Applications of BERT Models Towards Automation of Clinical Coding in Icelandic

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Abstract

This study explores the potential of automating clinical coding in Icelandic, a language with limited digital resources, by leveraging over 25 years of electronic health records (EHR) from the Landspitali University Hospital. Traditionally a manual and error-prone task, clinical coding is essential for patient care, billing, and research. Our research delves into the effectiveness of Transformer-based models in automating this process. We investigate various model training strategies, including continued pretraining and model adaptation, under a constrained computational budget. Our findings reveal that the best-performing model achieves competitive results in both micro and macro F1 scores, with label attention contributing significantly to its success. The study also explores the possibility of training on unlabeled data. Our research provides valuable insights into the possibilities of using NLP for clinical coding in low-resource languages, demonstrating that small countries with unique languages and well-segmented healthcare records can achieve results comparable to those in higher-resourced languages.

1 Introduction

In recent decades, the healthcare industry's transition from paper-based to digital systems, particularly through the adoption of electronic health records (EHR), has opened up new avenues for accessing and utilizing healthcare data in research (Jha et al., 2009). This research has predominantly concentrated on structured data, including diagnostic codes and quantitative data from blood tests and other medical measurements. More recently, there has been a significant shift towards analyzing and using unstructured data. During patient visits and treatments, medical staff compile clinical notes, consisting of unstructured, free-form text. This text often relates to diverse medical codes, like the International Classification of Diseases (ICD) diagnostic codes, encompassing over 70,000 entries.

Precise ICD coding is crucial for the healthcare industry. It plays a vital role in accurately recording patient medical histories, billing for treatments, and enabling research and analysis. Nevertheless, traditional clinical coding has been a manual, labor-intensive process prone to human error (Burns et al., 2012; O'malley et al., 2005; Cheng et al., 2009). Since the transition from paper to digital systems, automating clinical coding has been a key objective. The rapid advancements in Natural Language Processing (NLP), especially with the advent of Transformer-based models (Vaswani et al., 2017), have demonstrated increasing potential in meeting this automation goal for English (Huang et al., 2022).

In our study, we investigate this task for Icelandic, which is categorized as low to medium resourced language, by using over 10 million EHR notes spanning over 25 years from the Landspitali University Hospital (LUH). Previous studies have predominantly focused on English-language datasets, specifically MIMIC-III/IV (Johnson et al., 2016, 2023). For other languages, access to data can be a limiting factor and the datasets studied are usually not large. We review results established across a range of different languages in the literature review section. The primary objective of our study is to ascertain the performance attainable for the Icelandic language, through continued pretraining of existing models and various adaptations.

This challenge was approached with budgetary constraints in mind, due to the limited computational resources available for conducting on-site studies of sensitive EHR data. We explored various approaches, including continued pre-training on EHR data and conducting an ablation study to compare differences in the fine-tuning step. The highest-performing models attained a micro F1 score of 72.2 and a macro F1 score of 65.2 for the

top 100 labels and a micro F1 score of 66.2 and a macro F1 score of 18.3 for the top 8922 labels. We performed an ablation study which revealed that integrating LAbel ATtention (LAAT) led to enhanced classification performance (Vu et al., 2021). Particularly noteworthy is the fact that the performance mirrors results obtained from higher-resourced languages, underscoring the value of EHRs even for smaller countries with unique languages.

Due to the sensitive nature of the training data, the release of both the models and the data is not feasible. Nevertheless, we are confident that our findings provide valuable insights into the possibilities for languages with limited resources, such as Icelandic, in this field.

2 Related Work

2.1 LLMs for Icelandic

The development of LLMs for Icelandic has depended on access to large monolingual corpora. The largest manually curated corpus is the Icelandic Gigaword Corpus (IGC) compiled by the Árni Magnússon Institute that now encompasses 2.43 billion words (Steingrímsson et al., 2018; Barkarson et al., 2022). The IGC can be contrasted with the Icelandic Common Crawl Corpus (IC3) that was compiled from 63.5 million web pages belonging to the Icelandic top-level domain (.is). The IC3 was specifically created for studying the effect that different sources have on model pre-training (Snæbjarnarson et al., 2022).

