Automated Tumor Name Standardization in the NIH Clinical Trials Registry Using the CANTOS Pipeline

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**The bigger picture**

The National Institutes of Health’s (NIH) clinical trials registry (CTR, ClinicalTrials.gov) is a public database that provides a wide range of information regarding a clinical trial, such as outcomes, interventions, conditions studied, and experimental design. This information is distributed in various text files each containing the National Clinical Trial Identifier number (NCT ID) to identify and aggregate data for a given clinical trial. In pursuit of studying the landscape of therapeutic agents and drug targets associated with cancer types and tumor names, the CTR serves as a valuable resource. However, the tumor names contained in the “conditions” file provided at the CTR are often unstandardized and thus difficult to identify using simple text matching, creating a barrier to further analysis. Here we present an and compare methods to identify and standardize tumor names from the CTR in order to facilitate downstream analysis and data integration.

**Summary**

This study aimed to identify and standardize tumor names from the NIH's clinical trials registry (CTR, ClinicalTrials.gov) using the World Health Organization Classification of Tumours (WHO system) and the National Cancer Institute Thesaurus (NCIt). We developed CANTOS (Clinical Trials Automated Nomenclature and Tumor Ontology Standardization), a computational pipeline that identified tumor names from the CTR and standardized them. We evaluated twelve methods based on text matching and embedding. We evaluated the accuracies of these methods only against the WHO system, as it is considered a clinical standard for tumor nomenclature. In general, text-embedding-based methods outperformed text-matching-based methods with standardization accuracies ranging from 60.5%-65.6% and 63.5%-68.5% for the 5th edition and all editions (3rd-5th) of the WHO system. The LTE-3+Euclidean Dist method, which mapped tumor names to the nearest WHO system term, achieved the highest standardization accuracy, with 65.6% for the 5th edition and 68.5% for all editions of the WHO system.

**Keywords**

NIH Clinical Trials Registry; WHO Tumor Classification; Text Embedding; Clinical Text Standardization

**Introduction**Cancer is a significant global health issue and the second leading cause of death in the United States [1](https://paperpile.com/c/Ky0na7/X96Sr). In 2024, over 2 million new cancer cases and 611,720 deaths are expected in the U.S. alone [2](https://paperpile.com/c/Ky0na7/F7rHM). While pediatric cancer survival rates have improved to 80% over the last five decades [3,4](https://paperpile.com/c/Ky0na7/SHbGN+A9NgY), which can primarily be attributed to successes in the treatment of common childhood hematological malignancies such as acute lymphoblastic leukemia [5](https://paperpile.com/c/Ky0na7/48hVk), unfortunately this success is not uniformly shared [6](https://paperpile.com/c/Ky0na7/jxNyc), and certain cancers, particularly those of the brain and nervous system [2](https://paperpile.com/c/Ky0na7/F7rHM), remain difficult to treat. Pediatric cancers are rarer than adult cancers and face unique challenges in clinical trials, including limited therapeutic agents, difficulty recruiting diverse populations, and tumor heterogeneity [7,8](https://paperpile.com/c/Ky0na7/I4Mmo+uogfj). To understand the therapeutic landscape of adult and pediatric tumors, it is critical to extract and analyze data from various biomedical databases, particularly from the NIH’s Clinical Trials Registry (ClinicalTrials.gov, CTR) which contains data from over 482,529 research studies across all 50 states in the US and 223 countries [9](https://paperpile.com/c/Ky0na7/aySgj). While the CTR has established protocols and guidelines for data the submission process, tumor names submitted to the CTR (provided by CTR in their “conditions.txt” file) contain extraneous information, typographical errors, missing values, non-standard nomenclature and other inconsistencies which create barriers for data integration and downstream analysis of the CTR data. Although the CTR mandates standardized terminology like Medical Subject Headings (MeSH) [10](https://paperpile.com/c/Ky0na7/gOhcD), these terms often fail to capture the specific details of many tumor types outlined in the conditions data file. In **Supplementary Document SD1**, we provide examples to compare the differences between the terms in the condition file and the MeSH terms. Thus there is a need to standardize the CTR conditions data file. Ideally, tumor names from the CTR would be classified using ontologies and/or standards, including from the WHO Classification of Tumours [11–44](https://paperpile.com/c/Ky0na7/SCe4+aLBf+6Tzs+iAfX+aUfU+AMLT+a91c+Sg4D+yJkJ+JK5P+yyW8+S1zA+s22A+6Ds9+nX0D+JDNi+tzpx+8pxB+9uvK+FyvQ+tM4k+iDQM+VcD7+Q1Ep+MPGp+1skj+XzSm+7ZzX+MKLQ+BIPR+u8nU+3Kyl+AT0b+qRRY) system (we refer to here as the “WHO system”, <https://tumourclassification.iarc.who.int/welcome/>) or National Cancer Institute Thesaurus (we refer to as the “NCIt database” <https://ncithesaurus.nci.nih.gov/ncitbrowser/>). The WHO and NCIt standardized nomenclature are available in **Supplementary Tables** **ST1-ST3**.

To analyze CTR data with accurately classified pediatric and adult tumor types, it would be important to standardize tumor names in the CTR with respect to standardized nomenclature from the WHO system and the NCIt database. To this end, we developed a computational pipeline CANTOS (Clinical Trials Automated Nomenclature and Tumor Ontology Standardization) that standardizes tumor names in the CTR’s “conditions” file using methods based on text-matching (based on edit distances) and text-embedding derived from OpenAI’s Large Language Models. This pipeline maps tumor names to their standardized counterparts in the WHO system and NCIt database. Standardizing these tumor names in the CTR enables integration of this data with other biomedical databases, such as Open Targets (OT,<https://www.opentargets.org/>) and Illuminating the Druggable Genome (IDG,<https://druggablegenome.net/>) , facilitating a more comprehensive understanding of tumor biology, drug-targets, and therapeutic agents.

**Results**

In this paper, we describe the CANTOS pipeline, which extracts and standardizes tumor names from the CTR according to the WHO system and NCIt resources. CANTOS extracted 13,230 tumor records from the CTR, with 6,324 identified as pediatric, and then implemented 12 methods based on text-matching (edit-distances) and text-embedding to standardize the tumor names from the CTR. To evaluate these methods, we needed ground truth (i.e., standardized terms) for all the 13,230 tumor names. In order to provide a ground-truth set for testing, we randomly sampled 1,600 tumor names from the 13,230 and manually annotated those tumor names to assess our methods' performance.

