Privacy-Preserving Generation of Clinical Narratives from Medical Terminologies

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Abstract

In high-stakes domains such as healthcare, privacy concerns severely limit the use of real-world training data. Differentially private (DP) synthetic data offers a promising alternative with formal privacy guarantees, but achieving strong utility remains challenging for clinical note generation due to domain specificity and long-form text complexity. We present **Term2Note**, a method for synthesising full-length clinical notes under strong DP constraints. By structurally separating content and form, Term2Note generates section-wise note content conditioned on medical terms, with terms and notes privatised under separate DP constraints, and applies a DP quality maximiser to improve outputs. Experiments demonstrate that Term2Note produces synthetic notes with statistical properties closely aligned with real clinical notes, and that downstream models trained on these notes achieve performance comparable to those trained on real clinical data. Compared to existing DP text generation baselines, Term2Note substantially improves both fidelity and utility, without relying on label distribution assumptions, highlighting its effectiveness as a practical privacy-preserving alternative to real clinical notes.

1 Introduction

The scaling law of neural language models (Kaplan et al., 2020) suggests that model performance improves with larger training corpora. As large language models (LLMs) continue to scale in size, with models such as Llama 3 (Meta, 2024), Gemma 3 (Google, 2025), and Qwen3 (Yang et al., 2025) ranging from 0.6B to over 405B parameters, the demand for large-scale, high-quality training data has risen accordingly. Synthetic data generation with LLMs has therefore emerged as a promising approach, with instruction-following synthetic datasets (Schick and Schütze, 2021; Taori et al., 2023; Li et al., 2025b) proving effective for model pretraining and fine-tuning. This is especially relevant for high-stakes domains such as healthcare (Li et al., 2025a), where real data is sensitive, highly regulated, and difficult to share (Schlegel et al., 2025). Although large amounts of clinical data exist within healthcare institutions, access to these datasets remains extremely limited. A practical and privacy-conscious solution is to share synthetic versions of sensitive clinical data instead of the raw data itself. However, to make such synthetic sharing viable, formal privacy guarantees are essential.

Differential privacy (DP) provides a principled framework for this purpose (Alzoubi and Mishra, 2025). By bounding the influence of any individual record on the synthesised dataset, DP offers quantifiable privacy guarantees. Prior work on DP-based text generation has focused mainly on short-form texts in low-risk domains such as reviews (Yue et al., 2023; Kurakin et al., 2023; Mattern et al., 2022; Flemings and Annavaram, 2024). In biomedical settings, efforts have been restricted to synthesising (public) PubMed abstracts (Xie et al., 2024) and relatively short clinical passages (Aziz et al., 2022; Ramesh et al., 2024), with no prior work addressing the more complex task of generating full-length clinical notes under DP constraints. Synthesising clinical notes with DP presents two key challenges. First, *generation complexity* (Kweon et al., 2024a; Weetman et al., 2021): clinical notes are long and exhibit diverse structures and free-form content, making it more difficult for generative models to maintain coherence and quality, particularly under privacy constraints. Second, *domain specificity* (Adnan et al., 2010): clinical notes typically contain extensive domain-specific terminologies, which require expert knowledge to understand and reproduce accurately.

In this paper, we tackle this underexplored and challenging task by proposing Term2Note, a novel methodology for DP synthetic clinical note generation. As illustrated in Figure 1, Term2Note ad-

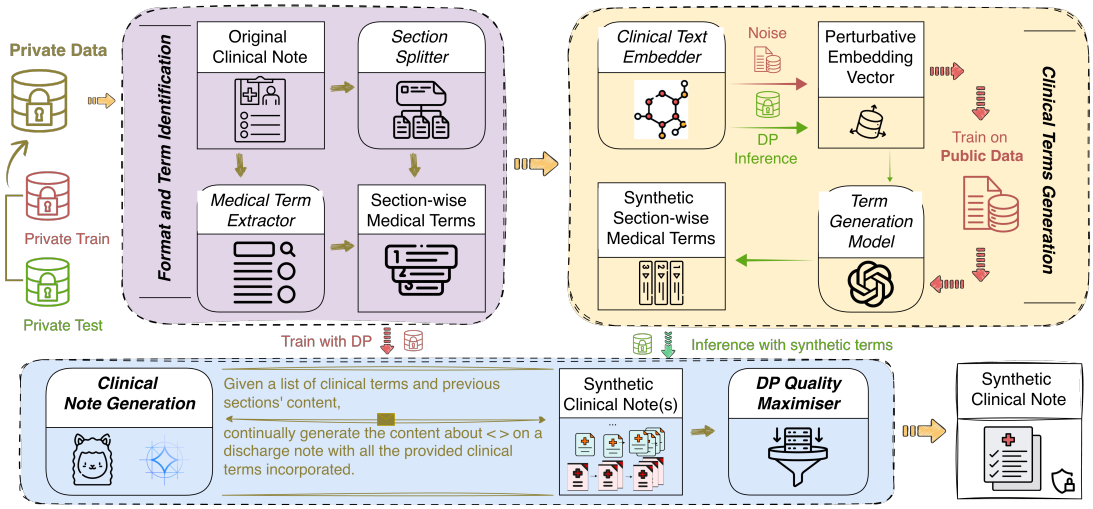

Figure 1: Overview of **Term2Note**. An original clinical note is split into sections and associated medical terms, which are embedded and optionally privatised via DP perturbation. A term generation model produces synthetic terms from these embeddings, and a DP-trained note generation model synthesises section-wise notes conditioned on them. A DP quality maximiser then selects the final synthetic note. Appendix A illustrates the whole process with a concrete example.

dresses the challenge of long-form generation by leveraging domain-specific document structures to decompose the task into smaller, section-wise subtasks. To handle domain specificity, it conditions generation not on generic metadata (e.g., class labels or diagnosis codes such as *Enterocolitis due to Clostridium difficile*), but on salient clinical terms (e.g., *[diarrhea, Clostridium difficile colitis, Vancomycin]*), which are subjected to an additional layer of DP protection. This term-based conditioning strategy allows the model to generate text that is both clinically meaningful and structurally coherent, while also enabling more fine-grained privacy control. Our experimental results show that Term2Note: (1) produces synthetic notes with high structural and semantic fidelity to real clinical data; (2) enables strong utility in the downstream task, such as ICD code prediction; (3) satisfies formal DP guarantees that make it suitable for safe data sharing. Moreover, Term2Note consistently outperforms baseline methods across all evaluation metrics, often by a large margin. In summary, Term2Note offers a promising solution for privacy-preserved clinical notes sharing.

2 Background & Related Work

Definition 1. (Dwork et al., 2006) A randomised algorithm $\mathcal{M} : \mathbb{N}^{|\mathcal{X}|} \to R$ is said to be (ϵ, δ)-***differentially private (DP)***, if, for any two neighboring datasets D and D' differing in one single instance, and for all subsets S of the output space of $\mathcal{M}$, it has

$$\mathbb{P}[\mathcal{M}(D) \in S] \leq e^{\epsilon}\mathbb{P}[\mathcal{M}(D') \in S] + \delta.$$

The definition implies the probability distributions induced by $\mathcal{M}$ on neighboring datasets must be close, with their likelihood ratios bounded by a multiplicative factor of e^{ϵ} and an additive slack of δ. Smaller ϵ values indicate stronger privacy, while δ denotes the (typically negligible) probability of a privacy breach exceeding the e^{ϵ} bound.

Theorem 1. (**Post-Processing**) (Dwork and Roth, 2014) Let $\mathcal{M} : \mathbb{N}^{|\mathcal{X}|} \to R$ be a randomised algorithm that is (ϵ, δ)-DP. Let $f : R \to R'$ be an arbitrary randomised function. Then $f \circ \mathcal{M} : \mathbb{N}^{|\mathcal{X}|} \to R'$ is also (ϵ, δ)-DP.

Theorem 2. (**Parallel Composition**) (McSherry, 2009) Let dataset $D = D_1 \cup \cdots \cup D_k$, and $D_i \cap D_j = \emptyset$ for $i \neq j$. Let $\mathcal{M}_i : \mathbb{N}^{|\mathcal{X}_i|} \to R_i$ be a randomised algorithm that is (ϵ_i, δ_i)-DP, for $i \in [k]$. Then $\mathcal{M}(D) = (\mathcal{M}_1(D_1), \cdots, \mathcal{M}_k(D_k))$ is $(\max_i \epsilon_i, \max_i \delta_i)$-DP.

The post-processing property ensures that once a randomised algorithm $\mathcal{M}$ satisfies (ϵ, δ)-DP, any deterministic or randomised function applied to its output cannot weaken its privacy guarantee. Thus, a generative model trained under DP retains its privacy during downstream use, e.g., generating synthetic data, applying further transformations, or training downstream models. The parallel composition property states that applying DP mechanisms to disjoint data subsets yields an overall privacy loss bounded by the maximum individual (ϵ, δ) values—a key feature in our method, where clinical

terms and notes can be privatised independently.

DP in Deep Learning can be achieved by injecting random noise into the input data, where the noise is typically sampled from a pre-determined distribution, such as the Gaussian distribution. In the context of deep learning, the DP-SGD algorithm (Abadi et al., 2016) introduces a principled way to achieve this by clipping per-sample gradients and adding noise at each optimisation step. This approach ensures that the influence of any single training example on the model's parameters remains bounded, thereby enforcing DP guarantees throughout training. Some subsequent research (Bu et al., 2023; Yousefpour et al., 2021; Lee and Kifer, 2020) has focused on improving the computational efficiency of DP-SGD, aiming to reduce the time and memory overhead associated with per-example gradient computation. Unless otherwise specified, we adopt the FastDP algorithm (Bu et al., 2023) to fully fine-tune the model under DP constraints throughout this paper.

