an object to describe a patient’s symptom in clinical texts, but this usage does not appear in CTB, so POS tags of words in a verb-complement phrase come with some ambiguity. For instance, “视物 模糊 (blurred vision)” in “伴有 视物 模糊 (with blurred vision)” is a symptom and can be seen as a noun phrase, so “视物 [see things]” can be tagged as an NN (common nouns); but from the perspective of phrase structure, “视物 [see things] 模糊 [blurred]” is a verb-complement phrase, and thus “视物 [see things]” should be tagged as a VV (other verbs). To solve this kind of ambiguity, POS tags are achieved according to the POS of the word itself, so “视物 [see things]” is tagged as a VV.

3. Annotation ambiguities caused by omitting some parts of the sentence. For example, the POS tag of “左侧 [left side]” in “左侧肢体麻木 (numbness in the left limbs)” and “右肺呼吸音清左侧弱 (right lung breath sounds clear and the left’s weak)” are different. In CTB, ambiguity between “NN” and “JJ” can usually be disambiguated by judging whether the word is the head of a noun phrase; however, neither occurrence of “左侧 [left side]” in the above two examples is the head of a noun phrase, so we need to complement omitted elements in the sentence. The former example has a normal grammatical structure in which “左侧 [left side]” modifies “肢体
Furthermore, we simplified the bracketing guidelines for CTB [37] and adapted these annotation specifications to the clinical domain, providing clear guidance in annotating for the parsing (shallow parsing and full parsing) task in Chinese clinical texts.

3.2.2. Guideline development for higher-level tasks

3.2.2.1. Entities and assertions

Concept annotation guidelines in the 2010 i2b2/VA challenge [31] include three categories of concept: medical problems, tests, and treatments. However, as Uzuner et al. [34] pointed out, patients’ medical problems can be represented as diseases and symptoms, and these two kinds of concept have separate UMLS semantic types; hence, we treated diseases and symptoms as two types of medical entity in our annotation guidelines, as shown in Table 2A.

In the 2010 i2b2/VA challenge, only assertions of medical problems were annotated, and each medical problem was assigned one of the six assertion types [32]. In our work, we did not find any hypothetical entity in Chinese clinical texts, but observed a relatively frequent assertion in the default category present, so we deleted the hypothetical assertion type and separated the additional kind of assertion occasional from present. We assigned six assertion types to diseases and symptoms in Chinese clinical texts. Furthermore, because the statuses of treatments administered in patients are important references for clinical diagnoses, we annotated three types of assertion in treatments: present, absent, and historical. Table 2B lists the assertions of medical entities with their examples.

**Table 2**
Entities and their assertions annotated in Chinese clinical texts

| Part A | Entity type | Example |
|--------|-------------|---------|
|        | Diseases    | 行支气管镜检查示：小细胞肺癌 (Bronchoscopy showed: small cell lung cancer) |
|        | Symptoms    | 疼痛时伴右下肢活动受限 (Pain accompanied by the right lower extremity activity limitation) |
|        | Tests       | 行支气管镜检查示：小细胞肺癌 (Bronchoscopy showed: small cell lung cancer) |
|        | Treatments  | 注射胰岛素控制血糖 (Injection of insulin to control blood glucose) |

| Part B | Entity type | Assertion type | Description | Example |
|--------|-------------|----------------|-------------|---------|
| Diseases | Present     | Disease or symptom exists in the patient |  | 头 CT 示：双侧多发腔梗 (head CT showed: bilateral multiple lacunar infarct) |
|         | Absent      | Disease or symptom does not exist in the patient | 双下肢无浮肿 | (no edema in both lower limbs) |
|         | Possible    | Disease or symptom may exist in the patient | 右肺下叶考虑创伤性湿肺 | (Right lung lower lobe consider traumatic wet lung) |
|         | Conditional | Disease or symptom occurs in the patient under certain conditions | 胸闷、气短，常于饮酒后出现 (...chest tightness, shortness of breath, commonly occurs after drinking) |
|         | Not associated with | Disease or symptom exists in the patient's relatives | 患者父母均患有糖尿病 | (parents of the patient suffer from diabetes) |
|         | Occasional  | Disease or symptom exists in the patient |  | 时有胸闷气短 (there are chest tightness and...
occasionally shortness of breath sometimes

Treatments Present The patient is experiencing or will experience the treatment
右侧胸部见引流管
(drainage tube in the right side of the chest)

Absent The patient does not experience the treatment
停用达那唑
(stop taking danazol)

Historical The patient experienced the treatment in the past
18年前剖宫产手术
(cesarean section 18 years ago)

In the examples, entities are underlined and indicators of the assertions are highlighted in bold and italics.

3.2.2.2. Relations

In Chinese clinical texts, entities of the same type usually appear one after the other in a sentence, and there are commonly concurrent relationships between these entities; for example, some treatments are administered for a disease or a disease causes some symptoms. Additionally, these entities may have the same type of relationship with an entity of a different type in the sentence, but one-to-one relationships between one of the former entities and the latter entity may not be clearly pointed out, causing some trouble in the annotation of one-to-one relationships. To avoid annotating fuzzy one-to-one relationships, we referred to the definition of narrative container that used in temporal relations [43], and proposed the concept of an “entity group” to assist in the relation annotation task in Chinese clinical texts.