For these 1,600 tumor names, we annotated two “ground truth” definitions from the WHO system: the “WHO 5th edition” [11–20](https://paperpile.com/c/Ky0na7/SCe4+aLBf+6Tzs+iAfX+aUfU+AMLT+a91c+Sg4D+yJkJ+JK5P) annotation based on the latest system release, and the “WHO all editions” which combines annotations from the WHO system’s 3rd, 4th, and 5th editions [11–44](https://paperpile.com/c/Ky0na7/SCe4+aLBf+6Tzs+iAfX+aUfU+AMLT+a91c+Sg4D+yJkJ+JK5P+yyW8+S1zA+s22A+6Ds9+nX0D+JDNi+tzpx+8pxB+9uvK+FyvQ+tM4k+iDQM+VcD7+Q1Ep+MPGp+1skj+XzSm+7ZzX+MKLQ+BIPR+u8nU+3Kyl+AT0b+qRRY). We used the WHO system (and not NCIt), exclusively as our annotation standard because the WHO system is considered a clinical standard for tumor nomenclature. During annotation, we encountered some CTR tumor names that could have multiple ground truth matches or no matches within the WHO system. Tumors with multiple ground truth matches that included the correct tumor name were included as accurate standardizations. Tumors without ground truth matches were excluded from accuracy evaluations. When standardizing using the WHO system 5th edition, we identified 567 CTR tumor names that did not have a ground truth, while 482 CTR tumor names did not have a ground truth when WHO system all editions was used. This difference arises because the WHO system all editions collectively contain more standardized tumor terms than the 5th edition. Consequently, we evaluated accuracy for 1,033 terms when using the WHO system 5th edition and 1,118 terms for the WHO system all editions. Accuracy for each method was calculated by counting instances where a method identified at least one ground truth associated with a CTR tumor name and dividing by the total number of terms (1,033 or 1,118). We report accuracy for all editions in **Table 1** and the 5th edition in **Table 2**.

**Tables 1** and **2** show that text-embedding-based methods consistently outperform text-matching methods, irrespective of the edition of the WHO system used for standardization. Generally, LTE-3 embeddings performed better than ADA-002, except for the LTE-3+K-means method, which slightly underperformed compared to ADA-002+AP and ADA-002+Euclidean Dist when using WHO system all editions (**Table 1**). Notably, LTE-3+K-means ranked higher than its ADA-002 variant method, ADA-002+K-means, for both editions of the WHO system. We attribute the superior performance of LTE-3 methods to the higher dimensionality of LTE-3, which likely captures the complexity of the input data better.

The method LTE-3+Euclidean Dist achieved the highest accuracy when either WHO system all editions or 5th edition were used in CANTOS. In **Figure 1**, we visualize the standardization performance of the method LTE-3 +Euclidean Dist. **Figure 1** shows the distribution of the closest Euclidean distances in the LTE-3 embedding space between the CTR condition names and the standardized tumor names from the WHO system as determined by the method LTE-3 + Euclidean Dist. It should be noted that in **Figure 1**, out of the 1600 randomly sampled CTR terms that we manually validated, only the terms which had a ground truth from the WHO 5th or all editions were considered. Thus, in **Figure 1a**, we have 1,033 CTR terms for which ground truths were identified in the WHO system 5th edition and in **Figure 1b**, we have 1,118 CTR terms for which ground truths were identified in the WHO system all editions. In both the 5th and all editions of the WHO system, the LTE-3+Euclidean Dist method correctly standardized a majority of the CTR terms and had a lower median Euclidean distance for the correctly standardized CTR terms than the incorrectly standardized CTR terms. This finding is consistent as it indicates that CTR terms which can be mapped to a standardized term from the WHO system should have a lower Euclidean distance between them in the LTE-3 embedding space. **Tables** **3** and **4** present the summary statistics for **Figures 1a** and **1b**. It is evident from **Figure 1** and **Tables** **3** and **4**, that the closest Euclidean distance in the LTE-3 embedding can distinguish between correct and incorrect standardization, however its performance needs to be improved for better standardization results. If the median closest Euclidean distance (0.6956 for WHO system 5th edition or 0.6866 for WHO system all editions) for the correctly standardized term is used as a threshold for determining which terms can be reliably standardized, we will still have a few terms that will be incorrectly standardized as the minimum closest Euclidean distance for the incorrectly standardized terms (0.4646 for WHO system 5th edition and 0.3942 for WHO system all editions) are lower than the median Euclidean distance for the correctly standardized terms. While the LTE-3+Euclidean Dist offers a method for standardizing the CTR, the performance can likely be improved with embeddings generated from LLMs specifically trained on tumor nomenclature.

Among the text matching methods based on edit distances, Levenshtein distance outperformed both Jarro-Winkler and cosine distances or any of their implementations using AP clustering. Jarro-Winkler is effective for minor text discrepancies and common prefixes, while cosine distance relies on word frequency ("bag of words") and ignores word order. In contrast, Levenshtein distance counts the minimum edit operations needed to transform one text into another while maintaining word order and without considering prefix similarity, which likely contributed to its superior performance. Ground truth annotations for the 1,600 CTR tumor names and their standardization results are available in **Supplementary Tables ST4** (WHO system all editions) and **ST5** (WHO system 5th edition). Standardized terms for each tumor in the CTR are reported in **Supplementary Tables** **ST6-ST9**.

**Discussion**

The CTR provides information that can be integrated with external databases to gain insights into therapeutic and drug-target landscapes for tumors. However, raw tumor names from the CTR cannot be directly linked to other databases due to inconsistencies such as extraneous information, typographical errors, missing values, and non-standard nomenclature. Since tumor names are not automatically identifiable in the CTR, they also need to be extracted. To address this, we developed CANTOS, a computational pipeline to extract and standardize tumor names from the CTR according to the WHO system (5th edition and all editions) and NCIt database.

CANTOS classified tumor names from the CTR as adult or pediatric, and we manually validated each classification. For pediatric tumors, we assigned citations that confirmed the classification (**Supplementary Table ST10**). CANTOS identified 13,230 unique tumors, of which 6,324 were pediatric tumors. It standardized these names according to the WHO system and NCIt database using 12 methods based on text-matching (edit distances) or text embedding. We evaluated these methods only against the WHO system, which is considered the gold standard for clinical tumor nomenclature. To assess accuracy, we randomly selected 1,600 tumor names from the 13,230 standardized by CANTOS and manually annotated their ground truths using the WHO system 5th edition and WHO system all editions. We found more tumors could be annotated using WHO system all editions, as the WHO system 5th edition has fewer terms. Overall, text-embedding methods proved more accurate than text-matching methods because text embeddings capture the semantic and contextual meaning between texts and map similar texts accordingly, while text-matching techniques focus only on syntactical differences between texts.

We generated text embeddings using OpenAI's LLM: text-embedding-ada-002 (ADA-002) and text-embedding-3-large (LTE-3). LTE-3 methods generally outperformed ADA-002, except for LTE-3+K-means, which slightly underperformed compared to ADA-002+Euclidean Dist and ADA-002+AP when standardized against WHO system all editions. Regardless of the edition of the WHO system, LTE-3+Euclidean Dist achieved the highest accuracy, followed by LTE-3+AP. The LTE-3+Euclidean Dist method standardizes clinical trial tumors by identifying the closest WHO term based on Euclidean distance in the LTE-3 embedding space. This method is simpler and faster than LTE-3+AP, as it does not require additional steps like clustering, cluster size analysis, or outlier detection.