Synthetic text generation has progressed rapidly with the rise of LLMs, especially through instruction-following datasets that enhance downstream performance (Taori et al., 2023; Peng et al., 2023; Schick and Schütze, 2021). Generating synthetic clinical text, however, is substantially more challenging due to the domain's complexity, reliance on expert knowledge, and lack of easily templated instructions. Prior attempts have often produced datasets with limited downstream utlity (Li et al., 2023a; Schlegel et al., 2023). Recent work has sought to improve realism by prompting LLMs with control code (e.g., ICD codes) (Falis et al., 2024) or transforming biomedical abstracts (e.g., PubMed content) into clinical-style text (Kweon et al., 2024b). While promising, these methods do not address privacy, a central concern in clinical settings. A straightforward strategy is de-identifying private information and prompting LLMs to fill in the gaps (Sarkar et al., 2025), but a more principled approach is to fine-tune or instruction-tune generative models with DP for formal protection (Aziz et al., 2022; Ramesh et al., 2024; Baumel et al., 2024). However, prior studies operate on relatively short clinical texts, either naturally brief or deliberately truncated, making generation considerably easier. In contrast, DP-constrained generation of full-length clinical notes, as addressed in this paper, is more challenging due to their length, unstructured format, and high variability.

3 Methodology

3.1 Problem Statement

Given a private dataset D^{src} consisting of clinical notes, our goal is to develop a mechanism $\mathcal{M}$ that satisfies (ϵ, δ)-DP and produces a synthetic dataset D^{syn} as its output. Let $X^{\text{src}} \in D^{\text{src}}$ denote an original clinical note and $X^{\text{syn}} \in D^{\text{syn}}$ its corresponding synthetic version. To support the development and evaluation of the mechanism, we partition the private dataset into a training set $D^{\text{src}}_{\text{train}}$ and a test set $D^{\text{src}}_{\text{test}}$. The training set is used to develop $\mathcal{M}$, while the test set remains completely unseen by $\mathcal{M}$ to provide an unbiased evaluation. Additionally, we assume access to a public dataset of clinical terms, denoted as D_{public}, which can be automatically derived from publicly available medical resources and therefore used freely without privacy constraints.

We introduce **Term2Note**, a section-wise DP generation framework for clinical notes. An overview is illustrated in Figure 1, with the detailed procedure in Algorithm 1. In the following, we first elaborate on Term2Note alongside the algorithm, and then present the implementation details.

3.2 Format and Term Identification

Since our framework synthesises clinical notes via section-wise generation conditioned on medical terms, we first standardise the structure of the notes and identify salient clinical terms. Let SECSPLIT denote an automatic section segmentation module. Given an original clinical note X^{src}, SECSPLIT outputs a list of m segmented sections: $[\text{SEC}^{\text{src}}_1, ..., \text{SEC}^{\text{src}}_m] = \text{SECSPLIT}(X^{\text{src}})$, where $\text{SEC}^{\text{src}}_i$ = "" if the i-th section is absent. Next, we apply an automatic term extraction module, denoted as TERMEXT, to each section to identify clinically salient terms, resulting in a list of section-specific medical terms: $[T^{\text{src}}_1, ..., T^{\text{src}}_m] = [\text{TERMEXT}(\text{SEC}^{\text{src}}_1), ..., \text{TERMEXT}(\text{SEC}^{\text{src}}_m)]$.

3.3 Clinical Terms Generation

Clinical terms from private notes may still contain sensitive information. For example, unique combinations of diagnoses and procedures could re-identify patients. To mitigate this, we introduce an optional DP step for term generation. We formulate it as a reconstruction task, fine-tuning a generative model on the public term dataset D_{public} to recover term lists from embeddings, and then applying it to private data under DP constraints. Specifically, any given (section-wise) term list is first embedded us-

ing a clinical text embedder, denoted EMB. A projection layer PROJ, parameterised by θ_p, maps the embeddings to the hidden dimensionality required by the generative model TERMGEN, parameterised by θ_t. The model then reconstructs the original term list from the projected embeddings. To ensure privacy, we adapt the DPRP schema (Gondara and Wang, 2020), a model-agnostic DP mechanism originally proposed for tabular data, to term embeddings derived from private notes, denoted as DPRP*. The procedure perturbs private embeddings in four steps: (1) add dimension-wise random noise to input embeddings; (2) compute the covariance matrix of the input embeddings and add random noise; (3) perform singular value decomposition (SVD) on the noisy covariance matrix; (4) reconstruct the inputs from the noisy embeddings and the right singular vectors. The pseudocode of DPRP* is provided in Appendix B. To minimise the distribution difference between embeddings used in training and those perturbed during inference, we additionally add Gaussian noise to the embeddings during training. Formally, the process is defined as follows:

$$E' = \begin{cases} \text{EMB}(D_{\text{public}}) + \mathcal{N}(0, \sigma_{\text{emb}}), & \text{if training,} \\ \text{DPRP}^*(\text{EMB}(T^{\text{src}}), \frac{\epsilon_t}{m}, \frac{\sigma_t}{m}), & \text{otherwise.} \end{cases} \quad (1)$$

$$T^{\text{syn}} \sim \text{TERMGEN}_{\theta_t}(\text{PROJ}_{\theta_p}(E')) \quad (2)$$

Here, ϵ_t and σ_t denote the privacy parameters of DPRP*, and m is the number of sections in a single note. Since E' is computed at the section level, the overall privacy cost for an entire note accumulates across sections. To account for this, we distribute the privacy budget evenly by scaling the cost for each section to $\frac{1}{m}$ of the total budget.

3.4 Clinical Note Generation

We define section-wise clinical note generation as a conditional text generation task. Given the task instruction I, the content of the previous (generated) sections $[\text{SEC}_1, ..., \text{SEC}_{i-1}]$, and a list of clinical terms T_i for the current section, a generative model NOTEGEN, parameterised by θ_n, is trained to produce the i-th section of the note under (ϵ_n, δ_n)-DP. During inference, each section is sampled sequentially as:

$$\text{SEC}_i^{\text{syn}} \sim \text{NOTEGEN}_{\theta_n}(I, [\text{SEC}_1^{\text{syn}}, ..., \text{SEC}_{i-1}^{\text{syn}}], T_i) \quad (3)$$

Here, T_i can be the original extracted terms T_i^{src} or the synthetic privatised terms T_i^{syn}, depending on the privacy configuration. With the section group named provided, the instruction I is defined as shown in Figure 1. Finally, a synthetic full note is obtained by concatenating the generated sections: $X^{\text{syn}} = [\text{SEC}_1^{\text{syn}}, ..., \text{SEC}_m^{\text{syn}}]$.

3.5 DP Quality Maximiser

To improve the quality of the synthetic data, we introduce a quality maximisation strategy during inference by leveraging the generative capabilities of LLMs. Specifically, instead of generating a single synthetic note, we perform preference sampling on k candidate notes for X^{src}, denoted $X^{\text{syn}}[1:k]$. Notably, this sampling procedure preserves the DP guarantee due to the post-processing property of DP. To select the most fluent and coherent output among the candidates, we use perplexity as the preference model. Perplexity reflects the likelihood of a sequence under an LLM, computed as the exponentiated average negative log-likelihood of the tokens. Lower perplexity indicates higher linguistic plausibility. To avoid bias from the generator itself, we compute perplexity scores using a reference domain-specialised LLM, denoted LLM_{ppl}. This ensures a more objective assessment of sequence quality. Formally, the perplexity of a candidate note $X^{\text{syn}}[i]$ is given by $\text{PPL}(X^{\text{syn}}[i]) = \exp\left(-\frac{1}{t}\sum_{i=1}^{t} log\ \text{LLM}_{\text{ppl}}(d_i|d_{<i})\right)$, where $d_{1,...,t}$ are tokens in $X^{\text{syn}}[i]$. The synthetic note with the lowest perplexity score is selected.

3.6 Privacy Analysis

The overall privacy guarantee of Term2Note depends on the composition of its two DP components: TERMGEN and NOTEGEN. Specifically, TERMGEN is trained on D_{public} and can optionally be applied to privatise terms for $D_{\text{test}}^{\text{src}}$, while NOTEGEN is trained on $D_{\text{train}}^{\text{src}}$ under DP. Since TERMGEN and NOTEGEN operate on disjoint subsets of private data, the overall privacy loss can be computed using parallel composition. Formally, the total privacy guarantee (ϵ, δ) is defined as below, and the proof is provided in Appendix C.

$$(\epsilon, \delta) = (\max(\epsilon_n, \epsilon_t), \max(\delta_n, \delta_t)) \quad (4)$$

3.7 Implementation Details

SECSPLIT Clinical notes lack a universally standardised structure, and while formats such as SOAP are common, they often require manual annotation for accurate segmentation (Gao et al., 2022). To enable automatic sectioning, we analyse formatting

patterns in the raw notes and design a rule-based segmentation approach using regular expressions to identify section titles. Section spans are determined greedily, from each detected title to the next. We automatically curate a list of frequent section titles and group them into six semantic categories: *Patient Information*, *Clinical Course & History*, *Examinations & Findings*, *Laboratory & Imaging Results*, *Hospital Stay & Treatment*, and *Medications & Discharge Plan*. This taxonomy underpins SECSPLIT, which splits each note into up to six standardised sections. The full list of section titles and groupings is provided in Appendix D.

TERMEXT Biomedical vocabularies vary by taxonomy. In this work, we focus on terms from SNOMED CT, a comprehensive clinical vocabulary widely used in electronic health records (EHRs) and included in the Unified Medical Language System (UMLS) metathesaurus (U.S. NLM, 2025). To extract medical terms from clinical text, we use QuickUMLS (Soldaini, 2016), an unsupervised approximate string-matching tool over UMLS concepts, and retain only SNOMED CT terms.

Backbone Models For clinical term embeddings, we use the encoder-only model MedEmbed-large (Balachandran, 2024) as the embedder **EMB**, which is fine-tuned for medical and clinical text. For the two generative modules in Term2Note, we adopt lightweight yet effective language models: GPT2-Large (Radford et al., 2019) for the term generator **TERMGEN**, and Llama-3.2-1B (Meta, 2024) or Gemma-3-1B (Google, 2025) for the note generator **NOTEGEN**. Using both Llama and Gemma increases architectural diversity and reduces model-specific bias while enabling reproducible evaluation. To compute the perplexity of generated notes, we use Asclepius-Llama3-8B (Kweon et al., 2024b) as the reference model $\mathbf{LLM_{ppl}}$. Pre-trained on clinical text and supporting up to 8192 tokens as input, it mitigates domain mismatch and accommodates full-length clinical notes.