 Entities of the same type in a sentence are combined into an entity group if they satisfy the following two conditions: (1) simultaneity, which means that these entities appear at the same time during a medical activity of the patient, indicating a concurrent relationship between entities; (2) these entities have the same type of relationship with an entity of a different type in the sentence.

According to the definition of an entity group, one-to-one relationships can be developed into a relationship between an entity and an entity group, or a relationship between an entity group and another entity group. In the example shown in Fig. 2, the patient had symptoms of “胸闷 (chest congestion)” and “心悸 (palpitation)”, and was diagnosed with “甲亢性心脏病 (hyperthyroid heart disease)”, so a relationship between entity group “[胸闷; 心悸]” and entity “甲亢性心脏病” was annotated.

The introduction of entity groups may weaken one-to-one relationships between entities, but solves the problem of fuzzy relationships. Besides, the definition of an entity group can also be explained by doctors’ habits of clinical diagnosis and treatment: when a doctor makes a diagnosis based on the patient’s current symptoms, the diagnosis is not based on one symptom but on a comprehensive judgment of a group of symptoms, and several tests or treatments are applied cooperatively to the patient.

In addition to the introduction of entity groups, we also made some adjustments to the relation types. Based on relations in the 2010 i2b2/VA challenge [33], we extended the relation types into five main categories and 16 subcategories in Chinese clinical texts, as shown in Table 3. All these relationships are bounded by sentences, and entity assertions are not considered when labeling relationships.

Table 3
Relations between medical entities annotated in Chinese clinical texts

| Entity pair | Relation | Description | Example |
|-------------|----------|-------------|---------|
|             |          |             |         |
| type | Treatment improves disease | Treatment worsens disease | Treatment causes disease | Treatment is administered for disease | Treatment is not administered because of symptom | Test reveals disease | Test conducted to investigate disease | Test reveals symptom | Disease causes symptom | Symptom indicates disease |
|------|-----------------------------|---------------------------|-------------------------|--------------------------------------|---------------------------------|-------------------|---------------------------------|-------------------|----------------------|--------------------------|
| D   | Treatment improves disease | Treatment worsens disease | Treatment causes disease | Treatment is administered for disease | Treatment is not administered because of symptom | Test reveals disease | Test conducted to investigate disease | Test reveals symptom | Disease causes symptom | Symptom indicates disease |

In the examples, entities are in brackets followed by the abbreviation of the entity type. D, diseases; S, symptoms; Te, tests; Tr, treatments.
3.3. Annotation method

Referring to the annotation methods in English clinical texts [11, 12], annotation guideline development and corpus construction for each NLP task were executed in three major stages (as shown in Fig. 4):

1. Building the draft guidelines: Annotation guidelines for CTB [35-37] and annotation guidelines in the 2010 i2b2/VA challenge [31-33] were chosen as the basis for developing guidelines for NLP tasks on Chinese clinical texts. With the help of two resident physicians (P1 and P2), four annotators with backgrounds in computational linguistics (CL1 and CL2 for low-level tasks, CL5 and CL6 for higher-level tasks) summarized the characteristics of Chinese clinical texts and drafted annotation guidelines adapted for them. In these guidelines, a large number of annotated examples are listed, and annotation ambiguities are analyzed in detail to make the annotation work easier.

2. Training the annotators and updating the guidelines: An iterative method was proposed to train the annotators and update the guidelines. In each round, a certain number of clinical documents were randomly sampled from the unannotated dataset. To accelerate the annotation progress as well as to ensure annotation quality, different strategies were implemented during the double-annotation period of different tasks: (1) automated tools trained in the general domain [44-46] were applied in the pre-tagging of low-level annotations, and four annotators with backgrounds in computational linguistics were divided into two groups (CL1 and CL3 in annotator group 1, CL2 and CL4 in annotator group 2) to conduct double verification and correction of the automatically added annotations (the annotators in each group accomplish the work collaboratively); annotation disagreements were then adjusted by a physician (P1); (2) since annotations of entities and assertions require professional medical knowledge, we had two physicians (P1 in annotator group 3, P2 in annotator group 4) annotate documents in parallel from the beginning; (3) in the relation annotation task, the documents were double-annotated by two annotator groups (CL5 and CL7 in annotator group 5, CL6 and CL8 in annotator group 6), and a physician (P2) was also assigned to resolve the annotation differences. IAA was then calculated to measure the quality of annotator training, and inconsistent cases were discussed to update the annotation guidelines.

3. Corpus construction: The iterative process in stage 2 continued until IAA was consistently high in the latest three iterations, showing that annotators reached an agreement on annotation guidelines. After the iterative annotator training process, two annotator groups in each task labeled different datasets separately to reduce the consumption of time and money. During this period, three measures were taken to ensure annotation quality: (1) duplicate documents were assigned to two annotator groups for the IAA evaluation of stage 3; (2) annotators recorded uncertain annotations, whose final results were achieved after discussion; (3) sampling inspection was carried out and at least one third of the annotations were checked, and the conflicts with the latest guidelines were then modified after further discussion.
Fig. 4. Iterative annotation method for guideline development and corpus construction. IAA, inter-annotator agreement.