Regarding transformer models, Snæbjarnarson et al. (2022) trained and released four monolingual RoBERTa models on these datasets providing baseline LLMs for Icelandic. Continued pre-training of the multilingual XLMR-base model on IC3 was also studied with the resulting model showing comparative performance to the monolingual RoBERTa models.

2.2 Applications of LLMs in Healthcare

LLMs have great potential to be applied on EHR data, primarily due to the performance of Transformer-based models, increased computational capacity, and the availability of extensive public datasets that have been used in the demonstration of state-of-the-art results (Johnson et al., 2016, 2023). For tasks such as ICD-code classification, the results are still far from perfect, especially on rare codes. However, they can create value in EHR interfaces, for example, they can be used to suggest ICD-codes when clinicians write a report.

Huang et al. (2022) put forth PLM-ICD, a framework for leveraging pre-trained language models (PLM) to tackle challenges encountered with automatic ICD classification. They show that using PLMs pretrained on domain-specific data provides performance improvement (an absolute increase of 5.7% and 1.5% respectively for micro and macro F1-scores) when compared to model that were pretrained on non-domain-specific data, but unfortunately, there's a lack of such models in low-resource languages and a lack of public clinical datasets, such as MIMIC-III/IV (Johnson et al., 2016, 2023) and n2c2 [1] being the biggest ones available.

Continued pretraining has turned out to be an improvement in other studies as well. Alsentzer et al. (2019) trained both BERT-base and BioBERT (Lee et al., 2020) on clinical EHR notes from the MIMIC-III dataset, getting the best performance from BioBERT, but showed that training BERT-base on out-of-domain clinical notes increased its performance across various tasks. In a similar vein, Lehman et al. (2023) found that smaller models pre-trained on clinical data outperform similarly sized general-domain models and show close performance to general-domain models of a much larger size. They also find that in-context learning of very large models such as GPT-3 for clinical tasks is not sufficient to replace fine-tuned clinical models. The issue on whether pre-training on domain-specific data is not settled. To contrast with the results above, (Agrawal et al., 2022) have shown that general-domain LLMs perform well on zero-shot clinical tasks without specific training in that domain which raises the question if domain-specific clinical LLMs are needed.

Several studies have further explored pretraining on text from the medical domain. Zhang et al. (2020) introduced BERT-XML for automatic ICD classification, a model trained solely on over 7 million clinical EHR notes, tackling the domain problem that PLMs generally encounter. Furthermore, they improved performance by using the multi-label attention output layer from AttentionXML (You et al., 2019), initializing each label with the BERT embeddings of the text descriptions of the ICD codes. Similarly, Chirigati (2023) pretrained a BERT-base architecture model on over

[1] https://portal.dbmi.hms.harvard.edu/projects/n2c2-nlp/

7 million notes from the same hospital and then fine-tuned it on various tasks, including readmission prediction where it greatly outperformed a group of physicians. Furthermore, they find that pre-training their model on a large corpus of data from multiple healthcare sites, and then fine-tuning models on local data for specific sites increases performance.

2.2.1 Applications in Other Languages

Table 1 gives an overview of studies that have been done on the medical code classification task in languages other than English. In the case of Icelandic, ICD classification has been the subject of two recent studies that are focused on a set of 4-6 ICD-10 codes in general practitioner (GP) EHR notes. Ellertsson et al. (2021) retrospectively compared the accuracy of GP's to ML models by hand annotating question-answer pairs to act as clinical features and then training an ensemble classifier which outperformed 6 physicians on the classification task. Furthermore, Hlynsson et al. (2022) expanded on this by using hand-annotated notes to train a Clinical Feature Extraction Model (CFEM) using IceBERT (Snæbjarnarson et al., 2022) to extract features on un-annotated notes and using logistic regression to label the notes with the predicted ICD-10 code.