The CANTOS pipeline is adaptable for standardizing biomedical nomenclature across various systems beyond the WHO and NCIt databases. It can be extended to work with other ontologies such as MONDO[45](https://paperpile.com/c/Ky0na7/B9tG), Disease Ontology (DO)[46–56](https://paperpile.com/c/Ky0na7/56LJ+lLtb+0Ocp+Pnbc+X0u7+bHvV+oLJv+DKaZ+T3El+SzcO+nKQq), Human Phenotype Ontology (HPO)[57](https://paperpile.com/c/Ky0na7/DWu8), and medical coding systems like ICD-10[58](https://paperpile.com/c/Ky0na7/UUSo) and SNOMED[59](https://paperpile.com/c/Ky0na7/uGTd). Future work includes generalizing CANTOS to incorporate additional embedding methods, including domain-specific biomedical LLMs, and expanding its functionality to standardize any collection of biomedical terms.

**Limitations of the study**

As more CTR samples are annotated with ground truth, the performance accuracies of each method will approach their true values. While we expect accuracy changes, our annotation of 1,600 CTR tumor names suggests that text-embedding methods will likely outperform text-matching methods. Expert annotation of CTR tumor names is crucial for accurately evaluating these methods and is a limitation of our study. Additionally, as the CTR updates, new tumor names must be identified and standardized, necessitating rerunning CANTOS and manually validating the findings, which is time-consuming. Beyond expert annotation, there are computational costs associated with running the CANTOS pipeline, generating embeddings, and storing data, which can become expensive over time. Another limitation is that the embeddings generated by OpenAI may require switching to other LLMs if the models are updated or discontinued. Furthermore, OpenAI’s models are not specifically trained on a medical corpus, so an LLM trained on such data would likely perform better and differentiate tumor names more precisely [60](https://paperpile.com/c/Ky0na7/z8PIr). Future work will include developing CANTOS to test across specific biomedical LLMs to improve its performance.

The CANTOS pipeline uses embeddings from LLMs that may inadvertently produce outputs reflecting biases inherent in their training data. It is important to recognize that LLM outputs are not always neutral or free from error, and results should be interpreted with caution. Importantly, the CANTOS pipeline is designed solely for research analysis purposes and should not be applied in clinical or diagnostic settings. This tool is not intended for use in contexts where decisions may directly affect human health, treatment, or care. Any conclusions drawn from the use of CANTOS in research should be further reviewed and validated by clinical professionals and subjected to rigorous peer-reviewed testing before any potential medical or therapeutic applications.

The CANTOS pipeline facilitates the extraction and standardization of tumor names from the CTR. While guidelines exist for submitting data to the CTR to ensure basic integrity, there are no enforced protocols for standardizing tumor names in the conditions file. Although studies have emphasized the need for standardization in clinical trials regarding study design [61,62](https://paperpile.com/c/Ky0na7/wP8dg+PGr74) and evidence reproducibility [63](https://paperpile.com/c/Ky0na7/2v4OQ), none have focused on standardizing tumors or condition names in the CTR. Standardizing tumor names will enhance their searchability in other biomedical databases, enabling researchers to quickly gather information on associated therapeutic agents, drug-targets, and clinical outcomes for specific tumors.

**Experimental procedures**

This section outlines the design and methods of the CANTOS computational pipeline, which performs two main tasks: (i) identifying tumor names from the CTR and (ii) standardizing CTR tumor names. CANTOS takes condition names from CTR and standardized tumor names from the WHO system and NCIt database as inputs. After identifying tumor names, CANTOS iterates through the standardization step twice to account for different editions of the WHO system. The WHO system is considered the gold standard for tumor nomenclature and has multiple versions due to updates over the years. We used the 3rd, 4th, and 5th editions of the WHO system, which are all publicly available online. In the first iteration, CANTOS used only the latest 5th edition of the WHO system, while the second iteration incorporated all editions of the WHO system. In other words, this approach first aims to standardize the tumor names from the CTR based on only the latest edition of the WHO system, i.e., 5th edition and then follows standardizing with the combined editions of the WHO system, i.e., WHO system all editions (includes 3rd, 4th, and 5th referred to in this text as the “WHO all edition”). Throughout these two iterations, tumor names from the CTR were also standardized against the NCIt database.

**Identification of tumor names from CTR**

The CTR provides information on various aspects of clinical trials, such as outcomes, interventions, conditions, experimental design, and study sponsors. The CTR data is distributed across multiple text files, and each of these files contains the National Clinical Trial Identification Number (NCTID). The NCTID serves as a unique identifier for each trial, which allows for referencing and aggregating related information distributed across the files. In this study, we focused on the conditions ("conditions.txt" or conditions file) and interventions ("intervention.txt" or interventions file), which detail the conditions and drugs used in each trial, respectively. The conditions file contains 801,197 records and is annotated with the fields: "*id*", "*nct\_id*", "*name*" , and "*downcase\_name*" . The "*id*" represents the record number within the conditions file, while the "*nct\_id*" is the foreign key. The "*name*" and "*downcase\_name*" fields include the names of the studied conditions, with "*downcase\_name*" in lowercase format. We identified 105,483 unique conditions based on string uniqueness in the conditions file.

The conditions file does not categorize the condition names into specific subtypes or classes, consequently the tumor names contained in the file are not easily identifiable and need to be extracted. Furthermore, we are focused on extracting tumor names that are associated with a therapeutic agent (i.e., has a drug-target) registered in the CTR, so that it enables us to obtain a clear view of the therapeutic and drug-target landscape for a given tumor in future studies. To address this need , we designed the CANTOS pipeline to extract tumor names from the rest of the conditions, and then annotate each unique tumor as pediatric or adult tumors (**Figure 2**). The tumor name identification step implemented by CANTOS is segregated into three phases.

In Phase 1, CANTOS extracted condition names (and consequently tumor names) linked with CTR registered therapeutic agents that potentially had an associated drug-target. It achieves this by subsetting the condition names in the conditions file using the types of drugs from the interventions file. The interventions file contains 786,898 records and includes the fields: "*id*", "*nct\_id*", "*intervention\_type*", "*name*", and "*description*". The "id" represents the record number, while the "*nct\_id*" serves as the foreign key. The "name" and "description" fields detail the interventions, and "*intervention\_type*" classifies them into eleven categories listed in **Supplementary Document SD2**. CANTOS extracts condition names (consequently tumors names) linked with therapeutic agents potentially associated with drug-targets by joining the intervention file with the conditions file via "*nct\_id*" and then filtering for the intervention types: "Drug", "Biological", "Combination Product", and "Genetic". Filtering therapeutic agents by these intervention types increases the likelihood that each agent has a corresponding drug target. Consequently, any tumor name extracted this way can potentially highlight the therapeutic and drug-target landscape associated with that tumor. After filtering, CANTOS extracted 50,410 unique condition names, which served as input for tumor identification in Phase 2 of the pipeline. The tumor extraction process is illustrated as Phase 1 in **Figure 2**.

