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研究課題名（和文）From Reports to Knowledge for Patient Safety Improvement through Advancements in Artificial Intelligence

研究課題名（英文）From Reports to Knowledge for Patient Safety Improvement through Advancements in Artificial Intelligence

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研究成果の概要（和文）：研究チームは、3つの特定の研究タスクすべてを完了しました。 2018-2022年度のKakenhi Bチームは最適な研究成果を達成し、基金は直接（本日現在）15の主要な国際的な査読付き出版物を生み出し、5人の博士号/修士課程の学生（ローカルおよびグローバル）をサポートしました。Health AI Acceleration Consortium（厚生労働省）で成果を広めました。 さらに、私たちのチームメンバーは、WHOグローバル患者安全ネットワークおよび多くのグローバル患者安全会議（フィレンツェでのWHO会議（2019年12月）など）に研究結果を発表しました。

研究成果の学術的意義や社会的意義
Our study innovates the way to collect, utilize and retrieve incident reports using the recent advances in AI/NLP methods. Our outcome is beneficial to local and global authorities/hospitals to enhance patient safety through enabling robust medication error detection and effective incident learning.

研究成果の概要（英文）：Our research team has successfully completed all three specific research tasks (including 1. developed and validated annotation guidelines for medication errors incident reports, 2. developed and evaluated AI models for named entity recognistion for incident reports and 3. created prototype of AI-empowered incident report system). The FY 2018-2022 Kakenhi B team has successfully achieved optimal research outcomes and the fund has directly (as of today) resulted in 15 major international peer-reviewed publications, supported 5 Ph.D./master students (locally and globally), built our team's significant roles in global patient safety informatics research, and our work has also drawn attention at the Health AI Acceleration Consortium (Ministry of Health, Labor and Welfare). Furthermore, our team members have disseminated to the WHO Global Patient Safety Network and many global patient safety meetings, such as WHO meeting in Florence (Dec 2019), WHO Policy Makers' Forum (Feb 2022).

研究分野：生命、健康および医療情報学関連

キーワード：WHO Patient Safety　Artificial Intelligence　Incident reports　NLP　NER　Adverse drug events　Deep learning

(1) 研究開始当初の背景/Background at the beginning of research

The World Health Organization (WHO) has initiated the third Global Challenge on Patient Safety with the thematic priority of "medication without harm" in 2017 [2; 3]. The goal is to achieve significant reduction of avoidable medication-related harm globally. As a mean to capture clinical near-misses and incidents, mandatory and voluntary reporting systems have been recommended by the Institute of Medicine (IOM) and WHO. WHO Minimal Information Model for Patient Safety (MIM PS) [1] also provides guidelines on the key data collection features for incident reports allowing for minimal information capturing but meaningful learning. Typical incident reporting system would allow users to select standardized selection of limited categorial items, and to rely on free text input to capture the incident background/causes, outcomes and actions.

Many developed countries, including Japan and the UK, also set up centralized incident reporting and learning systems, as well as encourage dedicated reporting systems put in place at individual hospitals. As of year 2017, more than 7 million adverse events and near misses have been captured by Japan Council for Quality Health Care (JQ) system and at least 9 million incidents have been collected from England, not to mention the massive number of reports collected by other national reporting systems in the world, as well as individual hospitals documentation. Due to the shared feature across these reporting systems, it is tremendously difficult to identify similar incidents and learn from past errors and mistakes. It is also time consuming and labor intensive to identify and analyze similar incidents that share common properties, due to the scale of *Big Data* collected (in unstructured free text format). This significantly hinders the development, advancement, and quality improvement of patient safety in healthcare.

The unstructured nature of incident reports and lacking systematic approach to register incidents pose tremendous challenges in incident report learning. Information from these reports needs to be retrieved in an automatic and efficient way and it requires solutions that are capable of scaling up to a truly 'big data' scale. Information retrieval refers to the search for material of an unstructured nature that fulfils certain criteria needed via retrieving documents from a large collection. Recently, information processing using advancements in artificial intelligence (AI) methods has begun to play an increasingly important role in clinical decision-making and shed light on overcoming this research gap.