Remmer et al. (2021) trained a classifier with the Swedish KB-BERT (Malmsten et al., 2020) using 6062 discharge summaries from gastrointestinal care units which had a zero F1-score on a label space of 263 values, but once aggregated to 10 code-blocks performed well. However, Tchouka et al. (2023), Coutinho and Martins (2022) and Suvirat et al. (2022) all trained ICD-10 classifiers using either monolingual or multilingual BERT models on corpus sizes of 56 to 169 thousand notes with various label counts and obtained macro F1-scores ranging from 38.5 to 88.2 depending on the size of the label space. Velichkov et al. (2020) compared different pre-trained language models for the task of ICD-10 classification from from diagnosis texts in Bulgarian, finding that the multilingual SlavicBERT (Arkhipov et al., 2019) which is trained on text in Bulgarian, Czech, Polish and Russian, was outperformed by MultilingualBERT (Devlin et al., 2019), BioBERT (Lee et al., 2020) and ClinicalBERT (Alsentzer et al., 2019).

Other model architectures have also been applied in this area. Pribán et al. (2023) pitted a small Czech ELECTRA model against a Hierarchical Attention GRU model, with the latter overall outperforming the former, emphasizing the model size required to apply transformers. Reys et al. (2020) compared Logistic Regression, CNN, GRU, and CNN with attention (CNN-Att) on the task on Brazilian-Portuguese EHR notes, where the CNN-Att vastly outperformed the other with a micro F1-score of 48.5. Their method achieved a 1.3% absolute increase in performance over CAML, resulting in an F1-score of 53.7, when trained on the MIMIC-III dataset. Almagro et al. (2020) then took a different approach by extracting all sentences in Spanish EHR notes which included medical terms[2], then extracting features from them and applying more traditional methods such as SVMs and gradient boosting for classification.

3 Methods

3.1 Dataset

For this study, we use EHR data from Landspítali University Hospital in Iceland. The dataset includes all written records (16 million) dating back from 1997 to March 2023. The records in the dataset cover all aspects of hospitalization, which can be contrasted with public datasets such as MIMIC-III that focus on discharge summaries (Johnson et al., 2016)[3]. The records are composed of over 200 categories that have been developed and some even deprecated over the time period with the most common categories being Outpatient notes, Treatment notes, and Day-patient treatment notes. Around 40% of the records did not have any ICD code associated with them. The rest had one or more codes with a total of 10,520 unique codes used in the dataset.

The dataset was processed locally at the hospital on a single machine with an Nvidia RTX 4090 GPU. We used the following open source libraries in this work: Transformers and Datasets from HF, PyTorch, NumPy, Pandas and Scikit-learn.

3.2 Data Pre-processing

The first step in the pre-processing pipeline was a cleaning step where occurrences of repeated characters that had been used to delimit sections of the

[2]They used the IxaaMedTagger, a Spanish clinical part-of-speech tagging software - http://ixa2.si.ehu.eus/prosamed/resources

[3]Conventions can be different between healthcare institutions and in Iceland, clinical codes are usually not assigned to discharge summaries so we cannot make a direct comparison with MIMIC.

Language	Reference	Corpus size	Labels	Acc	Macro Pre	Macro Rec	Macro F1
Br.-Portuguese	Reys et al. (2020)	69309	6918	-	-	-	-
Bulgarian	Velichkov et al. (2020)	345591	5854	81.9	-	-	86.0
French	Tchouka et al. (2023)	56014	6161	-	45.0	52.0	40.0
	-		1564	-	45.0	67.0	53.0
Icelandic	Ellertsson et al. (2021)	2563	4	-	-	-	-
	Hlynsson et al. (2022)	∼1200000	6	-	-	-	-
Portuguese	Coutinho and Martins (2022)	121536	1418	80.0	39.6	39.6	38.5
	-		611	83.7	53.1	49.9	50.1
	-		18	90.1	74.9	70.6	72.3
Spanish	Almagro et al. (2020)	7254	7078	-	69.5	-	-
Swedish	Remmer et al. (2021)	6062	263	-	0.0	0.0	0.0
	-		10	-	78.0	55.0	60.0
Czech	Pribán et al. (2023)	316808	1126	78.3	47.4	46.2	44.8
	-		1126	78.2	48.4	45.6	45.1
	-		1523	-	27.1	17.5	20.0
	-		1523	-	50.3	38.3	41.8
Thai	Suvirat et al. (2022)	91756	100	-	91.0	86.2	88.2
	-	148183	300	-	84.3	79.5	81.5
	-	168598	500	-	81.5	72.9	76.2