3.4. Inter-annotator agreement

To evaluate the annotation quality of our corpus, IAA was calculated using the $F_{\beta}$ measure. The annotations of one annotator group were seen as the gold standard, and were used to calculate the precision, recall, and $F_{\beta}$ measure of the second annotator group, as described in the following equations [47]:

\[
\text{Precision} = \frac{\text{AgreedNumber}(AG_i, AG_j)}{\text{AnnotationNumber}(AG_j)},
\]

\[
\text{Recall} = \frac{\text{AgreedNumber}(AG_i, AG_j)}{\text{AnnotationNumber}(AG_i)},
\]

\[
F = (1 + \beta^2) \times \frac{\text{Precision} \times \text{Recall}}{\beta^2 \times \text{Precision} + \text{Recall}},
\]

where $\text{AgreedNumber}(x, y)$ means the number of the consistent annotations between $x$ and $y$, $\text{AnnotationNumber}(x)$ means the annotation number of $x$, $AG_i$ means annotator group $i$, and $\beta = 1$ in our work.
For parsing annotations, Evalb [48] was utilized to calculate the IAA of the parsing trees. Since entities and their assertions were annotated simultaneously to accelerate the annotation progress, we merged these two IAA evaluations into one, in which the agreement should satisfy the condition that the extent, type, and assertion of an entity are consistent. Considering the existence of entity groups in entity relations, two types of IAA for relations were computed: the first measured the IAA of relation annotations that preserve entity groups in the relationship; the second separated entity groups into entities and then calculated the IAA of the one-to-one relationships.

4. Results

4.1. Annotation consistency

As shown in Table 4, the IAA values of these annotation tasks show an increasing trend in the latest three annotator training iterations, indicating that an annotator’s mastery of the annotation guidelines improves continually. Furthermore, on account of the fact that the IAA values of relation annotations in the training stage are relatively lower, we added duplicate documents in the corpus construction stage of higher-level tasks. The last column of Table 4 shows that the IAA of these documents remained at a relatively high level, indicating that annotators have the ability to accomplish these annotation tasks with acceptable consistencies.

Table 4
Inter-annotator agreement in the latest three annotator training iterations and corpus construction stage ($F_1$ measure)

| IAA                                      | Training[-3] | Training[-2] | Training[-1] | Corpus construction |
|------------------------------------------|--------------|--------------|--------------|---------------------|
| Word segmentation                        | 0.965        | 0.979        | 0.983        | –                   |
| POS tagging                              | 0.893        | 0.952        | 0.956        | –                   |
| Shallow parsing                          | 0.956        | 0.969        | 0.970        | –                   |
| Full parsing                             | 0.805        | 0.840        | 0.865        | –                   |
| Entity (span, type, assertion)           | 0.848        | 0.920        | 0.927        | 0.922               |
| Relation (entity group preserved)        | 0.765        | 0.781        | 0.843        | 0.772               |
| Relation (one-to-one)                    | 0.742        | 0.774        | 0.805        | 0.755               |

*–* means not evaluated. IAA, inter-annotator agreement; POS, part-of-speech.

4.2. Data analysis of annotations for low-level tasks

Annotations for low-level tasks cover 72 Chinese discharge summaries and 66 progress notes, including 2553 full parsing trees. There are 47,424 tokens in this corpus, and its average sentence length is 18.58 tokens, which is much shorter than the 27.09 in CTB 5.0. Within clinical texts, the average sentence length of discharge summaries is shorter than that of progress notes (14.13 vs. 22.42) because sentences in some sections of discharge summaries are quite short, especially in the case of only one token in the “treatment effect” section. Fig. 5 gives a detailed comparison between tag distributions in Chinese clinical texts and CTB.
Fig. 5. POS and syntactic tag distributions in Chinese clinical texts and CTB 5.0. The tags, whose percentages in clinical texts and CTB are both below 1%, are not listed in this figure. CTB, Chinese Treebank; NN, common nouns; PU, punctuation; VV, other verbs; CD, cardinal numbers; VA, predicative adjective; JJ, noun-modifier other than nouns; AD, adverbs; M, measure word; VE, you3 as the main verb; P, prepositions; LC, localizer; NT, temporal nouns; CC, coordinating conj; DT, determiner; NR, proper nouns; VC, copula shi4; PN, pronouns; DEG, associative de5; DEC, de5.
Compared with CTB, the POS tag distribution in clinical texts is relatively concentrated, and some tags are rare, such as NR (proper nouns), VC (copula shi4), PN (pronouns), DEG (associative de5), and DEC (de5 for relative-clause etc.). The low percentage of NR in clinical texts is due to the de-identification of patients. Furthermore, the 22.7% of PU (punctuation) in clinical texts is much higher than the 15.29% in CTB because phrase structures, which are separated by punctuations, appear frequently in clinical texts to describe patients’ conditions. Moreover, some of the test results in clinical texts are described in the form of a numerical value, resulting in the percentage of CD (cardinal numbers) much higher than that in CTB.

As shown in Fig. 5b, syntactic tag distribution in clinical texts is quite different from that of CTB, and this is closely related to the sublanguage properties of clinical texts. Some syntactic tags are rare in clinical texts, such as DNP (phrase formed by “phrase + DEG”) and CP (clause headed by complementizer). Moreover, the low proportion of DNP can be attributed to the same low percentage of DEG in POS tags. Furthermore, some sections in clinical texts, such as case characteristics and treatment plans, are detailed in the form of a list. For this reason, the 2.08% of LST (list marker) in clinical texts is understandably higher than the 0.03% in CTB.