In Phase 2, CANTOS identified tumor names from the Phase 1 extracted condition names using two independent protocols (**Figure 2**, “Phase 2”) .The first protocol consisted of checking if each condition name contained a tumor key word listed in **Supplementary Document** **SD3**. If the condition name contained a tumor keyword, that condition was annotated as a potential tumor. The second protocol of CANTOS matched each condition name in the CTR to tumor names in the WHO system 5th edition using a fuzzy string matching algorithm. If a condition name from the clinical trials exactly matched a term in the WHO system 5th edition (**Supplementary Table** **ST3**), it was annotated as a tumor. If there were no exact matches, we performed a fuzzy match by calculating the generalized Levenshtein edit distance between the CTR condition name and each term in the WHO system 5th edition. This was implemented using the agrepl function in R [64](https://paperpile.com/c/Ky0na7/iclH9), with a maximum distance set to 0.2. If a WHO system 5th edition term fell within this distance, the clinical trial condition was flagged as a potential tumor. Once flagged, we manually validated these findings to confirm that the conditions marked as potential tumors were indeed tumors. A total of 13,230 unique (by string uniqueness) tumor names were extracted from the CTR at the end of Phase 2.

During Phase 3, CANTOS focused on determining which extracted tumor names were pediatric (see **Figure 2**, Phase 3) by applying a fuzzy string matching algorithm similar to that used in Phase 2. However, this time, the algorithm compared the tumor names against only the pediatric tumor names (**Supplementary Table** **ST11**), listed in the WHO system 5th edition. After CANTOS flagged the tumors as pediatric or adult, we manually validated the results. For tumors confirmed as pediatric, we added citations from peer-reviewed literature, government websites, or articles from research institutions that specify the tumor as pediatric. If the tumor was found in the WHO system, we reported it as “Listed in WHO Ped Tumor” instead of providing a literature reference. From the 50,410 conditions, 13,230 were identified as tumors, with 6,324 classified as pediatric tumors. These annotations are recorded in the **Supplementary Table** **ST10**.

A cursory analysis of the identified tumor names revealed various discrepancies, including typographical errors, extraneous information, missing values, drug names instead of condition names, and multiple tumor names. Furthermore, many tumor names in the disease file did not adhere to standardized nomenclature from the WHO system or the NCIt database. These unstandardized names hinder integration with other biomedical databases like IDG or OT. Additionally, they obstructed the manual annotation of tumors as pediatric or adult, leading to 144 tumors being labeled as “DA” (Do not Annotate) in the pediatric tumor designation field (“PedCanTumor”) in **Supplementary Table ST10**. **Supplementary Document SD4** highlights common discrepancies in tumor names. To address these issues, standardization is needed to link tumor names to external databases and gain insights into associated drug targets and therapeutic agents. The standardization methods used by CANTOS are detailed in the following section.

**Standardization of tumor names from CTR**

We implemented various methods in CANTOS to standardize the tumor names in the CTR. These methods are based either on text-matching (edit-distances) or text-embedding. It also combines unsupervised clustering with these approaches for improved standardization. In total, CANTOS implemented 12 standardization methods, and their performance accuracies are discussed in the results section. The following subsections will detail the text-matching methods first, followed by the text-embedding techniques.

**Text matching technique: closest match using edit distance**

The aim of standardizing tumor names from the CTR to corresponding WHO system or NCIt database terms is to ensure each unstandardized term aligns accurately with its standardized equivalent while preserving the original meaning of the CTR tumor name. Edit distances measure the similarity between text strings by calculating the minimum number of edit operations (deletions, substitutions, insertions, etc.), q-grams, or heuristics needed to transform one string into another. The larger the edit distance between two strings, the further apart the strings are, thus, two strings with minimal edit distance could potentially convey the same meaning. CANTOS employs normalized Levenshtein distance, Jaro-Winkler distance, and cosine distance to compute edit distances. An example of using edit distances for string comparison is provided in **Supplementary Document** **SD5**, followed by brief descriptions of each method.

*Normalized Levenshtein distance*: Levenshtein distance measures the minimum number of single-character edits (insertions, deletions, substitutions) needed to transform one string into another. Levenshtein distance between two strings can be normalized by dividing it by the length of the longer string thus the distance would range from [0,1] and allow comparison of multiple strings on the same scale. We defined the normalized Levenshtein distance between two strings S1 and S2 as follows:

In the above equation, |S1| and |S2| represent the respective lengths of strings S1 and S2 between which we are computing the normalized Levenshtein distance. We calculate Levenshtein distance using the stringdist library in the R programming language [65,66](https://paperpile.com/c/Ky0na7/PKMio+DXAOo). Following the calculation of the Levenshtein distance, we compute the normalizing factor (i.e. divide the Levenshtein by the longest string size) for distance between each pair of strings and normalize the Levenshtein distance.

*Jarro-Winkler distance*: The Jarro-Winkler distance is a normalized edit distance between two strings. It is a variant of the Jarro similarity measure which is defined as follows between two strings S1 and S2 respectively:

Where S1 and S2 are lengths of the strings S1 and S2 respectively , m is the number of matching characters and t is the number of transpositions. It should be noted that when estimating ‘m’, each character in S1 compared to the characters in S2, and match is counted only when the characters are the same and if the characters are within a certain distance of each other typically defined as half the length of the longer string, rounded down, minus one, i.e. .

The Jarro-Winkler similarity measure builds on top of the Jarro similarity measure and introduces two more parameters for rewards and favorable scales the Jarro similarity score if the two strings share similar prefixes. The Jarro-Winkler similarity is defined as follows:

Where *l* is defined as the length of the common prefix at the start of the string (maximum of 4 characters) , whereas *p* is a scaling factor that rewards the score for having common prefixes. Typically *p* is set to 0.1 and should not exceed 0.25 (or ¼ as the maximum length of prefix being considered is 4). With the above definition of Jarro-Winkler similarity, the Jarro-Winkler distance is defined as follows:

We calculate the Jarro-Winkler distance using the stringdist package in the R-programming language.

*Cosine Distance***:** To define cosine distance , we first need to establish the concept of cosine similarity. For two non-zero vector vectors, cosine similarity is defined as the dot product of the two vectors divided by the product of their lengths. Cosine similarity ranges from [-1,1], with -1 representing total opposition, 0 representing complete dissimilarity, and 1 representing full similarity between the vectors. Cosine similarity between two vectors A and B is defined as follows:

However, to use cosine similarity in the context of strings, the vectors A and B represent the frequencies of unique words in strings S1 and S2. Since frequencies cannot be negative, the cosine similarity ranges between [0,1]. Thus, there is no need to normalize this metric, and cosine distance is defined simply as:

We calculate the cosine distance using the stringdist package in R. Based on the three edit distances, CANTOS computed the pairwise distances between each tumor name identified in the CTR and the standardized tumor terms with respect to the WHO system (5th edition and all editions) and NCIt database. For each CTR tumor name, CANTOS selects the nearest standardized terms under each edit distance. If more than one term qualified as the closest term, CANTOS reported them all by separating individual terms with a semicolon.