Table 1: An overview of recent studies applying NLP methods to the problem of medical code classification in non-English languages.

text were removed[4]. HTML and XML segments were further removed and newlines were replaced by spaces.

After the cleaning step, we performed deduplication. We applied the MinHash approach which has been commonly used to deduplicate these types of datasets (Broder, 1997; Lee et al., 2022). We used the implementation in the `text-dedup` package (Mou et al., 2023). For the deduplication, we used a threshold of 0.5 for Jaccard similarity and the default amount of 256 permutations of hashing and an n-gram size of 5.

Due to the size of the dataset, it could not fit completely into memory on the machine (which had 64 GB of RAM). For that reason, we performed deduplication on subsets of the datasets that would fit in memory. We approached the deduplication both temporally and using random subsets. In the temporal step, we split the dataset into 8 parts with 25% overlap between contiguous parts. This step reduced the size of the dataset to 59.14% of its original size. After the temporal deduplication, we split the resulting dataset into 4 disjoint parts and performed deduplication on each one. We repeated that process four times and in total it reduced the dataset size to 59.04% of its original size. That is, random deduplication was not effective after performing the temporal deduplication step.

3.3 Pre-training

Prior to fine-tuning, we performed continued pre-training on an existing BERT model to study its effect on downstream task performance. We split the dataset into 90% for training and 10% for validation. When continued pre-training was applied, the model was trained for 10 epochs in the standard masked language modeling task as in RoBERTa (Liu et al., 2019). The existing pre-trained model used in this study is the Icelandic BERT model `IceBERT` (Snæbjarnarson et al., 2022), and we refer to our further pre-trained model as `MedIceBERT` in this paper.

3.4 Classification

Despite language differences the dataset from LUH is considerably different in structure when compared to the MIMIC datasets, which in turn affects the underlying classification task. The MIMIC datasets do not represent EHR notes overall as it

[4]This is a convention used by many professionals to structure the text.

only includes critical care patients from a single hospital and prior research has been focused on classifying all ICD codes for whole admissions, with an average of 15 codes each. However, notes at LUH are shorter and have an average of 1.6 codes each.

For the classification task, we fine-tuned `MedIceBERT` on different dataset and label-set sizes to study how differences in these variables relate to classification performance. We used a 95/5 train/test split. During fine-tuning, we omitted notes with 20 or less words as well as truncated all tokens after 512, the context length of our RoBERTa models. This truncation affected 17% of our dataset.

To address the challenge of having a large label-space, we used the LAAT mechanism introduced by Vu et al. (2021) in our classifier. Prior work on ICD classification in English has shown that LAAT is an effective approach to learn label-specific features (Huang et al., 2022; Liu et al., 2022). We used the implementation by Huang et al. (2022), which is accessible online[5].

For a label space with ℓ labels, the label attention mechanism takes in $\mathbf{H} \in \mathbb{R}^{512\times768}$, the hidden representation of the last layer from our encoder, and computes the following

$$\mathbf{Z} = \tanh(\mathbf{H}\mathbf{W}^\top) \tag{1}$$

$$\mathbf{A} = \text{softmax}(\mathbf{Z}\mathbf{U}^\top) \tag{2}$$

where $\mathbf{W} \in \mathbb{R}^{d_a\times768}$ and $U \in \mathbb{R}^{\ell\times d_a}$ are trainable parameters. We set the hyperparameter $d_a = 768$ as done by Huang et al. (2022). We proceed by computing

$$\mathbf{V} = \mathbf{A}^\top\mathbf{H} \tag{3}$$

where the ith row represents the label-specific vector of the input document w.r.t. the ith label. Finally, we output the vector

$$\left[\sum_{j=1}^{768}(\mathbf{L}\odot\mathbf{V})_{ij} + b_i\right]_{i=1}^{\ell} \tag{4}$$

where $\mathbf{L} \in \mathbb{R}^{\ell\times768}$ and $\mathbf{b} = [b_1, b_2, \ldots, b_\ell] \in \mathbb{R}^\ell$ correspond to trainable parameters. The i-th output of the result corresponds to the logit of the i-th label.