4 Experimental Setting

Datasets The MIMIC dataset series is one of the most widely used resources for clinical NLP. We use discharge notes from MIMIC-III (Johnson et al., 2016) and MIMIC-IV (Johnson et al., 2023) for different purposes. MIMIC-III serves as the *public* dataset to train the term generation model TERMGEN, while MIMIC-IV is treated as the *private* dataset for training the note generation model NOTEGEN under DP constraints. For both datasets, we filter out notes without associated ICD codes. We further exclude notes annotated in the SNOMED CT Entity Linking Challenge (Hardman et al., 2025) from MIMIC-IV notes and reserve them as the test set. This results in three datasets (statistics in Appendix E) for our experiments: D_{public}, with 52.7k MIMIC-III notes (500 held out for development); $D^{\text{src}}_{\text{train}}$, with 122k MIMIC-IV notes after exclusion; $D^{\text{src}}_{\text{test}}$, consisting of 204 SNOMED-annotated notes.

Hyperparameters Following common practice in previous work (Yu et al., 2021; De et al., 2022; Baumel et al., 2024), we experiment with different privacy budgets by varying the overall $\epsilon \in [2, 5, 8]$. Accordingly, the privacy budget for term generation (ϵ_t) or note generation (ϵ_n) is set to one of these values, and the corresponding δ value is set as $\frac{1}{NlogN}$ where N denotes the size of the private dataset. All experiments are conducted on up to two Nvidia A100 80GB GPUs. More training details, including learning rate, number of epochs, batch size, etc., are provided in Appendix F.

Baselines We compare our proposed method with existing DP approaches for synthetic text generation. Specifically, we consider the following baselines: (1) DP-SGD with control codes (Yue et al., 2023): fine-tuning a language model under DP constraints using DP-SGD, where task-relevant control codes are prepended to the input. To ensure consistency with the DP training setup used in Term2Note, we adapt this method to use the FastDP algorithm. (2) AUG-PE (Xie et al., 2024): a recent method based on private evolution, designed to generate synthetic text without requiring model training. For a fair comparison with Term2Note, we adapt both baselines to the clinical note generation task. Specifically, ICD codes associated with each note are prepended as control codes to guide the generation process, aligning with the conditioning setup used in our framework. For consistency in privacy accounting, we introduce ϵ_{meta} to denote the privacy budget allocated to the ICD codes, while ϵ_n denotes the privacy budget for note generation.

Evaluation Automatic evaluation of synthetic data typically considers fidelity, privacy, and utility. In this work, we focus on fidelity and utility. Privacy is formally guaranteed by DP; we additionally conduct a preliminary empirical privacy analysis

	Method	Fidelity				Utility					
		Length	Unary/Binary Term		Semantic	F1		AUC		Precision@k	
		KL Div.↓	Jaccard↑	KL Div.↓	MAUVE↑	Micro	Macro	Micro	Macro	$k=3$	$k=5$
	Original Data					57.03	30.80	82.01	58.88	68.93	62.14
Synthetic	$\epsilon = \infty$										
	AUG-PE ($\epsilon_{\text{meta}} = \infty, \epsilon_n = \infty$)	11.96	0.14/0.02	7.59/16.34	0.01	45.82	14.84	79.52	54.35	68.48	61.77
	FastDP ($\epsilon_{\text{meta}} = \infty, \epsilon_n = \infty$)	1.04	**0.53/0.28**	0.32/**0.84**	0.12	53.02	25.51	79.35	51.05	69.77	60.39
	Term2Note ($\epsilon_{\text{meta}} = \infty, \epsilon_n = \infty$)	0.25	0.52/0.20	**0.22**/1.08	**0.59**	49.95	21.89	**81.40**	**55.43**	69.77	61.96
	Term2Note ($\epsilon_t = \infty, \epsilon_n = \infty$)	0.68	0.43/0.14	0.45/1.95	0.46	49.24	21.90	80.24	51.54	67.81	61.08
	Term2Note ($\epsilon_t = \infty, \epsilon_n = 8$)	0.26	0.39/0.13	0.50/1.19	0.35	48.16	20.63	78.72	50.01	65.35	58.72
	Term2Note ($\epsilon_t = \infty, \epsilon_n = 5$)	0.28	0.38/0.13	0.53/1.23	0.27	51.00	22.73	78.80	50.37	67.15	59.91
	Term2Note ($\epsilon_t = \infty, \epsilon_n = 2$)	0.43	0.37/0.12	0.60/1.35	0.36	48.57	20.31	79.56	51.75	68.64	60.41
	$\epsilon = 8$										
	AUG-PE ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 8$)	11.71	0.19/0.03	5.03/12.18	0.01	40.73	13.28	78.13	53.49	63.24	59.03
	FastDP ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 8$)	4.51	0.31/0.10	2.88/5.88	0.02	48.58	16.40	80.74	51.57	**69.79**	61.59
	Term2Note ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 8$)	0.39	0.40/0.13	0.47/1.14	0.53	49.71	21.28	80.03	52.80	67.49	61.48
	Term2Note ($\epsilon_t = 8, \epsilon_n = 8$)	0.16	0.38/0.13	0.62/1.15	0.37	52.31	26.50	78.19	50.17	67.81	57.36
	Term2Note ($\epsilon_t = 5, \epsilon_n = 8$)	**0.15**	0.39/0.13	0.64/1.16	0.46	49.52	21.36	79.08	50.11	68.29	60.68
	Term2Note ($\epsilon_t = 2, \epsilon_n = 8$)	0.19	0.38/0.12	0.61/1.18	0.38	53.25	24.66	78.85	49.41	68.31	59.91
	$\epsilon = 5$										
	AUG-PE ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 5$)	11.70	0.11/0.01	7.75/13.58	0.01	48.10	17.44	77.78	53.33	63.01	56.94
	FastDP ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 5$)	3.40	0.29/0.09	2.97/5.67	0.04	49.30	16.23	80.54	54.22	67.31	**61.98**
	Term2Note ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 5$)	0.20	0.41/0.14	0.42/1.17	0.39	47.94	20.31	79.29	51.19	66.04	61.69
	Term2Note ($\epsilon_t = 5, \epsilon_n = 5$)	0.20	0.38/0.13	0.63/1.19	0.43	**54.83**	**28.96**	78.20	50.32	64.56	57.18
	Term2Note ($\epsilon_t = 2, \epsilon_n = 5$)	0.36	0.38/0.12	0.64/1.32	0.36	51.26	21.45	79.05	50.44	66.36	60.49
	$\epsilon = 2$										
	AUG-PE ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 2$)	12.11	0.19/0.03	5.42/11.85	0.01	40.90	13.57	78.29	53.38	63.74	60.10
	FastDP ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 2$)	9.67	0.14/0.03	5.79/10.89	0.01	51.06	20.04	79.98	51.31	66.32	59.99
	Term2Note ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 2$)	0.43	0.39/0.12	0.48/1.17	0.31	51.78	23.36	79.00	50.60	67.00	59.52
	Term2Note ($\epsilon_t = 2, \epsilon_n = 2$)	0.48	0.37/0.12	0.68/1.29	0.31	51.87	23.06	79.43	51.30	69.45	60.31

Table 1: Fidelity and utility evaluation of synthetic datasets generated by different methods on Llama-3.2-1B. $\epsilon_{\text{meta}} = \infty$ indicates that note generation is conditioned on ground-truth labels, i.e., no perturbation is applied to the input labels, whereas ϵ_t indicates that the input labels are privatised by the model. Utility metrics are reported with the average score across 5-fold cross-validation. The **best result** among all methods to generate synthetic datasets is shown in bold, and the best result at the same privacy cost is underlined. Additional results on Gemma-3-1B, as well as further evaluation results, including the standard deviations of utility metrics and precision and recall scores, are provided in Appendix I.

to assess potential leakage, with results presented in Appendix G, showing encouraging outcomes.

Fidelity assesses how closely synthetic notes resemble real data across structural, syntactic, and semantic dimensions. Structural similarity is measured by comparing text length distributions using Kullback–Leibler (KL) divergence. Syntactic similarity is evaluated via clinical term overlap, measured by Jaccard similarity and KL divergence over unary and binary term sets, where binary terms refer to co-occurring term pairs within a note. Semantic similarity is assessed using MAUVE (Pillutla et al., 2021), which compares global distributional similarity in an embedding space. We use BioMistral-7B (Labrak et al., 2024) to obtain domain-relevant semantic representations.

Utility evaluates the usefulness of synthetic notes for downstream clinical tasks. We consider **ICD coding prediction**, where a model predicts all applicable ICD codes given a discharge note. To reduce label sparsity, we normalise ICD-9 and ICD-10 codes to chapter-level categories and merge them into 20 unified groups (mapping provided in Appendix H). We compare two training settings: (1) Train-Real-Test-Real, where the model is trained and evaluated on real data, and (2) Train-Synthetic-Test-Real, where training uses synthetic data and evaluation uses real data. Performance is reported using standard multi-label metrics, including micro- and macro-averaged F1 and AUC, as well as Precision@k. We adopt Clinical-Longformer (Li et al., 2023b) as the classifier due to its support for long clinical documents and pretraining on clinical corpora. Evaluation is conducted on the private test set $D^{\text{src}}_{\text{test}}$ (204 notes), which is split into training and testing subsets. The classifier is trained on $D^{\text{src/syn}}_{\text{test-train}}$ and evaluated on $D^{\text{src}}_{\text{test-test}}$. Owing to the limited data size, we use 5-fold cross-

validation with an 80:20 train–test split.