4.3. Data analysis of annotations for higher-level tasks

Annotations for higher-level tasks contain 500 discharge summaries and 492 progress notes, including 39,511 entities and 7695 one-to-one relations. Compared with discharge summaries, entities and relations contained in progress notes occur in larger quantities, accounting for three fifths and four fifths of the total numbers, respectively. Fig. 6 shows entity and relation type distributions in these discharge summaries and progress notes.
Fig. 6. Entity and relation type distributions in Chinese discharge summaries and progress notes. The types, whose percentages in discharge summaries and progress notes are both below 1%, are not listed in this figure. D, diseases; S, symptoms; Tr, treatments; Te, tests; R (entity1, entity2), relation between entity1 and entity2; TrAD, treatment is administered for disease; TrID, treatment improves disease; TrWD, treatment worsens disease; TrAS, treatment is administered for symptom; TrIS, treatment improves symptom; TrWS, treatment worsens symptom; TrCS,
treatment causes symptom; TeRD, test reveals disease; TeRS, test reveals symptom; TeAS, test is administered because of symptom; SID, symptom indicates disease; DCS, disease causes symptom.

Discharge summaries and progress notes have similar distributions of the four entity types, as shown in Fig. 6a. Symptoms account for nearly half of the total entities in discharge summaries and progress notes, respectively, and almost three fifths of these symptoms are absent, which can be used by physicians to distinguish patients’ conditions. In addition to these approximate distributions, the proportions of some assertion types in discharge summaries and progress notes show some differences. In discharge summaries, admission diagnosis results in more possible diseases, while clinical definite diagnosis leads to more present diseases; however, case characteristics describe the patient’s medical history, leading to many more absent diseases and historical treatments in progress notes.

In Fig. 6b, relation type distributions in discharge summaries and progress notes are quite different for some relation types, especially disease-symptom relations, and this is closely related to the content emphasis of different clinical text types. In progress notes, present illness history is presented in the section of case characteristics, including patients’ conditions, tests, and relevant diagnoses, so the proportion of TeAS (test is administered because of symptom) and SID (symptom indicates disease) are much higher than those in discharge summaries.

4.4 System development

To verify the usefulness of our annotated corpus, we developed a Chinese clinical text processing and information extraction system (CCTPIES) that consisted of a word segmenter, POS tagger, shallow parser, full parser, named entity recognizer, and relation extractor [49], and the performance of these modules was evaluated by 10-fold cross validation on the annotated corpus; results are shown in Table 5.

| Table 5 | Performance of system modules trained on our annotated clinical texts |
|---------|-------------------------------------------------------------------|
| Module             | Precision | Recall  | F1    |
| Word segmenter     | 0.981     | 0.979   | 0.980 |
| POS tagger         | 0.966     | 0.964   | 0.965 |
| Shallow parser     | 0.946     | 0.949   | 0.948 |
| Full parser        | 0.845     | 0.841   | 0.843 |
| Named entity recognizer | 0.923   | 0.902   | 0.912 |
| Relation extractor | 0.784     | 0.691   | 0.735 |

We used a sequence-labeling method to train statistical models for word segmentation, POS tagging, shallow parsing, and named entity recognition. CRF++ [50], an open-source implementation of the conditional random fields algorithm, was used to train these models. As shown in Table 5, the evaluation results of these modules trained by CRF++ are quite excellent in that all of them achieved the level of practical application. To build a full parsing model, we trained the Stanford parser and the Berkeley parser [51] on our annotated corpus; results showed that both parsers were satisfactory, but that the Berkeley parser was slightly better. However, there were some null outputs in the Berkeley parser, so we used the corresponding outputs in the Stanford parser to replace them. This improvement further enhanced the evaluation of the full parser, and we chose this combined parser as our full parser. Moreover,
similarly to most relation extraction research on English clinical texts, we used the support vector machines (SVM) algorithm to train models on our annotated Chinese clinical texts, and LIBSVM [52] was selected as the training tool.

5. Discussion

5.1. Contributions of this work

In this study, we constructed a comprehensive syntactic and semantic corpus of Chinese clinical texts, covering annotations for word segmentation, POS tagging, shallow parsing, full parsing, NER, assertion classification, and relation extraction. Because extensive medical knowledge exists in clinical texts, we referred to annotation guidelines from the general domain and the clinical domain, and developed annotation guidelines for Chinese clinical texts with the help of physicians. As described in the guideline development section, many improvements were proposed to adapt to the characteristics of Chinese clinical texts.

Before building the corpus, annotators kept training by following annotation guidelines until their annotation consistency remained at a relatively high level. During the annotation period, existing open-source tools were used for pre-labeling, and significantly reduced the burden on annotators. As is widely known, double annotation improves corpus quality; however, as the corpus scale grows, annotation costs in terms of time and money can be a challenge. Therefore, we balanced these factors and proposed an annotation method: double annotation was adopted in the annotator training stage; then, annotators were allowed to annotate separately in the corpus construction stage, using certain annotation quality assurance measures. The annotation consistency shows that our annotated corpus is of good quality.

Based on this corpus, some syntactic and semantic features of Chinese clinical texts were analyzed (more analysis results are provided in Appendix A). Moreover, a Chinese clinical text processing and information extraction system was developed, and its modules can be seen as baselines for research in the clinical domain. To our knowledge, some of these modules described here are introduced into Chinese texts in the clinical domain for the first time, including the POS tagger, shallow parser, full parser.