[5] https://github.com/MiuLab/PLM-ICD/blob/master/src/modeling_bert.py#L96

3.4.1 Top-100 Codes

We reduced the label scope by assigning all codes beyond the top 100 to a separate "rare disease" label and we also added a "no code assigned" label for notes with an empty label set. We trained `MedIceBERT` for 10 epochs on the classification task.

With an abundant amount of pre-training data, we studied the effect of continued pretraining before the fine-tuning phase by varying the size of the fine-tuning corpus from 32.5k to 1000k notes. For a standardized comparison, the training always had a fixed number of 1000k steps.

3.4.2 Full-set

To compare our models to those using the MIMIC-III full-set of ICD-10 codes, we fine-tuned our model using the top 8,922 labels in our dataset. We used both the RoBERTa classifier[6] and the LAAT (Vu et al., 2021) classifier as implemented by Huang et al. (2022). We studied performance of checkpoints after 1 epoch and 10 epochs.

3.5 Evaluation

For measuring the model performance we report the following metrics: macro F1-score, micro F1-score, macro AUC[7] and micro AUC. We omitted precision@K which is commonly used for this task on the MIMIC-III dataset as 90% of our notes have 2 or fewer ICD codes and only 1% have 5 or more.

To make our results comparable to prior results, we omit rare and no code labels when the performance metrics are computed. This makes sure that the performance metrics do not appear inflated in case the performance on rare and no codes is good.

4 Results

4.1 Classification Performance

The results of the 100-most-frequent and 8922-most-frequent models on their test sets are shown in Table 2 and Table 3. To understand how models in Icelandic compare to well-known results in English, we compare our results to models that were trained on the MIMIC-III dataset.

[6] https://github.com/huggingface/transformers/blob/main/src/transformers/models/roberta/modeling_roberta.py

[7] We used the method to calculate macro AUC by Mullenbach et al. (2018) which only averages the AUC score over those labels which were found in the evaluation dataset. https://github.com/jamesmullenbach/caml-mimic

Model	Reference	Micro F1	Macro F1	Micro AUC	Macro AUC
LAAT	Vu et al. (2021)	71.5	66.6	94.6	92.5
JointLAAT	-	71.6	66.1	94.6	92.5
CAML	Mullenbach et al. (2018)	61.4	53.2	90.0	87.5
DR-CAML	-	63.3	57.6	91.6	88.4
Longformer	Ren et al. (2021)	68.9	63.1	93.1	90.5
BERT-ICD	Pascual et al. (2021)	-	-	88.7	84.5
HiLAT	Liu et al. (2022)	73.5	69.0	95.0	92.7
Ours (100)		72.2	65.2	99.5	99.3
Ours (50)		74.9	67.8	99.5	99.3

Table 2: Results on our 100-most-frequent dataset and MIMIC-III-50 test set. Note that *Ours (50)* still corresponds to the model trained with 100 labels, but the evaluation is only performed with respect to the top 50 labels.

For our top 100 codes model, we achieve superior performance with respect to the AUC score when comparing to models trained on the MIMIC-III-50 dataset. For the F1-score, our model is close to the best performing models. This performance is noteworthy considering that our label-space is twice as large as those of the other models. Furthermore, when evaluating only on the top 50 labels, we see a modest improvement in the performance.