(2) 研究の目的/ Purpose of the research

This research aims to develop an innovative information retrieval solution to extract actionable data from incident reports for medication errors. The research objectives are:

(1) to develop terminology collections (annotating corpus) for incident reports of medication errors,
(2) to develop named entity recognition (NER) model approaches that are suitable for the application of incident reports learning, and
(3) to develop prototype AI-enabled incident reporting system for automatic structuring incident reports.

This research provides an innovative way to collect, retrieve and utilize incident reports for preventing adverse events and promoting safety in medical care. To ensure significant global and local impact, our team research on both Japanese and English incident reports.

(3) 研究の方法/ Research method

Incidents Datasets. Our team has accessed to incident report data in a *Big Data* scale from national and hospital-level incident reporting systems. These included

- the Project to Collect Medical Near-Miss/Adverse Event Information from the Japan Council of Quality Healthcare (JQ)
- St. Luke's International Hospital's incident reports
- English incident reports from AIRS in Hong Kong

Incident reports usually capture the background, causes, and responses to medical incidents. Many medication incidents are often occurred due to procedural mishaps and weaknesses. The set of vocabulary used to describe incidents is generally different from that of in daily clinical record taking. Based on the state-of-the-art literature, we conduct an extensive narrative review of medication errors, classification schemes and annotation methods. Literature from the WHO International Classification of Patient Safety, WHO Minimal Information Model for Patient Safety (MIMPS), National Coordinating Council for Medication Error Reporting and Prevention (NCC MERP), Agency for Health Research and Quality (AHRQ) Common Formats Version 2.0 and European Medicines Agency Good Practice Guide were carefully reviewed, referenced and synthesised. We also refer to guidelines for the development of a classification scheme suitable for information extraction in general and clinical contexts.

Using our developed annotation methods, we develop natural language processing (NLP), rule-based and artificial intelligence approaches for incident report classification and NER. The methods we employ, included but not limited to, feature extraction methods (such as Bag-of-words, term frequency, TFIDF, resampling methods, random oversampling, SMOTE), machine learning classifiers (such as Naïve Bayes, Support Vector Machine (SVM), random forest), neutral network-based deep learning approaches (deep neural network (DNN), long-short term memory (LSTM)), and transformer-based language models (such as BERT, GPT-3). Precision, recall, and F-score are measured for evaluating performance of various models. We employ the latest NLP, deep learning and AI packages/libraries using R and/or Python code operating on Google Colab and internal server PCs.

Information and communication technology (ICT) systems in health are innately a socio-technical system that accounts for both social and technical factors influencing the functionality and usage of computer-based systems. We attempt to develop a prototype incident reporting system that takes into consider human, social and organizational factors, as well as technical factors in the design of health systems. The prototype system incorporates basic authentication and log-in function using test user accounts, an introduction page, a correctable AI model output, annotation instruction and examples to guide first time users. The system itself allows real time incident reporting, structuring and confirmation functions and is able to divert relevant incident learning resources upon incident report submission. Furthermore, filter option maximizing cosine similarity index via SpaCy was employed to automatic funnel similar incident reports to the users.

(4) 研究成果/Research Results

The main results of the research. Our research team has successfully completed all three specific research tasks according to predefined schedule. Here, we briefly summarize our research outcomes accordingly to specific research tasks below. For the details, one may refer to the list of publications.

Task 1: Developed and validated annotation guidelines for medication errors incident reports,

Medication errors are among the most frequently occurring medical incidents and can potentially cause life-threatening harm to patients. We researched on medication error classification scheme[8], as shown in Figure 1, aiming to evaluate the explicit properties of medication errors associated with incident reporting and to organise complex concepts into meaningful entities. The resulting classification scheme comprises both the essential concepts of medication errors and the corresponding methods of annotation used to extract practical information from incident reports. Subsequently, we developed and validated annotation guidelines for information retrieval from medication incident reports [12] which is suitable for the automatic extraction of essential medication errors based on recent advances in natural language processing (NLP) and artificial intelligence (AI) methods. The annotation guidelines and e-learning annotation training materials are available from our research homepage [10].