**Text matching technique: edit distance combined with affinity propagation clustering**

CANTOS implements another set of standardization methods based on edit distances and clustering techniques. These methods consist of a clustering step followed by a mapping step. CANTOS applied affinity propagation (AP) clustering to form the clusters, where the divergence matrix is computed by calculating the pairwise edit distance between the tumor names in CTR, WHO system, and NCIt database. CANTOS computes three divergence matrices using normalized Levenshtein distance, Jarro-Winkler distance, and cosine distance. Using each of these divergence matrices, CANTOS runs the AP clustering and forms three sets of clusters. We selected the AP algorithm for clustering as it automatically determines the number of clusters instead of requiring the number of clusters (unknown to us) to be a user-defined hyperparameter. AP is also not dependent on the initialization conditions and is deterministic [67](https://paperpile.com/c/Ky0na7/Wd6H9). AP works by recursively passing real-valued messages between each data point until they converge, and based on these converged values, the algorithm establishes the clusters and assigns each cluster an "exemplar data point" which serves as an ideal representative of that cluster [68](https://paperpile.com/c/Ky0na7/IA9aj). Furthermore, AP clustering methods have shown success in clustering textual data [69,70](https://paperpile.com/c/Ky0na7/VSMBe+xYCZ3). Once the clusters were computed using AP, CANTOS performed a cluster size analysis to check if any clusters were large and may contain members that should not belong together. This was done by determining the median cluster size, and clusters larger than the median cluster size were identified and designated as large clusters. On each of these large clusters, CANTOS performs nested AP clustering until their sizes drop below the previously determined median cluster size or if the AP clustering algorithm converges and no more new clusters can be performed.

CANTOS then detects outliers in each cluster using isolation forest and local outlier factors (LOF) algorithms. Outliers identified by either method are removed from their clusters and reassigned as single-member clusters. CANTOS implements isolation forest using the R isolation.forest package [71](https://paperpile.com/c/Ky0na7/cdFjN), where we set the hyperparameter number of trees (ntrees) to 100 as recommended by Lie et al.2008 [72](https://paperpile.com/c/Ky0na7/DWjAe) in their original introduction of the isolation forest algorithm and the dims argument to 3, as suggested for numeric datasets in the package documentation [71](https://paperpile.com/c/Ky0na7/cdFjN). The standardized outlier scores are calculated for each data point within a cluster, a score close to 1 indicates the data point is a likely outlier, while a score close to 0 indicates the data point is likely a member of the cluster. The CANTOS pipeline uses an outlier score of 0.5 as the threshold and any data point with an outlier score greater than 0.5 is deemed as an outlier. Similarly, CANTOS uses the lof function within the dbscan package [73](https://paperpile.com/c/Ky0na7/MyFnH) in R to compute the LOF values to determine outliers in each cluster. The LOF value for a data point *p* is defined as the local reachability density *p* and the local reachability density of “minPts”-nearest neighbors of *p* [*74–76*](https://paperpile.com/c/Ky0na7/Ma9O0+5rBwu+xVmoV). The hyperparameter “minPts” specifies the minimum number of nearest data points around *p* that need to be considered for calculating LOF value. An LOF value close to 1 indicates that the data point *p* is in a region with a relatively uniform density, whereas a LOF > 1 indicates the data point *p* has a lower density than its neighbors and is likely an outlier[76](https://paperpile.com/c/Ky0na7/xVmoV). To compute the LOF values for each cluster member in each cluster, the CANTOS pipeline requires the users to define the minPts parameter. We set minPts to be integers ranging from 2 (clusters need to have more than one element to have an outlier) to *Size(cluster)*-1. Iterating through each value of minPts, CANTOS then computes LOF values for each cluster element and then computes their median LOF value. If the median LOF value is above 1 for a data point *p* in a cluster, then it is designated as an outlier.

Upon completing the outlier analysis, CANTOS implements the mapping step, in which each cluster member is mapped to a standardized term. To achieve this, CANTOS iterates through each cluster and identifies the closest standardized term from the WHO system and NCIt database based on the edit distance implemented in the pipeline. If most of the tumor names in a cluster are close to a specific standardized term, then all the tumor names are mapped to that standardized term. In case there is a tie, where two or more standardized terms are equally represented in a cluster, then each tumor name within that cluster is assigned to its closest (based on the edit distance used so far) matching standardized tumor name. The text-based matching pipeline is described in detail in **Supplementary Figure** **SF1** and the summarized version is shown in **Figure 3**. The following section will discuss the pipeline that standardizes the clinical trial tumors based on text embeddings.

**Text embedding analysis: closest match in embedding space**

​​The methods in the previous section employed edit distances to compare texts. These methods primarily focus on syntactical differences to quantify the differences between texts. In this section, the standardization methods deployed by CANTOS are based on text embeddings (or word embeddings), which can also be used for comparing texts. Text embeddings are low dimensional numeric vector representations of unstructured text data. Unlike edit distances, text embeddings focus on capturing the semantic and contextual meaning of the input text they encode; consequently, in the embedding vector space, texts with similar meanings should have embeddings close to each other and texts which differ in meaning should be further apart [77–80](https://paperpile.com/c/Ky0na7/go38q+24pLh+2IhPR+A2KRB). Text-embeddings have been used in various applications such as developing search engines [81,82](https://paperpile.com/c/Ky0na7/NUuiR+WxsSK), text clustering [83](https://paperpile.com/c/Ky0na7/xitGO) and classification [84](https://paperpile.com/c/Ky0na7/JzjPe), recommender systems [85](https://paperpile.com/c/Ky0na7/NSAEQ), and anomaly detection [86](https://paperpile.com/c/Ky0na7/xrXuV). Text-embeddings can be generated by natural language processing models such as Word2Vec [78](https://paperpile.com/c/Ky0na7/24pLh), GloVE [87](https://paperpile.com/c/Ky0na7/7ier), FastText [88–90](https://paperpile.com/c/Ky0na7/0INY+eFNQ+XHtN) or through large language models (LLM) such as BERT [91](https://paperpile.com/c/Ky0na7/fI1V), GPT [92–96](https://paperpile.com/c/Ky0na7/Z7Fl+YO9o+n0s4+Fr9A+loVq), ELMO [80,97](https://paperpile.com/c/Ky0na7/A2KRB+gaqu). For this study, we generated text embeddings using two OpenAI models: text-embedding-ada-002 (ADA-002) and text-embedding-3-large (LTE-3) [98](https://paperpile.com/c/Ky0na7/ZzZVH). LTE-3, the newer model, produces 3072-dimensional embeddings, while ADA-002 generates 1536-dimensional ones. We used both models to create embeddings for tumor names in the CTR, WHO system, and NCIt database. Utilizing these embeddings, CANTOS standardizes the tumor names in CTR by calculating Euclidean distances in the embedding space (LTE-3 or ADA-002) between each tumor name in the CTR and standardized terms in the WHO system and NCIt database and mapping each tumor name to its nearest standardized term. CANTOS applied this method with both types of embedding to standardize tumor names according to the WHO system 5th edition, WHO system all editions, and the NCIt database.

**Text embedding analysis: embeddings and clustering** Similar to CANTOS's approach of using edit distances to compute divergence matrices for AP clustering, in this approach, CANTOS calculated the pairwise Euclidean distances in the embedding space (LTE-3 or ADA-002) among tumor names in the CTR, WHO system and NCIt database. However, this method is computationally expensive due to the high dimensionality of the embedding space: ADA-002 (1536) and LTE-3 (3072). To address this issue, CANTOS applied principal component analysis (PCA) to each set of embeddings (ADA-002 and LTE-3) and based on the iteration of pipeline that depended on the edition of WHO (5th edition or all editions) system used in the pipeline, generated four sets of PCA-transformed embeddings. The dimensions of the four PCA-transformed embedding spaces are summarized in **Table 5**. For each case, CANTOS retained the minimum number of principal components necessary to explain 80% of the variance in the data.