Similarly, our top 8922 codes model, which has the same label-space size as the MIMIC-III full dataset, achieved higher performance metrics compared to models trained on MIMIC-III. Our model outperforms the best-performing baseline by obtaining absolute increases of 6.4%, 7.9%, 0.9%, and 5.4% in micro-F1, macro-F1, micro-AUC, and macro-AUC.

4.2 Effect of Pre-training

We conducted an analysis to understand the impact of additional pretraining on the performance of models during fine-tuning. Specifically, we worked with 12 different models, each undergoing fine-tuning for 1 million steps. The duration of this fine-tuning varied between 1 and 32 epochs, depending on the size of the dataset used for fine-tuning. We adjusted the number of epochs for each model so that the total number of fine-tuning steps always summed up to 1 million. Six out of the twelve models corresponded to `MedIceBERT`, which was further pre-trained, and six corresponded to `IceBERT`, which was not pretrained explicitly on text from EHRs. Further pretraining provided an increase in our performance over the base model at all dataset sizes as shown in Table 4. We note that repetitions of these experiments are required to get more robust results. The performance metrics for all models were calculated on the same evaluation dataset.

4.3 Ablation Study

To investigate the effects of using LAAT and training on unlabeled data, we conducted an ablation study. The results of which are shown in Table 5. These were performed on the top-50, top-100, and top-8922 label datasets.

We found that using LAAT overall improved our F1-scores and AUC metrics, with a smaller impact for smaller label-spaces but being crucial at 8922 labels. Furthermore we observed that training on unlabeled data reduced our F1-score across all label sizes, but instead increased our micro and macro AUC.

5 Discussion

This study has demonstrated the feasibility of automating clinical coding in Icelandic, a language with limited digital resources, by leveraging a substantial corpus of electronic health records. Our findings indicate that Transformer-based models, particularly when enhanced with label attention mechanisms, can achieve competitive results in clinical coding tasks. The best-performing model in our study attained micro and macro F1 scores that are not only competitive but also comparable to those achieved in higher-resourced languages. Specifically, when measuring performance using AUC, our models outperform the English state-of-the-art models. However, we note that due to structural and language differences, these direct comparisons need to be taken with a grain of salt.

The implications of our findings are significant for the field of NLP in clinical coding. They sug-

Model	Reference	Micro F1	Macro F1	Micro AUC	Macro AUC
LAAT	Vu et al. (2021)	57.5	9.9	98.8	91.9
JointLAAT	-	57.5	10.7	98.8	92.1
CAML	Mullenbach et al. (2018)	53.9	8.8	98.6	89.5
DR-CAML	-	52.9	8.6	98.5	89.7
Longformer	Ren et al. (2021)	56.7	7.6	98.8	91.3
PLM-ICD	Huang et al. (2022)	59.8	10.4	98.9	92.6
Ours		66.2	18.3	99.8	98.0

Table 3: Results on our 8922-most-frequent and MIMIC-III-full test set

Dataset size	Epochs	`IceBERT`	`MedIceBERT`
31.25k	32	68.2	71.8
62.5k	16	69.3	74.0
125k	8	72.4	75.3
250k	4	74.4	77.3
500k	2	75.5	78.4
1000k	1	74.4	78.6

Table 4: Reported micro F1-Score for both models over various fine-tuning regimes. `IceBERT` and `MedIceBERT` are the models we fine-tuned.

EC	LAAT	F1-Score		AUC	
		Micro	Macro	Micro	Macro
✗	✗	72.9	62.0	99.3	98.9
✓	✗	70.0	59.6	99.4	99.1
✗	✓	72.8	62.4	99.3	98.9
✓	✓	70.1	59.1	99.5	99.2
✗	✗	69.7	58.7	99.4	99.0
✓	✗	67.0	56.4	99.5	99.2
✗	✓	70.5	60.0	99.5	99.2
✓	✓	66.9	58.0	99.5	99.3
✗	✗	31.2	0.7	98.8	92.7
✓	✗	0.0	0.0	93.4	49.5
✗	✓	57.9	7.7	99.6	97.6
✓	✓	55.6	8.2	99.7	98.2

Table 5: Ablation study results on top 50, 100 and 8922 codes. EC stands for Extra Codes, i.e., training on notes with no assigned code or rare codes.

gest that even languages with relatively small digital footprints can benefit from the advances in machine learning and NLP. This is particularly encouraging for smaller countries or those with unique languages, where digital resources may be scarce. Our research demonstrates that with the right strategies, such as continued pretraining and model adaptation, it is possible to overcome the challenges posed by limited computational resources.