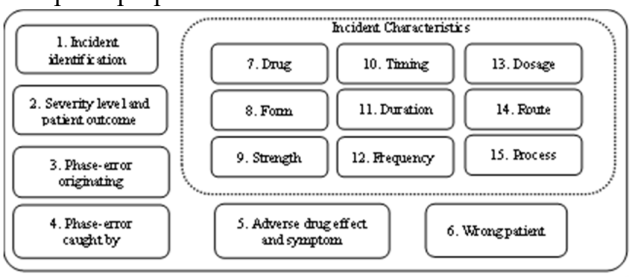

Figure 1. Proposed 15-category classification scheme.

Most narrative texts in medical incident reports describe what medication was intended to be given and what was actually given due to the fact that what happened in an incident is largely due to discrepancies between intended and actual medications. Recognizing the intention of upstream operation and the factuality of the downstream is essential to understand the causes of medical incidents and avoid similar incidents in the future. Based on the developed annotation guidelines, we developed and published a medical incident reports corpus with annotation of intention and factuality as well as of medication entities and their relations [13]. The annotated gold standard corpus consists of 522 Japanese medical incident reports and the F-measure was 0.960 with an agreement rate of 0.928.

Task 2: Developed and evaluated AI models for incident reports NER recognition

Using available global and local incident report datasets, our AI modelling team investigated incident report classification and NER problems using different state-of-the-art methods, including data analytics[5], resampling approaches[7; 14], machine learning [4; 6], deep learning[11], transformer language models, including BERT and GTP-3 (paper is under preparation). Through observing the imbalance property of incident reports, we propose an effective incident report classification framework, as shown in Figure 2 [7]. This framework provides a systematic approach to classify incident reports and statistically overcome the innate incident report data challenge - through

resampling methods. The framework is promising because it demonstrates an improved F-score of 30% and the framework can be applied to incident reports collected in other countries such as Australia.

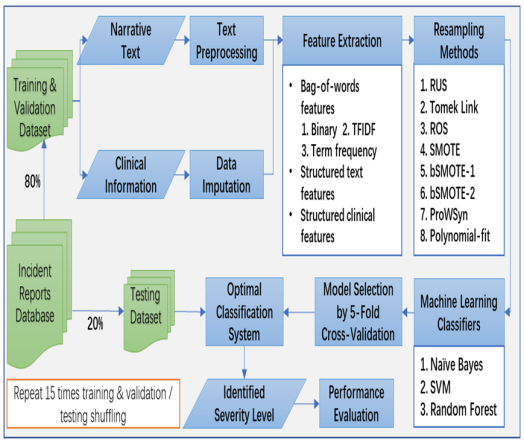

Figure 2: Incident report classification framework

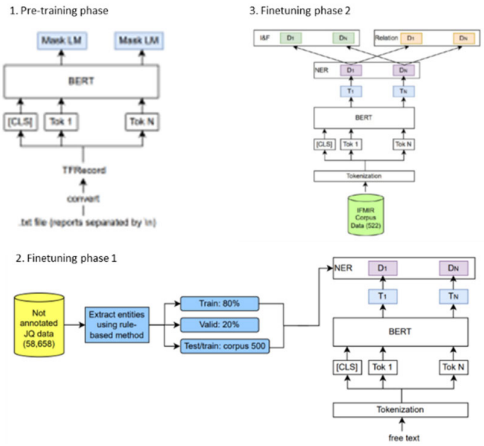

Figure 3: Workflow of Multitask BERT Deep Learning

Furthermore, we developed Japanese BERT model for Named Entities, Intention and Factuality Analysis (I & F), and Relation identification, as shown in Figure 3. We adopted pre-trained BERT on Japanese Wikipedia & Twitter data (https://github.com/yoheikikuta/bert-Japanese), pre-trained all types of incident reports using free text JQ data (121,244) and carried out two phases of finetuning for NE tasks and for I&F and relations. The densely layered BERT model has achieved F-1 score of 0.97 and 0.84 in the validation and testing sets respectively for the NER task. The model to detect whether an NE isn't error (i.e. I&A) at F-1 score of 0.82. It is found that the deep learning language model increased F1 score (comparing with rule-based only) by 15%.

Task 3: Created prototype of AI-empowered incident report system

Considering the socio-technical aspects of a hospital incident reporting system, out team has launched the trial version of the 'AI-enabled Incident Reporting and Learning System' on Amazon Web Services (AWS) [9], as shown in Figure 4. The aim of the system is to facilitate learning from past patient safety incidents and ultimately improve patient safety. The system can automatically capture information from unstructured, free-text incident reports and present it as structured data. Once an incident report has been 'structured', it can be analyzed automatically with the trained clinical AI BERT model.