5.2. Limitations and future work

Although our annotated corpus makes a contribution to research on Chinese texts in the clinical domain, there are some limitations in our study. Because of limited annotation resources, the syntactic corpus only covers two departments within the Second Affiliated Hospital of Harbin Medical University. There are differences in medical terminologies from different hospital departments, which may weaken the adaptability of some NLP techniques across different departments.

As future work, some explorations will be conducted. First, transfer learning approaches will be introduced to solve the adaptation problem among different hospital departments. Second, some additional types of clinical text should be annotated to improve the practicability of NLP techniques developed based on this corpus. Third, active learning methods will be explored to reduce the annotation burden on annotators by filtering redundant samples from unlabeled data.
while selecting undertrained samples for the annotators. Finally, algorithms used to improve the performance of NLP systems for clinical texts will be developed.

6. Conclusions

In this paper, we described the construction of a corpus of Chinese clinical texts using an iterative annotation method. By following the annotation guidelines developed in this study, good levels of annotation consistency were achieved. Moreover, a CCTPIES was developed to verify the usefulness of the corpus, which achieved excellent performance. To the best of our knowledge, this corpus is the first comprehensive annotated corpus of Chinese texts in the clinical domain, laying a solid foundation for future research. The related annotation resources are available at http://github.com/WILAB-HIT/Resources.

Author contributions

This work was a collaboration of all the authors. BH, JY, ZJ, and CQ developed the annotation guidelines and took part in corpus construction. BH, BD, YG, and QY performed corpus analysis. BH, ZJ, and JC developed system modules and evaluated their performance. All authors contributed to drafting, revision, and final approval of this manuscript.

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Conflict of interest

The authors have no conflicts of interest to declare.

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Appendix A. Distributions of annotations in Chinese clinical texts

| Annotation type | Description                                      | Counts | % in our annotated corpus |
|-----------------|--------------------------------------------------|--------|---------------------------|
| NN              | common nouns                                     | 14,782 | 31.17                     |
| PU              | punctuation                                      | 10,763 | 22.70                     |
| VV              | other verbs                                      | 5896   | 12.43                     |
| CD              | cardinal numbers                                 | 3484   | 7.35                      |
| VA              | predicative adjective                            | 2762   | 5.82                      |
| JJ              | noun-modifier adjective other than nouns         | 2086   | 4.40                      |
| AD              | adverbs                                          | 1759   | 3.71                      |
| M               | measure word (including classifiers)             | 1736   | 3.66                      |
| VE              | you3 as the main verb                            | 1160   | 2.45                      |
| P               | prepositions (excluding ba3 and bei4)            | 628    | 1.32                      |
| Annotation type | Description                                                                 | Counts | % in our annotated corpus |
|-----------------|-----------------------------------------------------------------------------|--------|---------------------------|
| NP              | noun phrase                                                                 | 17,254 | 32.43                     |
| VP              | verb phrase                                                                 | 14,573 | 27.39                     |
| IP              | simple clause                                                                | 9634   | 18.11                     |
| QP              | quantifier phrase                                                           | 2701   | 5.08                      |
| ADJP            | adjective phrase                                                            | 2114   | 3.97                      |
| ADVP            | adverbial phrase                                                            | 1754   | 3.30                      |
| CLP             | classifier phrase                                                           | 1736   | 3.26                      |
| LST             | list marker                                                                 | 1104   | 2.07                      |
| PP              | preposition phrase                                                          | 662    | 1.24                      |
| LCP             | phrase formed by "phrase + LC"                                              | 598    | 1.12                      |
| FRAG            | fragment                                                                    | 341    | 0.64                      |
| DP              | determiner phrase                                                           | 251    | 0.47                      |
| VCD             | coordinated verb compound                                                   | 164    | 0.31                      |
| VSB             | verb compounds formed by a modifier + a head                                | 121    | 0.23                      |
| PRN             | parenthetical                                                               | 106    | 0.20                      |
| VRD             | verb resultative compound                                                   | 37     | 0.07                      |
| Annotation type | Counts | % in the corresponding entity type | % in all the annotated entities |
|-----------------|--------|-----------------------------------|-------------------------------|
| Diseases: Possible | 3255 | 39.09 | 8.24 |
| Diseases: Present | 2686 | 32.25 | 6.80 |
| Diseases: Absent | 2352 | 28.24 | 5.95 |
| Diseases: Not associated with the patient | 35 | 0.42 | 0.09 |
| Diseases: Conditional | 0 | 0.00 | 0.00 |
| Diseases: Occasional | 0 | 0.00 | 0.00 |
| **Diseases: Total** | **8328** | **100.00** | **21.08** |
| Symptoms: Absent | 12,070 | 63.69 | 30.55 |
| Symptoms: Present | 6425 | 33.90 | 16.26 |
| Symptoms: Conditional | 257 | 1.36 | 0.65 |
| Symptoms: Occasional | 153 | 0.81 | 0.39 |
| Symptoms: Possible | 41 | 0.22 | 0.10 |
| Symptoms: Not associated with the patient | 5 | 0.03 | 0.01 |
| **Symptoms: Total** | **18,951** | **100.00** | **47.96** |
| Treatments: Present | 3703 | 70.63 | 9.37 |
| Treatments: Historical | 1413 | 26.95 | 3.58 |
| Treatments: Absent | 127 | 2.42 | 0.32 |
| **Treatments: Total** | **5243** | **100.00** | **13.27** |
| **Tests: Total** | **6989** | **100.00** | **17.69** |