With the four sets of PCA-transformed embeddings, CANTOS computed the divergence matrices for AP clustering using pairwise Euclidean distance. After clustering, CANTOS performs cluster size analysis by computing the z-scores for each cluster based on the number of cluster members. Using the default z-score of 2.5 as a threshold, CANTOS determined the maximum cluster size and designated any cluster with a z-score greater than 2.5 as a large cluster. For each large cluster, CANTOS performed nested AP clustering until their sizes were below or equal to the maximum number of cluster members or the AP clustering algorithm converged. The use of z-score for determining large clusters differs from the edit distance-based AP clustering method in the previous section, where the median cluster size was used as the threshold for determining the large clusters in CANTOS. The median cluster size for embedding-based AP clustering was lower than the maximum cluster size established by z-score-based clustering. This consequently led to more clusters with relatively homogeneous cluster members being labeled as large clusters and flagged for nested clustering. The maximum cluster size determined using the z-score was larger, and fewer such clusters were flagged as large, hence it was selected as the threshold for deciding large clusters in CANTOS. It should be noted that CTR has a diverse range of tumor names; thus, clustering these tumor names will produce clusters of nonuniform cluster size. Hence, estimating a maximum cluster size is not trivial when considering the variation in the entire dataset. With more curation and classification of the tumors within the CTR, one can get a more accurate estimate of a reasonable cluster size for each tumor type.

After clustering, CANTOS performed outlier detection as in the previous section using isolation forest and LOF analysis. The hyperparameters for isolation forest and LOF analysis were kept the same as they were for edit-distance-based AP clustering. Following the outlier detection step, CANTOS iterates through each cluster and determines the standardized term from the WHO system (5th edition and all editions) and the NCIt database that are closest to each cluster member by computing the Euclidean distance in the embedding space (not the PCA-transformed space). If a majority of the tumor names in a cluster are close to a specific standardized term, then all the tumor names are mapped to that standardized term. In case there is a tie, where two or more standardized terms are equally represented in a cluster, then each tumor name within that cluster is assigned to its closest matching standardized term. **Table 6** compares the number of AP clusters formed when we use text-embeddings and text-matching (edit distances).

In addition to AP clustering, CANTOS implemented K-means clustering on PCA transformed embeddings to standardize the tumor names in CTR. Unlike AP, K-means requires users to define the number of clusters, "K," as a hyperparameter[99](https://paperpile.com/c/Ky0na7/G2bKQ). Without prior information on the types of tumors present in CTR, it is difficult to estimate "K" qualitatively and thus we used a computational method to decide on an optimal value for “K”. To determine “K”, we implemented a commonly used cluster performance metric known as the silhouette coefficient[100](https://paperpile.com/c/Ky0na7/O9sM2) within CANTOS. For a given value of “K”, when K-means clustering is completed, the silhouette coefficient is computed for each data point. The silhouette coefficient has a range of [-1,1]. A silhouette coefficient of 1 signifies that the data point is well-matched to other elements in its own cluster and poorly matched to members of neighboring clusters[101](https://paperpile.com/c/Ky0na7/nAd3N). A silhouette coefficient of 0 indicates that the data point is at the decision boundary of neighboring clusters and a score of -1 indicates that the data point is poorly matched with other cluster members and likely assigned to an incorrect cluster[101](https://paperpile.com/c/Ky0na7/nAd3N). Intuitively, a higher silhouette coefficient for a data point represents high cohesion of that data point with rest of the cluster members and high separation from members of neighboring clusters. CANTOS iterates through several values of “K” and performs K-means clustering and calculates the silhouette coefficient for each data point. For each cluster, CANTOS calculates the average silhouette coefficient which indicates the performance for that cluster. CANTOS then computed the average of each of the averaged silhouette coefficients per cluster, this produces a metric that can be used to evaluate the overall clustering performance of the K-means algorithm for a given value of “K”. We refer to this metric as the mean silhouette score which ranges from [-1,1] and a higher positive value indicates better clustering performance. Using this method, CANTOS evaluated the mean silhouette score for various values of “K” under both ADA-002 and LTE-3 embeddings for each iteration (WHO system 5th edition and WHO system all editions). In **Figure 4**, we plot the mean silhouette score for each of these cases.

After K-means clustering is completed, CANTOS follows the same steps for outlier detection (isolation forest and LOF analysis) and standardization (compute Euclidean distances with standardized term and identify the closest match) as it did for embedding based AP clustering, while maintaining the exact hyperparameter configurations. A detailed view of the text-embedding based standardization pipeline is displayed in **Supplementary Figure** **SF2**, and a brief summary is presented in **Figure 3**.

**Conclusion**

The CTR records various aspects of clinical trials, including conditions studied, and shares this information publicly in text file format. However, it lacks a mechanism for identifying tumor names, which are often unstandardized, making it challenging to integrate them with other biomedical databases for downstream analysis. In this paper, we present CANTOS, a computational pipeline that extracts tumor names from the condition file in CTR and classifies them as adult or pediatric tumors. It then standardizes the extracted tumor names with respect to the WHO system and NCIt database using 12 standardization methods based on text-matching and text-embedding. Our findings show that embedding-based methods outperform text-matching methods, with the LTE-3+Euclidean Distance method achieving the highest accuracy. We standardized all 13,230 tumors in the CTR against the WHO system and NCIt database and reported the results.

Our findings suggest using a more specifically trained LLM for embedding analysis beyond a general-purpose LLM like ADA-002 and LTE-3. A domain-specific LLM, trained on biomedical and oncology-related data and the WHO resource, may improve the identification and classification of non-standard tumor names, potentially enhancing the accuracy and robustness of the CANTOS pipeline.

**Resource availability**

**Data and code availability**

Users can download the data used in this paper from the CTR website (<https://clinicaltrials.gov/>)[9](https://paperpile.com/c/Ky0na7/aySgj), Clinical Trials API or from the Aggregate Analysis of ClinicalTrials.gov-Clinical Trials Transformative Initiative (AACT-CTTI) website (<https://aact.ctti-clinicaltrials.org/download>). We downloaded a copy of the database from the ACCT-CTTI website on August 22, 2023 which is available as a zip file titled “20230822\_export.zip” under the section titled “Monthly Archive of Static Copies”. The AACT-CTTI website is updated daily with content from ClinicalTrials.gov and provides a static database at the beginning of each month. This database includes information on all registered studies in the CTR, with details about clinical trials, such as experimental design, conditions, and interventions, available in separate pipe-delimited text files within the zip file. The process for downloading the dataset used in this study is outlined in **Supplementary Document SD6**. The code files for building and running CANTOS, along with the instructions for downloading the embeddings generated using Open AI are publicly available at our GitHub repository: <https://github.com/TaylorResearchLab/CANTOS>.

**Lead contact**

Further information and requests for resources should be directed to and will be fulfilled by the lead contact, Deanne Taylor (taylordm@chop.edu).