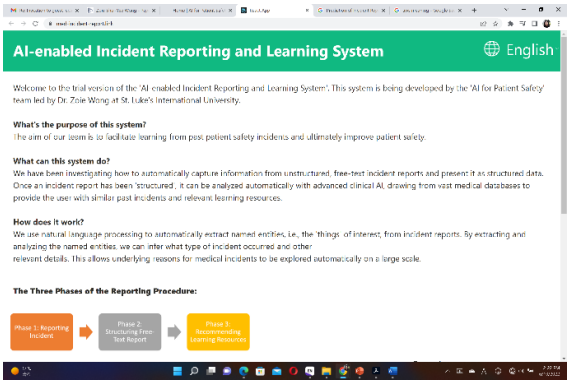

Figure 4: Prototype AI-empowered Incident Reporting System

The system can also draw from vast medical databases to provide the user with similar past incidents and relevant learning resources. There are three phases of reporting, namely reporting incident, structuring free-text report and recommending learning resources.

The position and impact of the obtained results in Japan and overseas.

Our study provides a totally new perspective in collecting, utilizing and retrieving incident report data using the recent advances in AI/NLP methods. Through our research effort, our guidelines, models and systems suggest potentials to innovate incident report learning. The FY 2018-2022 Kakenhi B team has successfully achieved optimal research outcomes and the fund has directly (as of today) resulted in 15 major international peer-reviewed high impact health informatics journals and conferences, such as Journal of the American Medical Informatics Association (JAMIA), International Journal of Medical Informatics (IJMI), Journal of Medical Internet Research (JMIR), IMIA Yearbook, Health Informatics Journal etc. Furthermore, our study also supported 5 Ph.D./master students (locally and globally), and built our team's significant roles in global patient safety informatics research.

Our study outcomes have been disseminated locally to the Ministry of Health, Labour and Welfare (MHLW) (including Health AI Acceleration Consortium, MHLW Patient Safety Day with a theme of "Medication Safety", 2023 G7 Health Ministers' Side Event) and globally to WHO Patient

Safety Network (such as WHO meeting in Florence (Dec 2019), WHO Policy Makers' Forum (Feb 2022), 2022 WHO World Patient Day), and many global patient safety meetings (such as 5th Ministerial Summit on Patient Safety in Montreux Switzerland Feb 2020 and Australian College of Health Service Management).

Future prospects

Our team envisions many potential future prospects in the direction of developing patient safety learning system and exploring its impact on hospital users' learning performance using out outcomes. Multiple directions of continued projects are underway, including to enhance the developed incident report annotation methods to detect hospital medication errors using electronic health records, to improve the performance of Japanese NER models and examining multi-language modeling approaches for incident reports in other languages, such as English, and to evaluate the system validity, usability and effectiveness in clinical settings. Our modeling effort and published annotated incident report datasets will be beneficial for other countries to learn from their massive narrative incident reports and subsequently ensure medication safety.

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５．主な発表論文等

〔雑誌論文〕　計14件（うち査読付論文　14件／うち国際共著　14件／うちオープンアクセス　10件）

１．著者名 Shui-Yee Wong Zoie、Hoshino Eri、Ikegami Naoki	４．巻 33
２．論文標題 A Cost Projection of Scheduled Physician Home-Visit Services in Japan: 2014 to 2064	５．発行年 2020年
３．雑誌名 Journal of Aging & Social Policy	６．最初と最後の頁 692～707
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１．著者名 Liu Jiaxing、Wong Zoie S Y、So H Y、Tsui Kwok Leung	４．巻 28
２．論文標題 Evaluating resampling methods and structured features to improve fall incident report identification by the severity level	５．発行年 2021年
３．雑誌名 Journal of the American Medical Informatics Association	６．最初と最後の頁 1756～1764
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2．論文標題	5．発行年
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3．雑誌名	6．最初と最後の頁
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2．論文標題 Medication-rights detection using incident reports: A natural language processing and deep neural network approach	5．発行年 2019年
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7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関