Human Evaluation is additionally conducted with three licensed physicians to assess the clinical quality of the generated notes. The evaluation follows a pairwise comparison protocol, where each physician is presented with a randomly selected pair of notes and asked to indicate which one is clinically better. The pairs are sampled from outputs generated by three different models under $\epsilon = 8$, as well as from the original (real) notes. Each physician evaluates a minimum of 100 pairs, resulting in a total of 412 pairwise comparisons across all annotators. Based on these annotations, we estimate pairwise model preferences and infer a global ranking using the Bradley-Terry (BT) (Bradley and Terry, 1952) model. The BT model also allows us to estimate the probability that one model $\mathcal{M}_1$ is preferred over another model $\mathcal{M}_2$, based on the aggregated comparison outcomes.

5 Results

Table 1 presents the main results.

Term2Note consistently achieves better structural, syntactic, and semantic similarity to the original data, despite operating under stronger privacy constraints and fewer assumptions. In terms of *structural similarity*, Term2Note achieves the lowest KL divergence in text length distribution (as low as 0.15), indicating faithful preservation of note structure. For *syntactic similarity*, it obtains the (almost) highest Jaccard scores for both unary and binary clinical terms, alongside the lowest KL divergence in term frequency distribution, suggesting close alignment with real clinical content. In *semantic space*, Term2Note substantially outperforms both baseline methods in MAUVE score, confirming that its generated text is significantly more aligned with the original notes in the semantic space. These advantages remain even under a strict privacy budget of $\epsilon = 2$ and when further enforcing DP on clinical term generation (i.e., $\epsilon_t = 2$), underscoring the robustness of the approach. Additionally, Figure 2 shows the distribution of n-gram frequencies, where Term2Note exhibits a distribution more closely aligned with the original notes compared to the baseline methods. More results are presented in Appendix I.

Regarding utility, Term2Note demonstrates strong overall performance and consistently preserves clinical utility across varying privacy budgets, even under stricter constraints on both term and note generation. Across all privacy levels, Term2Note achieves the highest F1 scores, outperforming both AUG-PE and FastDP, and showing the closest performance to the original data. While AUC and Precision@k scores are comparable, rather than uniformly superior, to those of AUG-PE and FastDP, this variation reflects the different aspects of model behaviour captured by each metric. Notably, even when the privacy budget for note generation is reduced to $\epsilon_n = 2$ and additional constraints are applied to privatise clinical terms (with $\epsilon_t = 2$), Term2Note maintains strong utility, with F1 and AUC scores comparable to or better than the baselines operating under looser privacy conditions.

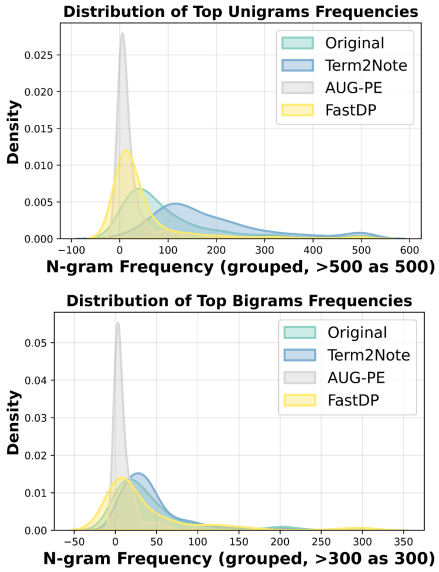

Figure 2: Distribution of n-gram frequencies in clinical notes generated by different DP methods under $\epsilon = 8$. Note: density estimates may extend below zero due to smoothing; all observed frequencies are positive integers.

Term2Note is consistently preferred by human experts over AUG-PE, with minimal quality loss under full privacy. As shown in Figure 3, Term2Note achieves a win rate of 52.2%–53.5% across DP settings, substantially outperforming AUG-PE (12.4%). The pairwise win probabilities (lower panel) further demonstrate that Term2Note reliably outperforms AUG-PE across all conditions. Importantly, introducing full privacy constraints, where both clinical terms and notes are protected, has only a marginal effect on human preference. These results suggest that Term2Note maintains high perceived quality while offering stronger privacy guarantees.

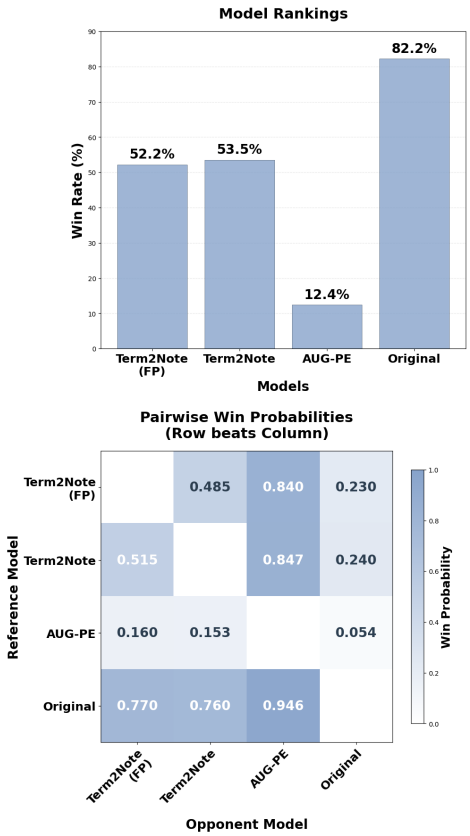

Figure 3: Human evaluation results summarised using the BT model. Term2Note (FP) denotes the *full privacy* setting, where both terms and notes are synthesised under DP constraints.

Term privatisation maintains a good level of semantic coherence while effectively abstracting away from potentially privacy-leaking details. We evaluate the semantic alignment of the term generation model **TERMGEN** on $D_{\text{test}}^{\text{src}}$ by computing the cosine similarity between the embeddings of original and generated term lists, using the clinical term encoder EMB. Without the DP mechanism DPRP*, the mean cosine similarity is high (0.82), indicating strong recovery of original terms. When DPRP* is applied, the mean similarity drops to 0.61, reflecting the expected privacy-induced noise. This drop indicates that the generated terms stay semantically coherent without closely matching the originals, reducing the risk of revealing sensitive information (see Appendix J for case studies).

Qualitative Analysis To further assess the quality of synthetic notes, two physicians each reviewed 20 samples generated by Term2Note, covering both standard and full privacy settings with $\epsilon = 5$. As intended by the design of the evaluation, where ***physicians were explicitly asked to identify any potential clinical issues, the feedback focuses on shortcomings rather than general plausibility***. Importantly, not all notes contained identifiable issues. In one physician's review, 45% were judged to have no clinical problems, indicating that a substantial proportion of generations were considered clinically plausible. **Both physicians agreed that many synthetic notes were plausible as discharge summaries and generally exhibited sound structural organisation.** However, recurring issues emerged around clinical accuracy and coherence. The first physician highlighted problems such as missing or misordered sections, internal inconsistencies (e.g., conflicting medications), and vague or overly generic phrasing; under full privacy constraints, repetition was more common. The second physician, who reviewed a different set of examples, reported more content-level issues, including medication misclassifications (e.g., labelling omeprazole as an antibiotic), illogical or irrelevant narrative insertions, and errors in clinical reasoning. These observations suggest that while Term2Note performs well in preserving structural fidelity, improvements are needed in clinical fact consistency and terminology use. Figure 5 illustrates examples of final note sections, demonstrating the model's ability to maintain coherence in longer contexts. Although Term2Note occasionally omits sections, its outputs more closely align with the structure of the original note compared to the baseline model.

6 Conclusions

In this paper, we introduce Term2Note, a novel framework for DP clinical note generation that synthesises section-wise content conditioned on medical terms while providing formal privacy guarantees. Experiments show that Term2Note consistently outperforms existing baselines, achieving the highest fidelity and closely matching real notes in structure, semantics, and medical term distributions. Models trained on Term2Note's synthetic data achieve utility comparable to real data on an ICD coding task, demonstrating strong practical effectiveness. Human evaluation further confirms its advantages, with clinical experts consistently preferring its outputs over those of baseline methods. Overall, Term2Note provides a promising and principled solution to data scarcity in healthcare NLP by enabling high-quality, privacy-preserving clinical note generation and facilitating privacy-conscious data sharing.

Limitations

Utility metrics exhibit some instability across privacy budgets; performance does not always degrade monotonically as the budget decreases. This may stem from label imbalance relative to training data size, which poses challenges for multi-label prediction when certain labels have limited training examples. Term2Note is currently tailored to clinical notes, while other forms of clinical narratives remain unexplored. Nevertheless, it demonstrates the broader applicability of generating clinical content from medical terms, which could be extended to additional clinical text formats in future work. Qualitative feedback also reveals limitations in clinical reliability. In particular, ensuring factual correctness and avoiding clinical inconsistencies (e.g., incorrect medication classes or contradictory clinical states) remain challenging. Future work could integrate clinical fact-checking mechanisms, structured consistency checks (e.g., validating medications against conditions), or lightweight clinical reasoning modules, either during decoding or as post-generation filters. We view these extensions as natural directions to further improve the clinical safety and usefulness of Term2Note.

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A Example Demonstration

Figure 4 presents the detailed process in Term2Note with example for each step.

Figure 5 presents examples of generation from different models.

B Algorithm Pseudocode

Algorithm 1 presents the pseudocode for Term2Note.

Algorithm 2 presents the pseudocode for DPRP*.

C Privacy Proof

Proof. We prove that for the full privatisation setting ($T_i = T_i^{\text{syn}}$), Term2Note achieves $(\max(\epsilon_n, \epsilon_t), \max(\delta_n, \delta_t))$-DP by applying the parallel composition theorem.

Step 1: Parallel Composition Lemma

First, we establish the parallel composition property.

Lemma 3 (Parallel Composition)**.** Let dataset $D = D_1 \cup D_2$, and $D_1 \cap D_2 = \emptyset$. Let $\mathcal{M}_1 : \mathbb{N}^{|\mathcal{X}_1|} \to R_1$ be (ϵ_1, δ_1)-DP and $\mathcal{M}_2 : \mathbb{N}^{|\mathcal{X}_2|} \to R_2$ be (ϵ_2, δ_2)-DP. Then $\mathcal{M}(D) = (\mathcal{M}_1(D_1), \mathcal{M}_2(D_2))$ is $(\max(\epsilon_1, \epsilon_2), \max(\delta_1, \delta_2))$-DP.