**Materials availability**

The WHO system and NCIt database standardized tumor names generated by CANTOS are available in **Supplementary Tables ST6-ST9**. The code for implementation of the CANTOS pipeline is available in our public GitHub repository:<https://github.com/TaylorResearchLab/CANTOS>.

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**Author contributions**

AL and DT conceived and designed the study. AL wrote the code. AL,SS, BS, TM performed the analyses. AL wrote the manuscript. DT, EM, and KB made critical revisions to the manuscript. All authors interpreted the content, made revisions to the manuscript, and had final approval of the completed version. DT oversaw the project. DT acquired funding for the project.

**Declaration of interests**

The authors declare no competing interests.

**Declaration of generative AI and AI-assisted technologies in the writing process**

During the preparation of this work the authors used ChatGPT 4.0 and Grammarly to improve clarity and conciseness of the written text. After using these services, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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**TABLES**

**Table 1: CANTOS Accuracies for Standardization Methods when WHO system all editions are used.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Ranking** | **Basis** | **Methods** | **Accuracy WHO system all editions** |
| 1 | Embedding | LTE-3 + Euclidean Dist | 0.6851521 |
| 2 | Embedding | LTE-3 + AP | 0.6708408 |
| 3 | Embedding | ADA-002 + Euclidean Dist | 0.6618962 |
| 4 | Embedding | ADA-002 + AP | 0.6466905 |
| 5 | Embedding | LTE-3 + K-means | 0.6449016 |
| 6 | Embedding | ADA-002 + K-means | 0.6359571 |
| 7 | Text Match | Levenshtein | 0.3246869 |
| 8 | Text Match | Levenshtein + AP | 0.2924866 |
| 9 | Text Match | Jarro Winkler | 0.2549195 |
| 10 | Text Match | Jarro Winkler + AP | 0.244186 |
| 11 | Text Match | Cosine | 0.2388193 |
| 12 | Text Match | Cosine + AP | 0.2271914 |

**Table 2: CANTOS Accuracies for Standardization Methods when the WHO system** **5th edition was used.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Ranking** | **Basis** | **Methods** | **Accuracy WHO system 5th edition** |
| 1 | Embedding | LTE-3 + Euclidean Dist | 0.6563408 |
| 2 | Embedding | LTE-3 + AP | 0.6456922 |
| 3 | Embedding | LTE-3 + K-means | 0.6360116 |
| 4 | Embedding | ADA-002 + Euclidean Dist | 0.6292352 |
| 5 | Embedding | ADA-002 + AP | 0.6263311 |
| 6 | Embedding | ADA-002 + K-means | 0.6050339 |
| 7 | Text Match | Levenshtein | 0.3059051 |
| 8 | Text Match | Levenshtein + AP | 0.286544 |
| 9 | Text Match | Jarro Winkler | 0.2342691 |
| 10 | Text Match | Jarro Winkler + AP | 0.232333 |
| 11 | Text Match | Cosine + AP | 0.2197483 |
| 12 | Text Match | Cosine | 0.2178122 |

**Table 3: Summary statistics for closest Euclidean distances in Figure 1a.** This table shows the summary statistics for closest Euclidean distances in **Figure 1a** between the CTR terms and standardized terms from the WHO system 5th edition as visualized for box plots in **Figure 1a** for the method LTE-3 + Euclidean Dist. 1,033 CTR terms had a ground truth in WHO system 5th edition.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Minimum** | **1st Quartile** | **Median** | **Mean** | **3rd Quartile** | **Maximum** |
| Correctly Standardized | 0 | 0.5852 | 0.6956 | 0.6657 | 0.8037 | 1.0112 |
| Incorrectly Standardized | 0.4646 | 0.7705 | 0.8448 | 0.8322 | 0.9104 | 1.0880 |

**Table 4: Summary statistics for closest Euclidean distances in figure 1b.** This table shows the summary statistics for closest Euclidean distances in **Figure 1b** between the CTR terms and standardized terms from the WHO system all editions as visualized for box plots in **Figure 1b** for the method LTE-3 + Euclidean Dist. 1,118 CTR terms had a ground truth in WHO system all editions.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Minimum** | **1st Quartile** | **Median** | **Mean** | **3rd Quartile** | **Maximum** |
| Correctly Standardized | 0 | 0.5640 | 0.6866 | 0.6458 | 0.8002 | 1.0759 |
| Incorrectly Standardized | 0.3942 | 0.7405 | 0.8258 | 0.8125 | 0.8962 | 1.0580 |

**Table 5: PCA dimensions used for each embedding space based on WHO system editions in CANTOS.**

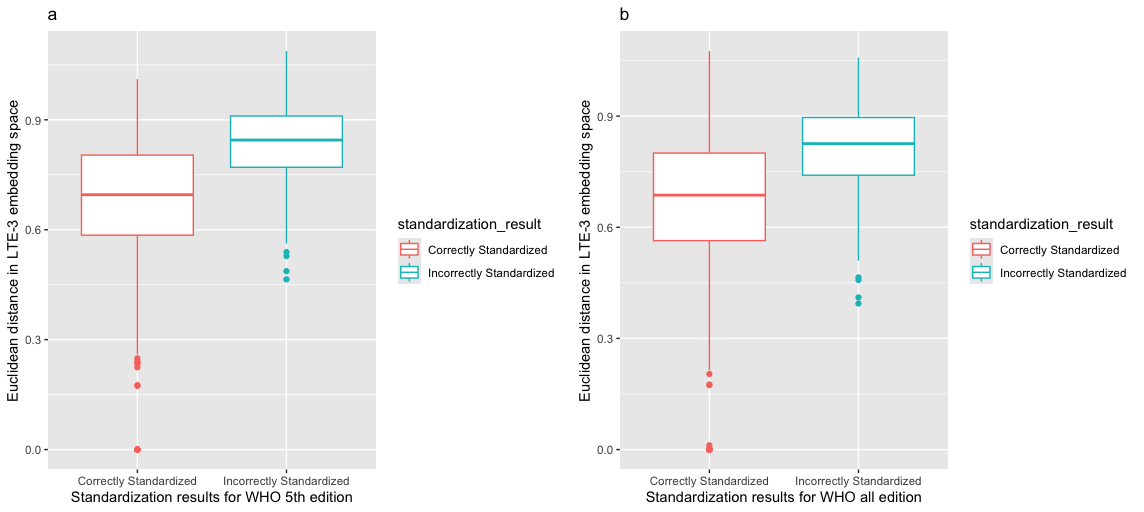
|  |  |  |
| --- | --- | --- |
| **Tumor Terms** | **Dimensions for PCA+ADA-002** | **Dimensions for PCA+LTE-3** |
| CTR + NCIT + WHO system 5th edition | 136 | 178 |
| CTR + NCIT + WHO system all editions | 141 | 185 |

**Table 6: Number of clusters from AP clustering under embedding and text-matching based methods.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Basis** | **Affinity Propagation Clustering Divergence Metric** | **Number of Clusters for CTR Terms, NCIt Terms, WHO system all editions** | **Number of Clusters for CTR Terms, NCIt Terms, WHO system 5th edition** |
| Text Match | Cosine | 1040 | 967 |
| Text Match | Levenshtein | 2020 | 1808 |
| Text Match | Jarro Winkler | 1965 | 1785 |
| Embedding | ADA-002 + Euclidean Dist | 3790 | 3456 |
| Embedding | LTE-3 + Euclidean Dist | 3894 | 3427 |