**Part D (Relations in the semantic corpus)**

| Annotation type | Description | Counts | % in the corresponding entity pair | % in all the annotated relations |
|-----------------|-------------|--------|-----------------------------------|-------------------------------|
| TrAD | Treatment is administered for disease | 393 | 58.66 | 5.11 |
| TrID | Treatment improves disease | 201 | 30.00 | 2.61 |
| TrWD | Treatment worsen disease | 70 | 10.45 | 0.91 |
| TrCD | Treatment causes disease | 6 | 0.90 | 0.08 |
| R(Tr, D) | 670 | 100.00 | 8.71 |
TrAS  Treatment is administered for symptom  613  30.35  7.97
TrIS  Treatment improves symptom  566  28.02  7.36
TrWS  Treatment worsen symptom  540  26.73  7.02
TrCS  Treatment causes symptom  298  14.75  3.87
TrNAS  Treatment is not administered because of symptom  3  0.15  0.04

$R(Tr, S)$  2020  100.00  26.26

TeRD  Test reveals disease  581  99.49  7.55
TeCD  Test conducted to investigate disease  3  0.51  0.04

$R(Te, D)$  584  100.00  7.59

TeRS  Test reveals symptom  1239  53.31  16.11
TeAS  Test is administered because of symptom  1085  46.69  14.11

$R(Te, S)$  2324  100.00  30.22

SID  Symptom indicates disease  1663  79.46  21.62
DCS  Disease causes symptom  430  20.54  5.59

$R(D, S)$  2093  100.00  27.21

R(entity1, entity2), relation between entity1 and entity2; D, diseases; S, symptoms; Te, tests; Tr, treatments.

Part E (Part-of-speech tags in the syntactic corpus: discharge summary vs progress note)

| Annotation type | Description | % in discharge summaries | % in progress notes |
|-----------------|-------------|--------------------------|---------------------|
| NN              | common nouns                  | 32.90                    | 30.23               |
| PU              | punctuation                   | 21.29                    | 23.46               |
| VV              | other verbs                   | 12.85                    | 12.20               |
| CD              | cardinal numbers              | 6.86                     | 7.61                |
| VA              | predicative adjective         | 6.62                     | 5.39                |
| JJ              | noun-modifier other than nouns| 4.41                     | 4.39                |
| AD              | adverbs                       | 3.40                     | 3.88                |
| M               | measure word (including classifiers) | 3.71            | 3.63                |
| VE              | you3 as the main verb         | 2.09                     | 2.64                |
| P               | prepositions (excluding ba3 and bei4) | 0.86                | 1.58                |
| LC              | localizer                     | 0.93                     | 1.43                |
| NT              | temporal nouns                | 1.84                     | 0.90                |
| CC              | coordinating conj             | 0.74                     | 1.11                |
| DT              | determiner                    | 0.54                     | 0.52                |
| OD              | ordinal numbers               | 0.81                     | 0.31                |
| ETC             | tags for deng3 and deng3deng3 in coordination phrases | 0.09 | 0.19 |
| NR              | proper nouns                  | 0                        | 0.17                |
| VC              | copula shi4                   | 0.02                     | 0.13                |
| Annotation Type | Description | % in discharge summaries | % in progress notes |
|-----------------|-------------|-------------------------|-------------------|
| NP              | noun phrase | 33.27                   | 31.95             |
| VP              | verb phrase | 27.38                   | 27.39             |
| IP              | simple clause | 18.08                 | 18.12             |
| QP              | quantifier phrase | 5.17             | 5.02              |
| ADJP            | adjective phrase | 3.90              | 4.01              |
| ADVP            | adverbial phrase | 2.95             | 3.49              |
| CLP             | classifier phrase | 3.23            | 3.28              |
| LST             | list marker | 1.60                    | 2.34              |
| PP              | preposition phrase | 0.83            | 1.48              |
| LCP             | phrase formed by "phrase + LC" | 0.78        | 1.32              |
| FRAG            | fragment | 1.45                    | 0.18              |
| DP              | determiner phrase | 0.47            | 0.47              |
| VCD             | coordinated verb compound | 0.50        | 0.20              |
| VSB             | verb compounds formed by a modifier + a head | 0.22 | 0.23 |
| PRN             | parenthetical | 0.07                   | 0.27              |
| VRD             | verb resultative compound | 0.05           | 0.08              |
| UCP             | unidentical coordination phrase | 0.03 | 0.06 |
| DNP             | phrase formed by "phrase + DEG" | 0.01       | 0.06              |
| CP              | clause headed by C (complementizer) | 0.01       | 0.01              |
| VPT             | potential form V-de-R or V-bu-R | 0            | <0.01             |
| VNV             | verb compounds formed by A-not-A or A-one-A | 0            | <0.01             |
| VCP             | verb compounds formed by VV + VC | 0            | <0.01             |
| DVP             | phrase formed by "phrase + DEV" | 0            | 0.02              |
References