Proof of Lemma. Let D and D' be neighboring datasets differing by one record. Since $D_1 \cap D_2 = \emptyset$, the differing record is in either D_1 or D_2, but not both.

Case 1: The differing record is in D_1, so $D_1 \neq D_1'$ but $D_2 = D_2'$.

For any measurable sets $B_1 \subseteq R_1, B_2 \subseteq R_2$:

$$
\begin{aligned}
&P[\mathcal{M}(D) \in B_1 \times B_2] \\
&= P[\mathcal{M}_1(D_1) \in B_1] \cdot P[\mathcal{M}_2(D_2) \in B_2] \\
&\leq \left(e^{\epsilon_1} P[\mathcal{M}_1(D_1') \in B_1] + \delta_1\right) \cdot P[\mathcal{M}_2(D_2) \in B_2] \\
&= \left(e^{\epsilon_1} P[\mathcal{M}_1(D_1') \in B_1] + \delta_1\right) \cdot P[\mathcal{M}_2(D_2') \in B_2] \\
&= e^{\epsilon_1} P[\mathcal{M}(D') \in B_1 \times B_2] + \delta_1 P[\mathcal{M}_2(D_2') \in B_2] \\
&\leq e^{\epsilon_1} P[\mathcal{M}(D') \in B_1 \times B_2] + \delta_1
\end{aligned}
$$

Case 2: The differing record is in D_2, so $D_1 = D_1'$ but $D_2 \neq D_2'$. Similarly:

$$
P[\mathcal{M}(D) \in B_1 \times B_2] \leq e^{\epsilon_2} P[\mathcal{M}(D') \in B_1 \times B_2] + \delta_2
$$

Combining cases: For arbitrary neighbouring datasets, we have:

$$
\begin{aligned}
&P[\mathcal{M}(D) \in B_1 \times B_2] \\
&\leq e^{\max(\epsilon_1, \epsilon_2)} P[\mathcal{M}(D') \in B_1 \times B_2] + \max(\delta_1, \delta_2)
\end{aligned}
$$

Therefore, $\mathcal{M}$ is $(\max(\epsilon_1, \epsilon_2), \max(\delta_1, \delta_2))$-DP. □

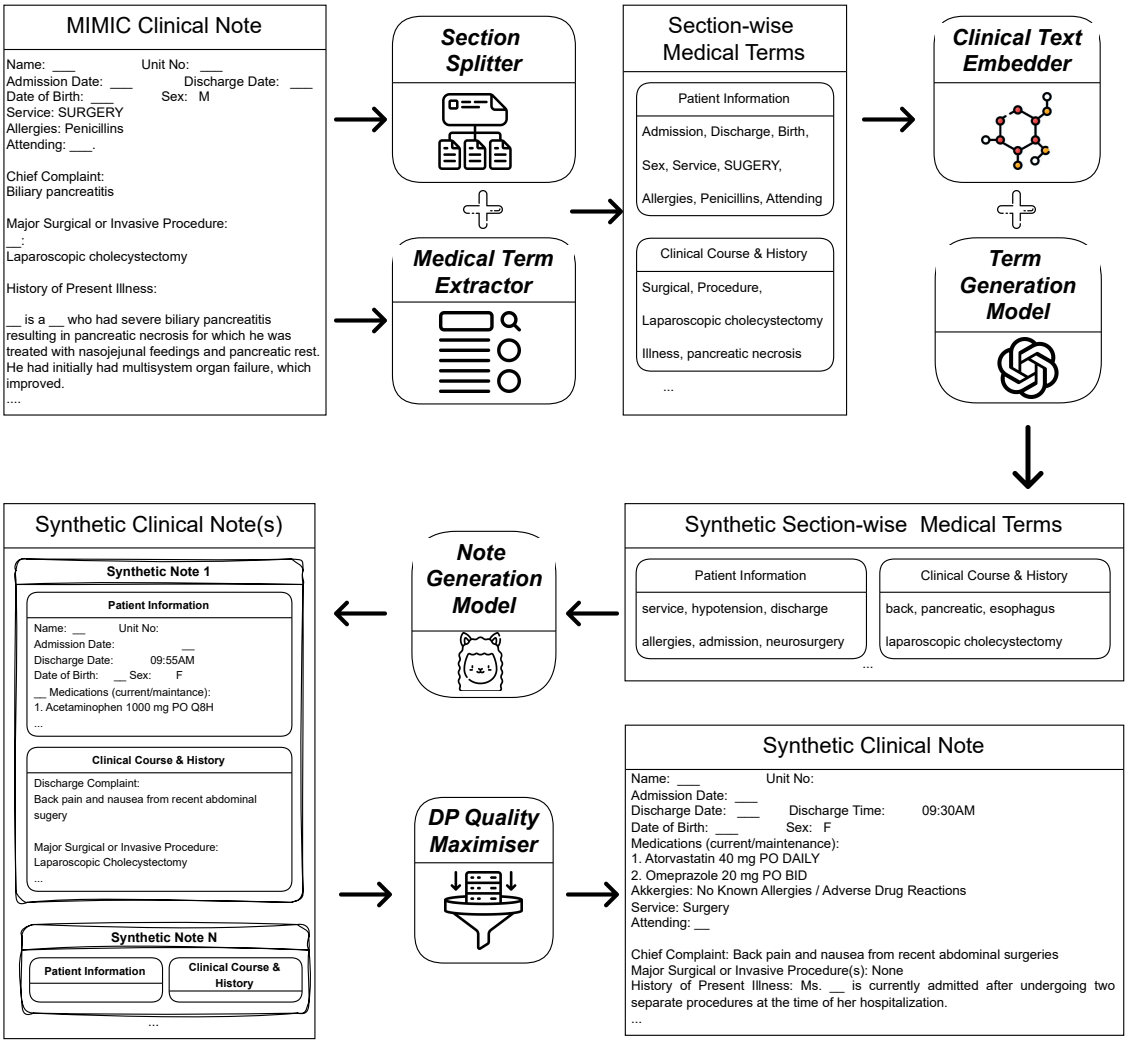

Figure 4: Example to demonstrate Term2Note.

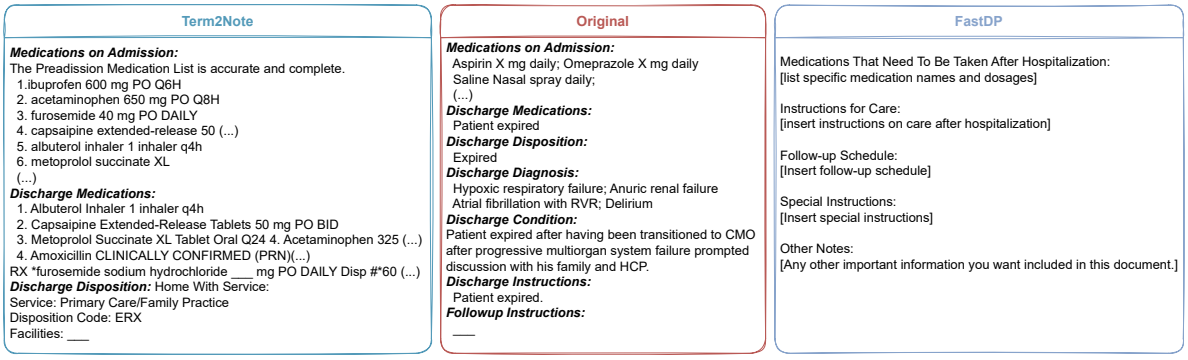

Figure 5: Examples of the last section in clinical notes generated by different models. For illustration purposes, some content is redacted with "(...)", and numeric values in the original note are de-identified. No other modifications were made.

Algorithm 1 Term2Note

Input: Private note X^{src}, public term lists D_{public}, privacy parameters for term generation (ϵ_t, δ_t) and note generation (ϵ_n, δ_n), #sections m, instruction I, noise variance σ_{emb}, #candidates k

Output: Synthetic note X^{syn} with (ϵ, δ)-DP guarantee

$\text{SEC}^{\text{src}}_{1:m} \leftarrow \textsc{SecSplit}(X^{\text{src}})$ **// 3.2 Format and Term Identification**

$T^{\text{src}}_{1:m} \leftarrow \textsc{TermExt}(\text{SEC}^{\text{src}}_{1:m})$

$E^{\text{src}}_{1:m}, E_{\text{public}} \leftarrow \textsc{Emb}(T^{\text{src}}_{1:m}), \textsc{Emb}(D_{\text{public}})$ **// 3.3 Clinical Terms Generation**

if train **then**

  $\theta_t, \theta_p \leftarrow \mathcal{L}(\textsc{TermGen}_{\theta_t}(\textsc{Proj}_{\theta_p}(E_{\text{public}} + \mathcal{N}(0, \sigma_{\text{emb}}))), D_{\text{public}})$ // Train on D_{public}

else

  $T^{\text{syn}}_{1:m} \sim \textsc{TermGen}_{\theta_t}(\textsc{Proj}_{\theta_p}(\text{DPRP}^*(E^{\text{src}}_{1:m}, \frac{\epsilon_t}{m}, \frac{\delta_t}{m})))$ // Infer for X^{src}

end if

if train **then**

  $\theta_n \leftarrow \text{FastDP}(\mathcal{L}(\textsc{NoteGen}_{\theta_n}(I, \text{SEC}^{\text{src}}_{<i}, T^{\text{src}}_i), X^{\text{src}}), \epsilon_n, \delta_n)$ **// 3.4 Clinical Note Generation**

end if

$\text{SEC}^{\text{syn}}_j[i] \sim \textsc{NoteGen}_{\theta_n}(I, \text{SEC}^{\text{syn}}_{<j}[i], T^{\text{src / syn}}_j)$ **for** $i = 1, \ldots, k; j = 1, \ldots, m$

$X^{\text{syn}} \leftarrow \arg\min_{i \in [k]} \text{PPL}(\text{SEC}^{\text{syn}}_{1:m}[i])$ **// 3.5 DP Quality Maximiser**

return X^{syn}

Algorithm 2 DPRP*

Input: Embeddings E, privacy parameters (ϵ, δ) , privacy allocation $b = 0.85$

Output: Privatised Embeddings E_{DP} with (ϵ, δ)-DP

$(\epsilon_1, \delta_1), (\epsilon_2, \delta_2) \leftarrow 0.85 * (\epsilon, \delta), 0.15 * (\epsilon, \delta)$

Derive σ_i from $(\epsilon_{1i}, \delta_{1i})$; $i \in [1, 2]$

$E' = E + \mathcal{N}(0, \sigma_1^2)$

$E'_C = E^T E + \mathcal{N}(0, \sigma_2^2)$

$V' \Sigma' V'^T = \text{SVD}(E'_C)$

$V'_k = V'[1, ..., k]; k = 0.6 * E_{\text{hdim}}$

$E_{\text{DP}} = E' V'^{T+}_k V'^T_k$ // + refers to the Moore-Penrose pseudoinverse

return E_{DP}

Step 2: Application to Term2Note

Now we apply the parallel composition lemma to Term2Note.