Our models, trained on a concise dataset of 100 labels, achieved accuracy comparable to those trained on the English MIMIC-III-50 dataset. This trend continued when expanding the label space to 8922 labels, mirroring the performance of models using the full MIMIC-III dataset. The success of our models can likely be attributed to the extensive dataset at our disposal and the brevity of Icelandic medical records, which may be more conducive to automated coding than the lengthy discharge summaries typically used. This has profound implications for the structure of healthcare data curation moving forward. In fact, recent methods have focused on segmenting clinical notes into sections to facilitate automated clinical coding (Lu et al., 2023). Our findings suggest that even languages with fewer resources can reach the performance of well-resourced languages if ample well-segmented data is available.

When examining how our work stacks up against studies in other languages, we face the challenge of inconsistent performance metrics and tasks, as shown in Table 1. To facilitate more meaningful comparisons, we advocate for the adoption of uniform reporting standards in this research domain, such as consistently including both micro and macro F1 and AUC scores, akin to the convention in MIMIC dataset studies. While standardizing label space categories and training constraints could enhance comparability, we must balance this with the risk of imposing limitations that may not fit all research contexts.

Our ablation study focused on the impact of LAAT and the inclusion of unlabeled or out-of-scope data across datasets of varying sizes. We

found that LAAT (Vu et al., 2021) had a marginal impact on smaller datasets but was essential for the expansive 8922-code dataset, likely due to the low frequency of certain codes. Intriguingly, training with out-of-scope data led to a slight decrease in F1-scores but an increase in AUC scores. An improvement in AUC could indicate that the model got better across all decision thresholds, but a decrease in F1-score could mean that it came at the cost of performance on low-frequency label categories. Further analysis will need to reveal the correct underlying nature of this tradeoff.

Our study confirms that additional pre-training on EHR notes using the masked-language objective markedly enhances code classification performance, aligning with prior findings on the benefits of domain-specific pre-training (Lehman et al., 2023). We observed that our further-pretrained model consistently outperformed IceBERT by a margin of at least 3% in micro F1-score across all dataset sizes, from 31.25k to 1000k, after an equivalent training duration of 1000k steps.

Our research was conducted under computational resource constraints, which limited the scope of our experiments and underscored the importance of powerful hardware in NLP research, particularly for large datasets. Nevertheless, in this resource-constrained scenario, we found temporal deduplication to be an effective data management strategy, which may be particularly suitable for medical datasets where note repetition is common.

Looking forward, potential research directions include aggregating all notes from a patient's stay to provide models with a richer context for code classification, contrasting with the current approach of analyzing individual notes. This could address the issue of incomplete code assignments in standalone notes. To manage the resulting long text sequences, techniques like document segment pooling (Huang et al., 2022), various text splitting strategies (Pascual et al., 2021), and alternative architectures capable of handling extended contexts, such as Mamba (Gu and Dao, 2023) and Hyena (Poli et al., 2023), could be explored.

In light of these findings and future research directions, we must also consider the ethical implications of automating clinical coding. As we move towards systems that can interpret and categorize medical text, questions of privacy, data security, and the potential for algorithmic bias must be addressed. Ensuring that these systems are transparent and equitable will be paramount, particularly as we extend these technologies to a broader range of languages and healthcare systems.

Moreover, the integration of NLP into clinical workflows raises important considerations about the role of human oversight. The balance between automated efficiency and expert judgment remains a delicate one and given the performance of our models the current aim should be to augment human judgment rather than replace it.