[1] T.J. Hannan, Electronic medical records, Health informatics: An overview. (1996) 133-148.
[2] Electronic medical records basic specifications (trial).
http://www.moh.gov.cn/mohyzs/s3585/201003/46174.shtml, 2010 (accessed 12.06.16).
[3] Measurement and standard of the capability level of electronic medical record system (trial).
http://www.moh.gov.cn/mohyzs/s3586/201111/53274.shtml, 2010 (accessed 12.06.16).
[4] Functional specification of electronic medical record system (trial).
http://www.moh.gov.cn/mohyzs/s3585/201012/50229.shtml, 2010 (accessed 12.06.16).
[5] D. Demner-Fushman, W.W. Chapman, C.J. McDonald, What can natural language processing do for clinical decision support?, J Biomed Inform. 42 (2009) 760-772.
[6] G.K. Savova, J.J. Masanz, P.V. Ogren, J. Zheng, S. Sohn, K.C. Kipper-Schuler, C.G. Chute, Mayo clinical Text Analysis and Knowledge Extraction System (cTAKES): architecture, component evaluation and applications, J. Am. Med. Informatics Assoc. 17 (2010) 507-513.
[7] Unified Medical Language System (UMLS). http://www.nlm.nih.gov/research/umls/, (accessed 12.06.16).
[8] Informatics for Integrating Biology & the Bedside (i2b2). http://www.i2b2.org/, (accessed 12.06.16).
[9] J. Yang, Q. Yu, Y. Guan, Z. Jiang, An Overview of Research on Electronic Medical Record Oriented Named Entity Recognition and Entity Relation Extraction, Acta Autom. Sin. 40 (2014) 1537-1562.
[10] P.M. Nadkarni, L. Ohno-Machado, W.W. Chapman, Natural language processing: an introduction, J. Am. Med. Informatics Assoc. 18 (2011) 544-551.
[11] D. Albright, A. Lanfranchi, A. Fredriksen, W.F. Styler, C. Warner, J.D. Hwang, J.D. Choi, D. Dligach, R.D. Nielsen, J. Martin, Towards comprehensive syntactic and semantic annotations of the clinical narrative, J. Am. Med. Informatics Assoc. 20 (2013) 922-930.
[12] J.-w. Fan, E.W. Yang, M. Jiang, R. Prasad, R.M. Loomis, D.S. Zisook, H. Xu, Y. Huang, Syntactic parsing of clinical text: guideline and corpus development with handling ill-formed sentences, J. Am. Med. Informatics Assoc. 20 (2013) 1168-1177.
[13] Y. Xu, Y. Wang, T. Liu, J. Liu, Y. Fan, Y. Qian, J. Tsujii, E.I. Chang, Joint segmentation and named entity recognition using dual decomposition in Chinese discharge summaries, J. Am. Med. Informatics Assoc. 21 (2014) e84-e92.
[14] S. Zhang, T. Kang, X. Zhang, D. Wen, N. Elhadad, J. Lei, Speculation detection for Chinese clinical notes: Impacts of word segmentation and embedding models, J Biomed Inform. 60 (2016) 334-341.
[15] S. Meystre, P.J. Haug, Natural language processing to extract medical problems from electronic clinical documents: performance evaluation, J Biomed Inform. 39 (2006) 589-599.
[16] A. Roberts, R. Gaizauskas, M. Hepple, G. Demetriou, Y. Guo, I. Roberts, A. Setzer, Building a semantically annotated corpus of clinical texts, J Biomed Inform. 42 (2009) 950-966.
[17] Ö. Uzuner, B.R. South, S. Shen, S.L. DuVall, 2010 i2b2/VA challenge on concepts, assertions, and relations in clinical text, J. Am. Med. Informatics Assoc. 18 (2011) 552-556.
[18] N. Elhadad, S. Pradhan, W. Chapman, S. Manandhar, G. Savova, SemEval-2015 task 14: Analysis of clinical text, Proc of Workshop on Semantic Evaluation. Association for Computational Linguistics, 2015, pp. 303-310.
[19] J. Lei, B. Tang, X. Lu, K. Gao, M. Jiang, H. Xu, A comprehensive study of named entity recognition in Chinese clinical text, J. Am. Med. Informatics Assoc. 21 (2014) 808-814.
[20] Y. Wang, Z. Yu, L. Chen, Y. Chen, Y. Liu, X. Hu, Y. Jiang, Supervised methods for symptom name recognition in free-text clinical records of traditional Chinese medicine: An empirical study, J Biomed Inform. 47 (2014) 91-104.

[21] H. Wang, W. Zhang, Q. Zeng, Z. Li, K. Feng, L. Liu, Extracting important information from Chinese Operation Notes with natural language processing methods, J Biomed Inform. 48 (2014) 130-136.

[22] Z. Jia, H. Li, M. Ju, Y. Zhang, Z. Huang, C. Ge, H. Duan, A finite-state automata based negation detection algorithm for chinese clinical documents, Progress in Informatics and Computing (PIC), 2014 International Conference on, IEEE, 2014, pp. 128-132.

[23] D. Xu, M. Zhang, T. Zhao, C. Ge, W. Gao, J. Wei, K.Q. Zhu, Data-Driven Information Extraction from Chinese Electronic Medical Records, PloS one. 10 (2015) e0136270.

[24] Y.-B. Li, X.-Z. Zhou, R.-S. Zhang, Y.-H. Wang, Y. Peng, J.-Q. Hu, Q. Xie, Y.-X. Xue, L.-L. Xu, X.-F. Liu, Detection of herb-symptom associations from traditional chinese medicine clinical data, Evidence-Based Complementary and Alternative Medicine. 2015 (2015).

[25] B. Santorini, Part-of-speech tagging guidelines for the Penn Treebank Project (3rd revision), (1990).