We have:

- $\mathcal{M}_1 = \textsc{NoteGen}$ training on D_{train}, which is (ϵ_n, δ_n)-DP
- $\mathcal{M}_2 = \textsc{TermGen}$ processing on D_{test}, which is (ϵ_t, δ_t)-DP
- $D_{\text{train}} \cap D_{\text{test}} = \emptyset$

Term2Note can be written as:

$$\text{Term2Note}(D) = f(\mathcal{M}_1(D_{\text{train}}), \mathcal{M}_2(D_{\text{test}}))$$

where f is a deterministic function that applies the trained NOTEGEN model to the synthetic terms from TERMGEN.

Since f is a post-processing function applied to the outputs of the parallel composition, and post-processing preserves differential privacy, we have:

$$\text{Term2Note}(D) \text{ is } (\max(\epsilon_n, \epsilon_t), \max(\delta_n, \delta_t))\text{-DP}$$

□

D Section Grouping

Table 2 presents the section grouping taxonomy for our SECSPLIT.

E Dataset Statistics

Table 3 summarises key statistics of the three datasets used in this study, including the number of clinical notes, and average note length, among other relevant attributes.

Group Name	Sections
Patient Information	"Name", "Unit No", "Admission Date", "Discharge Date", "Date of Birth", "Sex", "Service", "Allergies", "Attending"
Clinical Course & History	"Chief Complaint", "Major Surgical or Invasive Procedure", "History of Present Illness", "Review of Systems", "Past Medical History", "Social History", "Family History"
Examinations & Findings	"Physical Exam"
Laboratory & Imaging Results	"Pertinent Results"
Hospital Stay & Treatment	"Brief Hospital Course"
Medications & Discharge Plan	"Medications on Admission", "Discharge Medications", "Discharge Disposition, "Discharge Diagnosis", "Discharge Condition", "Discharge Instructions", "Followup Instructions"

Table 2: The grouped section titles.

Corpus	MIMIC-III	MIMIC-IV	
Dataset	D_{public}	$D^{\text{src}}_{\text{train}}$	$D^{\text{src}}_{\text{test}}$
# notes	52,722	122,202	204
avg. # tokens	3327.93	3360.60	2818.63
avg. # sections	4.59	5.77	5.79
avg. # terms	176.26	203.20	173.33
avg. # ICD codes	-	-	6.73

Table 3: Dataset statistics. avg. refers to the average of. # tokens is calculated by taking the average of tokens in each note, tokenised by Llama-3.2-1B-Instruct.

F Hyperparameters

TERMGEN We fine-tune GPT-2-large on section-wise clinical terms extracted from D_{public} for up to 5 epochs. The final model is selected based on the checkpoint with the highest F1 score, evaluated on a held-out set of 500 notes. During training, we set the embedding perturbation scale $\sigma_{\text{emb}} = 0.05$, with a batch size of 8 and a learning rate of 2e-5. At inference, we use a batch size of 16 and a maximum generation length of 512 tokens. To ensure reproducibility, decoding is performed with a temperature of 0.1 and top-p set to 1.0.

NOTEGEN **Training:** We fine-tune Llama-3.2-1B-Instruct or Gemma-3-1B-IT on $D^{\text{src}}_{\text{train}}$ for up to 2 epochs using 2 GPUs. The batch size per device is 2, with a gradient accumulation step of 64 and a learning rate of 5e-5. We enable DeepSpeed ZeRO Stage 3 to optimise memory usage. **Inference:** We adapt vLLM for faster generation, with decoding parameters set as temperature = 0.1, top-p = 1.0, repetition penalty = 1.2 and max tokens per section = 2048 across all experiments. Llama-3.2 tends to generate overly long outputs during section-wise generation, so we apply a logit bias on the EOS token to encourage early stopping. This bias is set between 0.5 and 6.0: for DP-enabled models, the value is 0.5 or 1.0; for the non-private setting ($\epsilon = \infty$), it is set to 6.0. Additionally, DP-enabled models use a frequency penalty of 0.4 to further discourage repetition.

For the FastDP baseline, which produces relatively short outputs, we apply only a repetition penalty during inference. Before applying the DP quality maximiser, we generate multiple candidates per input: 4 for Term2Note and FastDP, and 7 for AUG-PE, using the same decoding settings described above.

G Distance-based Privacy Evaluation

A preliminary privacy evaluation is conducted to assess the privacy-preserving properties of the synthetic clinical notes using a membership inference attack (MIA) framework. We compare the distribution of minimum cosine distances between the synthetic notes generated by Term2Note and the original training data to a baseline of real, non-member test notes. As illustrated in Figure 6, the synthetic notes are, on average, located significantly further from the training data than the test notes. Notably, the setting with $\epsilon_n = \infty$, which is generated without DP, exhibited the most overlap with the test set's distribution. This expected outcome highlights the privacy benefits of the other DP settings, and provides a clear baseline for comparison.

In future work, we intend to expand our privacy evaluation using canary-based membership inference attacks. This approach involves injecting specially crafted canaries into the training data to establish a worst-case lower bound on privacy risks.

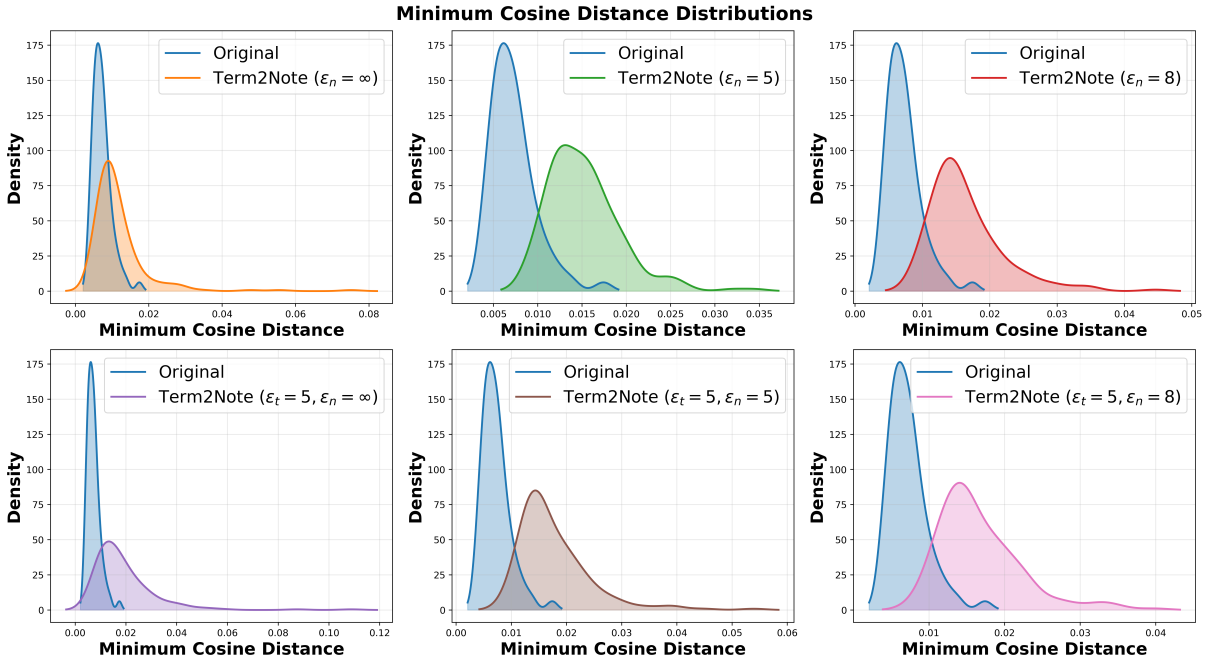

Figure 6: Distribution of minimum cosine distances for all evaluated synthetic strategies compared to the baseline of original test notes. Here, ϵ_t and ϵ_n are the privacy budgets for TERMGEN and NOTEGEN, respectively.

H ICD Codes Grouping

Table 4 shows the mapping between our combined ICD categories and the corresponding ICD-9 and ICD-10 chapter headings. For fine-tuning Clinical-Longformer on this classification task, we train for 30 epochs per setting (i.e., model and data fold), with a batch size of 8 and a learning rate of 2e-5.

I Supplementary Experimental Results

I.1 Fidelity

Table 5 presents supplementary fidelity evaluation results, including an ablation analysis of the DP Quality Maximiser. These results further support the effectiveness of our approach in preserving structural and semantic fidelity under DP constraints.

Larger Model We present preliminary results using a larger model, Llama-3.3-70B, evaluated with two non-private methods: Retrieval-Augmented Generation (RAG) and LoRA-based fine-tuning. In the RAG setup, we retrieve the top-5 most similar sections from the training set $D^{\text{src}}_{\text{train}}$ to assist section-wise generation. While neither approach offers privacy guarantees, they serve as reference points for performance with large-scale models. As shown in the results, fine-tuning significantly outperforms RAG, highlighting the importance of parameter adaptation for note synthesis. However, the high computational cost of fine-tuning such large models motivates our focus on efficient methods based on smaller models, such as the 1B-parameter version used in Term2Note.