**FIGURES**

**Figure 1: Distribution of closest Euclidean distances in the LTE-3 embedding space by the standardization method LTE-3+Euclidean Dist.** This figure Illustrates the distribution of the closest Euclidean distances in the LTE-3 embedding space, used by the standardization method LTE-3+Euclidean Dist, to map tumor names from the CTR to the nearest term from the WHO system. This distance is the minimum Euclidean distance between a given tumor name in the CTR and all the standardized terms in the WHO system within the LTE-3 embedding space. For a given tumor name from the CTR, the method LTE-3 + Euclidean Dist uses this distance to identify the nearest standardized term from the WHO system and then maps it to the respective tumor name in the CTR. The box plot in red shows the instances when the LTE-3 + Euclidean Dist method correctly standardized the CTR terms, whereas the blue box plot shows the instances when the method incorrectly standardized the CTR terms. **a.** displays the distribution of the closest Euclidean distances in LTE-3 embedding space when the CTR terms are standardized against the WHO system 5th edition, and **b.** displays the distribution of the closest Euclidean distances in LTE-3 embedding space when the CTR terms are standardized against WHO system all editions.

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**Figure 2: Tumor Annotation Process in the CANTOS Pipeline:** The annotation workflow within the CANTOS pipeline, specifically for categorizing tumor names extracted from the NIH Clinical Trials Registry. The process involves filtering extracted tumor names, matching them to the WHO system, and categorizing them as adult or pediatric tumors. The conditions flagged as tumors were manually reviewed and citations were added for the pediatric tumor types.



**Figure 3: Text Matching and Embedding Pipeline for Tumor Standardization in CANTOS.** Designed to standardize tumor names extracted from the NIH Clinical Trials Registry. The pipeline uses both edit-distance-based text matching and embedding-based methods to standardize the registered tumor names with entries in the WHO system and NCIt database.



**Figure 4: Average Silhouette Score vs Number of clusters (K) used in K-means. a**. ADA-002 when WHO system all editions terms are used. **b**. ADA-002 when WHO system 5th edition terms are used **c**. LTE-3 when WHO system all editions terms are used **d**. LTE-3 when WHO system 5th editions terms are used.

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**Supplemental Information**

**Figures**

**Supplementary Figure SF1:** SF1\_CANTOS\_Standardization\_Workflow\_Edit\_Distances.pdf. This file contains a detailed view of the workflow employed by CANTOS to standardize the CTR tumor names using methods based on text-matching (edit distances).

**Supplementary Figure SF2:** SF2\_CANTOS\_Standardization\_Workflow\_Embedding.pdf. This file contains a detailed view of the workflow employed by CANTOS to standardize CTR tumor names using methods based on text-embedding.

**Tables**

**Supplementary Table ST1:** ST1\_WHO\_Tumor\_all\_edition.xlsx. This file contains the standardized tumor names from the WHO Tumor Classification System 3rd, 4th, and 5th editions.

**Supplementary Table ST2:** ST2\_NCIT\_Neoplasm\_Core\_terms.csv. This file contains the standardized tumor names from the NCIt database.

**Supplementary Table ST3:** ST3\_who\_cancer\_key\_words\_general\_5th\_edition.xlsx. This file contains the standardized tumor names from the WHO Tumor Classification System 5th edition only.

**Supplementary Table ST4:** ST4\_tumor\_sample\_df\_gt\_annotated\_all.csv. This file contains the ground truth annotation with respect to all editions (3rd, 4th, and 5th) of WHO Tumor Classification System for the 1600 tumor names randomly sampled from the CTR. Furthermore, this file also contains the standardization results obtained from the 12 standardization methods implemented by CANTOS.

**Supplementary Table ST5:** ST5\_tumor\_sample\_df\_gt\_annotated\_5th.csv. This file contains the ground truth annotation with respect to the 5th edition of WHO Tumor Classification System for the 1600 tumor names randomly sampled from the CTR. Furthermore, this file also contains the standardization results obtained from the 12 standardization methods implemented by CANTOS.

**Supplementary Table ST6:** ST6\_WHO\_Results\_all.csv. This file contains the standardized tumor names for each CTR tumor identified by CANTOS. The standardization was done with respect to all editions (3rd, 4th, and 5th) of WHO Tumor Classification System. This result was obtained when all editions (3rd, 4th, and 5th) of WHO Tumor Classification System was in the CANTOS pipeline.

**Supplementary Table ST7:** ST7\_WHO\_Results\_5thed.csv. This file contains the standardized tumor names for each CTR tumor identified by CANTOS. The standardization was done with respect to the 5th edition of WHO Tumor Classification System. This result was obtained when 5th edition of WHO Tumor Classification System was in the CANTOS pipeline.

**Supplementary Table ST8:** ST8\_NCIT\_Results\_all.csv.This file contains the standardized tumor names for each CTR tumor identified by CANTOS. The standardization was done with respect to the NCIt database. This result was obtained when all editions (3rd, 4th, and 5th) of WHO Tumor Classification System was in the CANTOS pipeline.

**Supplementary Table ST9:** ST9\_NCIT\_Results\_5thed.csv.This file contains the standardized tumor names for each CTR tumor identified by CANTOS. The standardization was done with respect to the NCIt database. This result was obtained when the 5th edition of WHO Tumor Classification System was in the CANTOS pipeline.

**Supplementary Table ST10:** ST10\_tumor\_annotated\_adult\_ped.csv.This file contains the list of tumor identified using CANTOS from the conditions file in CTR. For each condition name, the file informs the user if it is a tumor and if it is also a pediatric tumor. For each pediatric tumor, the file also provides a literature citation confirming that it is a pediatric tumor.

**Supplementary Table ST11:** ST11\_who\_cancer\_key\_words\_paediatric\_5th\_edition.xlsx.This file contains the standardized pediatric tumor names from the WHO Tumor Classification System 5th edition only.

**Documents**

**Supplementary Document SD1:** SD1\_Condition\_MeSH\_Term\_Comparison.pdf. This file compares the MeSH terms and conditions terms in the CTR and establishes that even though MeSH terms are standardized, they are not an appropriate representation of the condition names.

**Supplementary Document SD2:** SD2\_Intervention\_Type\_NIH\_CTR.pdf. This file lists the different types of intervention types found in the CTR**.**

**Supplementary Document SD3:** SD3\_Tumor\_Key\_Words.pdf . This file contains the tumor key words that were used to detect tumor from CTR, along with standardized terms in ST3 and ST11.

**Supplementary Document SD4:** SD4\_NIH\_CTR\_Conditions\_Discrepancies.pdf . This file displays examples of condition names from the CTR and the various discrepancies associated with them and if there are any standardized terms from the WHO Tumor Classification System.

**Supplementary Document SD5:** SD5\_Example\_Edit\_Distance.pdf. This file demonstrates an example of how edit distance can be used to transform one string to another.

**Supplementary Document SD6:** SD6\_data\_download\_instructions.pdf. This file shows the steps involved in downloading the CTR database.