[26] A. Bies, M. Ferguson, K. Katz, R. MacIntyre, V. Tredinnick, G. Kim, M.A. Marcinkiewicz, B. Schasberger, Bracketing guidelines for Treebank II style Penn Treebank project, University of Pennsylvania. 97 (1995) 100.

[27] L. Hirschman, N. Sager, Automatic information formatting of a medical sublanguage, Sublanguage: studies of language in restricted semantic domains. (1982) 27-80.

[28] C. Friedman, P. Kra, A. Rzhetsky, Two biomedical sublanguages: a description based on the theories of Zellig Harris, J Biomed Inform. 35 (2002) 222-235.

[29] A. Rector, J. Rogers, A. Taweel, D. Ingram, D. Kalra, J. Milan, P. Singleton, R. Gaizauskas, M. Hepple, D. Scott, CLEF: joining up healthcare with clinical and post-genomic research, (2003).

[30] Fourth i2b2/VA Shared-Task and Workshop Challenges in Natural Language Processing for Clinical Data. http://www.i2b2.org/NLP/Relations/, 2010 (accessed 12.06.16).

[31] 2010 i2b2/VA Challenge Evaluation Concept Annotation Guidelines. http://www.i2b2.org/NLP/Relations/assets/Concept%20Annotation%20Guideline.pdf, 2010 (accessed 12.06.16).

[32] 2010 i2b2/VA Challenge Evaluation Assertion Annotation Guidelines. http://www.i2b2.org/NLP/Relations/assets/Assertion%20Annotation%20Guideline.pdf, 2010 (accessed 12.06.16).

[33] 2010 i2b2/VA Challenge Evaluation Relation Annotation Guidelines. http://www.i2b2.org/NLP/Relations/assets/Relation%20Annotation%20Guideline.pdf, 2010 (accessed 12.06.16).

[34] O. Uzuner, J. Mailoa, R. Ryan, T. Sibanda, Semantic relations for problem-oriented medical records, Artif. Intell. Med. 50 (2010) 63-73.

[35] The Segmentation Guidelines for the Penn Chinese Treebank (3.0). http://www.cis.upenn.edu/~chinese/segguide.3rd.ch.pdf, 2000 (accessed 28.10.15).

[36] The Part-Of-Speech Tagging Guidelines for the Penn Chinese Treebank (3.0). http://repository.upenn.edu/cgi/viewcontent.cgi?article=1039&context=ircs_reports, 2000 (accessed 27.06.16).

[37] The Bracketing Guidelines for the Penn Chinese Treebank (3.0). http://www.cis.upenn.edu/~chinese/parseguide.3rd.ch.pdf, 2000 (accessed 28.10.15).
[38] The Segmentation Annotation Guidelines on Chinese Clinical Texts. http://github.com/WILAB-HIT/Resources/blob/master/segmentation_pos_parsing/annotation_guidelines/Seg.pdf, 2016 (accessed 24.10.16).

[39] The Part-Of-Speech Tagging Annotation Guidelines on Chinese Clinical Texts. http://github.com/WILAB-HIT/Resources/blob/master/segmentation_pos_parsing/annotation_guidelines/POS.pdf, 2016 (accessed 24.10.16).

[40] The Bracketing Annotation Guidelines on Chinese Clinical Texts. http://github.com/WILAB-HIT/Resources/blob/master/segmentation_pos_parsing/annotation_guidelines/Bracketing.pdf, 2016 (accessed 24.10.16).

[41] The Entity-Assertion-Relation Annotation Guidelines on Chinese Clinical Texts. http://github.com/WILAB-HIT/Resources/blob/master/entity_assertion_relation/annotation_guidelines/Entity_Assertion_Relation.pdf, 2016 (accessed 24.10.16).

[42] Y. Shi-wen, D. Hui-ming, Z. Xue-feng, S. Bin, The Basic Processing of Contemporary Chinese Corpus at Peking University, Journal of Chinese information processing. 16 (2002) 51-66.

[43] J. Pustejovsky, A. Stubbs, Increasing informativeness in temporal annotation, Proceedings of the 5th Linguistic Annotation Workshop, Association for Computational Linguistics, 2011, pp. 152-160.

[44] NLPIR/ICTCLAS2016. http://github.com/NLPIR-team/NLPIR/tree/master/NLPIR%20SDK/NLPIR-ICTCLAS, (accessed 12.06.16).

[45] Stanford POS Tagger. http://nlp.stanford.edu/software/tagger.shtml, (accessed 27.06.16).

[46] Stanford Parser. http://nlp.stanford.edu/software/lex-parser.shtml, (accessed 27.06.16).

[47] G. Hripcsak, A.S. Rothschild, Agreement, the f-measure, and reliability in information retrieval, J. Am. Med. Informatics Assoc. 12 (2005) 296-298.

[48] Evalb. http://nlp.cs.nyu.edu/evalb/, (accessed 27.06.16).

[49] The Chinese Clinical Text Processing and Information Extraction System. http://wi.hit.edu.cn/cemr/, 2016 (accessed 24.10.16).

[50] CRF++. http://taku910.github.io/crfpp/, (accessed 28.10.15).

[51] Berkeley Parser. http://github.com/slavpetrov/berkeleyparser, (accessed 27.06.16).

[52] LIBSVM. http://www.csie.ntu.edu.tw/~cjlin/libsvm/, (accessed 28.10.15).