DP Quality Maximiser We evaluate the effectiveness of our proposed DP quality maximiser on models trained with $\epsilon = 8$. As shown in the results, it consistently improves MAUVE scores for both Term2Note and FastDP. For FastDP, improvements extend across all fidelity metrics, highlighting the value of the maximiser in enhancing output quality under DP constraints.

Beyond perplexity, we investigate a range of reference-free (RF) metrics to guide the selection of high-quality generations, including maximum and mean sentence length (in words and characters), self-BLEU, and distinct-n variants. To evaluate these metrics, we manually annotate a small set of synthetic sections as "good" or "bad" based on readability, with approximately 12% labelled as "bad". Metrics are evaluated on their ability to identify these poor-quality sections via scalar thresholds. We then assess how well each metric identifies poor-quality sections using scalar thresholds. Our results indicate that metrics based on sentence length—particularly maximum sentence character count—align most closely with human annotations. A rejection threshold of 2181 characters yields the strongest correspondence. Table 6

Combined ICD Category	ICD-9	ICD-10
Certain Infectious And Parasitic Diseases	Infectious And Parasitic Diseases	Certain Infectious And Parasitic Diseases
Neoplasms	Neoplasms	Neoplasms
Endocrine, Nutritional And Metabolic Diseases, And Immunity Disorders	Endocrine, Nutritional And Metabolic Diseases, And Immunity Disorders	Endocrine, Nutritional And Metabolic Diseases
Diseases Of The Blood And Blood-Forming Organs And Certain Disorders Involving The Immune Mechanism	Diseases Of The Blood And Blood-Forming Organs	Diseases Of The Blood And Blood-Forming Organs And Certain Disorders Involving The Immune Mechanism
Mental And Behavioural Disorders	Mental Disorders	Mental And Behavioural Disorders
Diseases Of The Nervous System And Sense Organs	Diseases Of The Nervous System And Sense Organs	Diseases Of The Nervous System
Diseases Of The Circulatory System	Diseases Of The Circulatory System	Diseases Of The Circulatory System
Diseases Of The Respiratory System	Diseases Of The Respiratory System	Diseases Of The Respiratory System
Diseases Of The Digestive System	Diseases Of The Digestive System	Diseases Of The Digestive System
Diseases Of The Genitourinary System	Diseases Of The Genitourinary System	Diseases Of The Genitourinary System
Complications Of Pregnancy, Childbirth, And The Puerperium	Complications Of Pregnancy, Childbirth, And The Puerperium	Complications Of Pregnancy, Childbirth, And The Puerperium
Diseases Of The Skin And Subcutaneous Tissue	Diseases Of The Skin And Subcutaneous Tissue	Diseases Of The Skin And Subcutaneous Tissue
Diseases Of The Musculoskeletal System And Connective Tissue	Diseases Of The Musculoskeletal System And Connective Tissue	Diseases Of The Musculoskeletal System And Connective Tissue
Congenital Malformations, Deformations And Chromosomal Abnormalities	Congenital Anomalies	Diseases Of The Musculoskeletal System And Connective Tissue
Congenital Malformations, Deformations And Chromosomal Abnormalities	-	Congenital Malformations, Deformations And Chromosomal Abnormalities
Certain Conditions Originating In The Perinatal Period	Certain Conditions Originating In The Perinatal Period	Certain Conditions Originating In The Perinatal Period
Symptoms, Signs And Abnormal Clinical And Laboratory Findings, Not Elsewhere Classified	Symptoms, Signs, And Ill-Defined Conditions	Symptoms, Signs And Abnormal Clinical And Laboratory Findings, Not Elsewhere Classified
Injury, Poisoning And Certain Other Consequences Of External Causes	Injury And Poisoning	Injury, Poisoning And Certain Other Consequences Of External Causes
External Causes Of Morbidity And Mortality, Injusy and Poisoning	External Causes Of Injury And Poisoning	External Causes Of Morbidity And Mortality, Injusy and Poisoning
Factors Influencing Health Status And Contact With Health Services	Factors Influencing Health Status And Contact With Health Services	Factors Influencing Health Status And Contact With Health Services
Diseases Of The Eye And Adnexa	-	Diseases Of The Eye And Adnexa
Diseases Of The Ear And Mastoid Process	-	Diseases Of The Ear And Mastoid Process
Codes For Special Purposes	-	Codes For Special Purposes

Table 4: The grouped ICD codes.

reports the KL divergence and MAUVE values of synthetic notes after integrating this metric into the inference process. Specifically, if a generated section exceeds the threshold, it is discarded and regenerated until acceptance. Incorporating this simple criterion yields measurable improvements, suggesting that lightweight, reference-free filters can enhance the realism of DP synthetic text. Future work may extend this approach by combining multiple RF metrics for greater robustness.

Comparison under $\epsilon = 8$ Figure 7 shows the distribution of sequence lengths for clinical notes generated by different methods under a fixed privacy budget of $\epsilon = 8$. While all synthetic methods shift the length distribution away from the original data to some extent, Term2Note exhibits the closest alignment. Its distribution captures the broad length range and multi-modal structure of the original notes more faithfully than the baselines. In contrast, AUG-PE produces much shorter and more narrowly distributed sequences, indicating a loss of structural richness. FastDP also generates relatively short sequences, with a sharp peak around 500 tokens. These deviations suggest that Term2Note is better able to preserve the structural properties of real clinical notes, which is crucial for downstream utility and realism in synthetic data.

I.2 Utility

Table 7 presents the detailed precision and recall scores for the downstream task evaluation.

		Length		Unary/Binary Term		Semantic
		mean	KL Div.↓	Jaccard↑	KL Div.↓	MAUVE↑
	Original Data	2819	-	-	-	-
Synthetic	$\epsilon = \infty$					
	AUG-PE	282	11.96	0.14/0.02	7.59/16.34	0.01
	Term2Note	3552	**0.25**	0.52/0.20	0.22/1.08	**0.59**
	Term2Note (Llama-3.3-70b 4-bit)	4115	0.87	**0.55/0.23**	**0.17/2.23**	0.38
	RAG (Llama-3.3-70b)	3220	0.75	0.43/0.17	0.62/1.60	0.22
	$\epsilon = 8$					
	AUG-PE	203	11.71	0.19/0.03	5.03/12.18	0.01
	FastDP	961	4.51	0.31/0.10	2.88/5.88	0.02
		449.25±148.65	7.79±2.03	0.25±.03/0.07±.02	3.53±.48/5.37±1.16	0.01±.0
	Term2Note	3768	0.39	0.40/0.13	0.47/1.14	0.53
		3364.43±118.37	0.39±.11	0.41±.0/0.13±.0	0.43±.01/1.14±.02	0.42±.13

Table 5: Supplementary results for fidelity evaluation: text length, term distribution, and semantic similarity (MAUVE). The **best result** among all methods to generate synthetic datasets is shown in bold, and the best result at the same privacy cost is underlined. Values in gray are aggregated across multiple inferences without DP quality maximiser applied.

Dataset	KL Divergence↓	MAUVE↑
w/o RF metric	1.99±0.37	0.24±0.04
w/ RF metric	1.03±0.10	0.36±0.07

Table 6: Fidelity evaluation of synthetic notes generated with and without integrating the RF metric (maximum sentence character count) into the inference process.

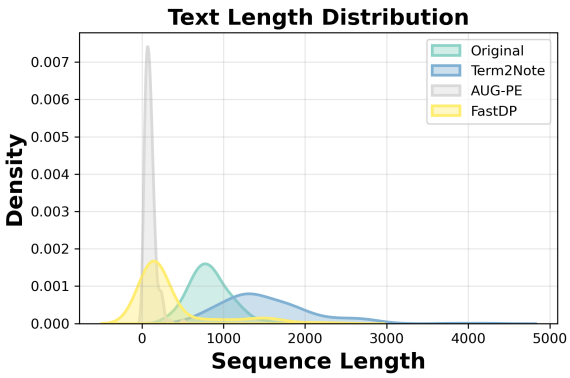

Figure 7: Text length distribution.

I.3 Gemma

Experimental results for Gemma are reported in Table 8. Both fidelity and utility metrics are comparable to those of Llama in Table 1, although the MAUVE score for Gemma without DP (i.e., $\epsilon = \infty$) is higher than that of Llama. Overall, the same trend holds across both models: stricter privacy guarantees lead to reduced fidelity, while full privatisation still preserves strong fidelity and utility.

J Case Studies for Term Generation

Table 9 presents examples of synthetic clinical terms generated with and without the application of DPRP*. The original list contains five salient terms extracted from a real clinical note. When no DP is applied, the generated list recovers only two of these terms ("air" and "discharge"), suggesting limited coverage despite the absence of privacy constraints. In contrast, the DP-enabled output does not directly replicate any of the original terms beyond "discharge", but instead generates a substantially longer and more diverse list of medically plausible terms.

This illustrates a key trade-off: the DP mechanism introduces sufficient variability to obscure direct term recovery, thus enhancing privacy protection. At the same time, the generated list remains semantically coherent and clinically relevant, containing realistic phrases such as "hemodynamically stable," "chronic low back pain," and "pulmonary vein," which contribute to the naturalness and utility of the resulting synthetic note. These findings align with our earlier quantitative analysis, confirming that DPRP* balances semantic fidelity with privacy-preserving diversity.