6 Conclusions

In this paper, we presented the results for the first Icelandic models trained in the task of multilabel ICD-10 classification of EHR notes. We compared their performance on datasets with label spaces of 50-, 100- and 8922-codes, which were accumulated over 25 years at the Landspitali University Hospital. Our models performed similarly to state-of-the-art models trained on the MIMIC-III dataset. We explored how training on unlabeled data affected our model performance as well as how label attention impacted the confidence of our models in their choices.

We hope that our work provides a foundation and guidance for researchers working in other low- to medium-resource languages to explore the fine-tuning of pre-trained LLMs in their respective language on medical text for the task of clinical coding.

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Limitations

Our study, while comprehensive, encounters several limitations that warrant discussion. Firstly, the quality and comprehensiveness of the EHR dataset pose significant limitations. The potential inaccuracies in labeling and representation within the EHR notes could impact the validity of our findings. More research will need to be done to uncover these issues, and the inherent limitations of real-world clinical data must be acknowledged.

The computational constraints we faced notably limited our exploration to base models only. This

presents a considerable limitation, as larger or more complex models might yield drastically different results. All our experiments correspond to single runs and for that reason we could not provide error estimates for the performance metrics. The scalability of our approach to longer texts and larger datasets remains untested, marking a crucial area for future research.

A critical gap in our study is the determination of the practical performance threshold for clinical utility. It is not entirely clear what level of accuracy and reliability is needed for these models to be effectively implemented in a clinical setting. This gap highlights the need for ongoing collaboration with healthcare professionals to establish these benchmarks.

Moreover, our comparison of the Icelandic models with those trained on English datasets like MIMIC may not fully capture the nuances due to structural differences in datasets. This limitation in cross-language comparisons must be considered when interpreting our results.

We also acknowledge the potential for bias in our models, given the disparities that may exist in the dataset. These biases, if unchecked, could lead to skewed or unfair outcomes in clinical coding. While our Ethics Statement covers our commitment to addressing these concerns, they remain a pertinent limitation of our current study.

Lastly, the practical implementation of AI in clinical settings is fraught with ethical and operational challenges. Our study does not fully explore the implications of deploying these models in real-world settings, an area that requires thorough investigation and careful consideration.

While our study offers valuable insights into the application of Language Models in clinical coding for Icelandic, the limitations outlined above highlight the need for cautious interpretation and further research in this domain.

Ethics Statement

This research, conducted in adherence to the ACM code of ethics and professional conduct, strives to enhance the efficiency and accuracy of clinical coding in healthcare, ultimately serving the well-being of medical staff and patients. We acknowledge the sensitive nature of the EHRs used and have followed stringent data privacy and security measures to safeguard patient information. All data handling procedures were designed to comply with relevant legal and ethical standards in healthcare data management.

We recognize the potential for biases in the models, stemming from disparities in the dataset that reflect existing healthcare inequalities. These biases, related to demographics, socioeconomic status, and medical conditions, need to be critcally examined to mitigate their impact on the model's fairness and accuracy before such a model is deployed. Our commitment to ethical AI extends to ongoing efforts to identify and rectify such biases, in collaboration with medical professionals who can provide invaluable insights and validation of our findings.

Transparency and reproducibility are key principles of our research, despite the inability to release the models and data due to privacy concerns. We have documented our methodologies and processes in detail, ensuring that other researchers can reproduce our study for other languages within ethical and legal boundaries.

The integration of AI in clinical coding bears significant implications for patient care, clinical practice and research on human diversity. Regarding deployment for clinical practice, we are acutely aware of the ethical responsibility this entails, including the potential risks and unintended consequences. We are working with healthcare experts to align our models with patient care priorities and clinical workflows.

Lastly, we emphasize the necessity for a cautious, measured approach to the deployment of such AI systems in clinical settings. Rigorous evaluation and validation, alongside ethical considerations such as non-discrimination and respect for patient privacy, are indispensable steps before these models can be considered for practical application. Through this research, we aim to contribute positively to the healthcare community.

Finally, we would like to state that GPT-4 was used as an aid in writing the code behind the experiments in this work, and to revise text in this manuscript.

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