	Method	F1		Precision		Recall		AUC		Precision@k	
		Micro	Macro	Micro	Macro	Micro	Macro	Micro	Macro	$k=3$	$k=5$
	Original Data	57.03±3.59	30.80±2.20	60.14±4.51	34.66±4.56	54.40±4.26	30.88±2.66	82.01±1.36	58.88±2.73	68.93±4.53	62.14±3.20
Synthetic	$\epsilon = \infty$										
	AUG-PE ($\epsilon_{\text{meta}} = \infty, \epsilon_n = \infty$)	45.82±2.33	14.84±2.97	67.30±5.10	17.91±5.33	34.94±3.19	16.27±2.67	79.52±1.23	54.35±1.75	68.48±6.11	61.77±3.03
	Fast-DP ($\epsilon_{\text{meta}} = \infty, \epsilon_n = \infty$)	53.02±3.03	25.51±1.92	56.19±5.62	26.83±2.31	50.99±6.67	27.27±4.23	79.35±1.55	51.05±2.48	69.77±4.99	60.39±4.44
	Term2Note ($\epsilon_{\text{meta}} = \infty, \epsilon_n = \infty$)	49.95±4.77	21.89±3.90	65.37±6.31	28.69±1.26	41.02±6.64	21.05±3.86	81.40±1.78	55.43±2.40	69.77±3.52	61.96±5.70
	Term2Note ($\epsilon_t = \infty, \epsilon_n = \infty$)	49.24±2.63	21.9±2.01	61.07±4.02	26.75±2.9	41.61±4.73	21.64±3.29	80.24±1.56	51.54±1.81	67.81±3.66	61.08±3.71
	Term2Note ($\epsilon_t = \infty, \epsilon_n = 8$)	48.16±4.39	20.63±3.18	59.07±4.04	26.64±5.14	40.84±5.3	20.68±3.41	78.72±0.85	50.01±4.19	65.35±5.21	58.72±3.9
	Term2Note ($\epsilon_t = \infty, \epsilon_n = 5$)	51.0±1.41	22.73±2.22	56.7±4.95	24.89±4.24	46.79±3.93	24.62±3.03	78.8±1.78	50.37±1.78	67.15±5.88	59.91±3.12
	Term2Note ($\epsilon_t = \infty, \epsilon_n = 2$)	48.57±0.89	20.31±1.25	59.92±5.19	24.63±2.69	41.23±3.46	20.75±2.05	79.56±1.08	51.75±0.85	68.64±3.55	60.41±3.43
	$\epsilon = 8$										
	AUG-PE ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 8$)	40.73±9.22	13.28±4.71	60.68±4.70	15.14±4.77	31.43±9.80	16.01±5.81	78.13±1.85	53.49±3.08	63.24±4.65	59.03±4.59
	FastDP ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 8$)	48.58±5.93	16.40±4.01	64.79±1.33	16.70±3.67	39.49±8.78	18.89±5.16	80.74±1.41	51.57±3.46	69.79±2.25	61.59±4.42
	Term2Note ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 8$)	49.71±1.90	21.28±1.28	61.37±4.28	25.17±1.55	41.96±2.98	21.31±1.63	80.03±1.44	52.80±1.15	67.49±4.42	61.48±4.45
	Term2Note ($\epsilon_t = 8, \epsilon_n = 8$)	52.31±4.45	26.5±3.95	53.04±3.34	26.9±2.62	51.87±6.45	28.66±4.65	78.19±0.91	50.17±2.33	67.81±5.88	57.36±3.3
	Term2Note ($\epsilon_t = 5, \epsilon_n = 8$)	49.52±4.44	21.36±3.11	58.74±6.32	24.59±5.36	43.23±5.68	22.04±3.52	79.08±1.34	50.11±4.08	68.29±5.36	60.68±4.65
	Term2Note ($\epsilon_t = 2, \epsilon_n = 8$)	53.25±1.1	24.66±1.82	56.93±2.49	28.23±4.52	50.16±2.52	26.94±2.17	78.85±0.98	49.41±2.86	68.31±5.53	59.91±3.34
	$\epsilon = 5$										
	AUG-PE ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 5$)	48.10±2.08	17.44±2.70	60.59±8.29	18.28±3.69	40.73±5.59	21.02±4.88	77.78±3.11	53.33±2.60	63.01±12.42	56.94±5.20
	Fast-DP ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 5$)	49.30±4.04	16.23±3.04	64.49±6.50	15.57±2.73	40.84±7.33	19.70±4.87	80.54±1.36	54.22±1.97	67.31±7.22	61.98±3.34
	Term2Note ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 5$)	47.94±4.47	20.31±3.40	60.88±4.95	25.76±4.44	40.15±6.22	20.20±3.71	79.29±1.49	51.19±3.40	66.04±5.73	61.69±4.86
	Term2Note ($\epsilon_t = 5, \epsilon_n = 5$)	54.83±2.24	28.96±1.81	51.64±4.44	29.07±4.58	58.92±4.33	34.06±2.99	78.2±0.8	50.32±3.94	64.56±4.1	57.18±3.09
	Term2Note ($\epsilon_t = 2, \epsilon_n = 5$)	51.26±1.97	21.45±1.88	58.92±4.45	25.08±3.48	45.63±3.55	23.28±1.99	79.05±1.37	50.44±3.5	66.36±5.89	60.49±4.89
	$\epsilon = 2$										
	AUG-PE ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 2$)	40.9±7.43	13.57±3.88	64.75±7.31	15.2±4.82	30.7±9.22	14.83±5.29	78.29±0.8	53.38±1.79	63.74±5.0	60.1±4.37
	Fast-DP ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 2$)	51.06±5.7	20.04±4.34	58.78±5.13	19.77±4.27	45.94±8.57	23.72±5.52	79.98±1.95	51.31±3.32	66.32±6.66	59.99±5.35
	Term2Note ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 2$)	51.78±3.99	3.36±3.87	57.45±5.97	25.59±4.84	47.21±3.16	25.26±2.64	79.00±1.67	50.60±2.75	67.00±3.39	59.52±5.59
	Term2Note ($\epsilon_t = 2, \epsilon_n = 2$)	51.87±2.73	23.06±2.51	57.77±6.18	26.58±5.04	47.37±2.88	24.77±2.01	79.43±1.41	51.3±2.96	69.45±4.73	60.31±5.39

Table 7: Supplementary results for utility evaluation: F1, Precision, Recall, AUC, and Precision@k, with **mean±standard deviation** values reported.

	Method	Fidelity				Utility					
		Length	Unary/Binary Term		Semantic	F1		AUC		Precision@k	
		KL Div.↓	Jaccard↑	KL Div.↓	MAUVE↑	Micro	Macro	Micro	Macro	$k=3$	$k=5$
	Original Data					57.03	30.80	82.01	58.88	68.93	62.14
Synthetic	$\epsilon = \infty$										
	Term2Note ($\epsilon_{\text{meta}} = \infty, \epsilon_n = \infty$)	**0.18**	**0.61/0.34**	**0.23**/1.55	**0.80**	52.56	25.32	**80.81**	**55.09**	67.30	60.78
	Term2Note ($\epsilon_t = \infty, \epsilon_n = \infty$)	0.36	0.40/0.18	0.77/**1.52**	0.66	53.77	25.72	79.94	51.86	66.98	60.71
	Term2Note ($\epsilon_t = \infty, \epsilon_n = 8$)	0.40	0.37/0.13	0.64/1.82	0.38	47.63	20.19	78.87	50.5	66.83	59.53
	Term2Note ($\epsilon_t = \infty, \epsilon_n = 5$)	0.25	0.37/0.13	0.65/1.76	0.32	49.98	21.50	79.77	52.57	68.14	59.91
	Term2Note ($\epsilon_t = \infty, \epsilon_n = 2$)	0.31	0.36/0.13	0.69/1.59	0.35	48.11	20.87	79.49	52.83	65.51	57.17
	$\epsilon = 8$										
	Term2Note ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 8$)	0.40	0.39/0.13	0.53/1.66	0.48	48.41	20.89	78.55	48.89	67.50	59.31
	Term2Note ($\epsilon_t = 8, \epsilon_n = 8$)	0.40	0.37/0.13	0.75/2.05	0.32	**55.46**	26.73	79.68	49.92	69.30	60.60
	Term2Note ($\epsilon_t = 5, \epsilon_n = 8$)	0.41	0.38/0.13	0.70/1.71	0.38	51.82	21.67	80.44	51.28	**70.92**	60.88
	Term2Note ($\epsilon_t = 2, \epsilon_n = 8$)	0.51	0.36/0.12	0.76/1.89	0.30	52.34	22.50	80.02	51.71	69.62	60.01
	$\epsilon = 5$										
	Term2Note ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 5$)	0.36	0.38/0.13	0.56/**1.52**	0.31	51.20	21.18	80.03	53.10	67.65	**61.38**
	Term2Note ($\epsilon_t = 5, \epsilon = 5$)	0.39	0.36/0.12	0.75/1.79	0.32	52.79	23.74	79.54	49.64	67.99	58.92
	Term2Note ($\epsilon_t = 2, \epsilon = 5$)	0.41	0.36/0.13	0.77/1.83	0.21	55.06	**27.86**	79.42	49.19	69.30	59.82
	$\epsilon = 2$										
	Term2Note ($\epsilon_{\text{meta}} = \infty, \epsilon_n = 2$)	0.49	0.36/0.12	0.60/1.65	0.27	49.26	21.17	79.21	50.33	67.16	59.24
	Term2Note ($\epsilon_t = 2, \epsilon_n = 2$)	0.46	0.35/0.12	0.80/1.78	0.31	53.66	24.43	79.91	50.26	69.28	61.08

Table 8: Fidelity and utility evaluation of synthetic datasets generated by Term2Note with Gemma-3-1B as the base model for NOTEGEN.

Method	Terms
Original	[“Physical”, “Discharge”, “Laparoscopic”, “incisions”, “air”]
No DP	[“air”, “discharge”]
DP	[“brief”, “discharge”, “negative”, “medications”, “placement”, “drainage”, “hemodynamically stable”, “therapy”, “chronic low back pain”, “symptoms”, “right chest”, “referred to cardiac surgery”, “chest discomfort”, “pulmonary vein”, “hyperlipidemia: he”, “hypertension-”, “difficulty”, “surgical service”, “anticoagulation”, “discontinued”, “increased”, “afebrile”, “asymptomatic”, “admission”, “intervention”, “hospitalization”, “cardiac enzymes x3”]

Table 9: Example of synthetic terms.