Early identification and characterisation of stroke to support prehospital decision-making using artificial intelligence: a scoping review protocol

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Early identification and characterisation of stroke to support prehospital decision-making using artificial intelligence: a scoping review protocol

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ABSTRACT

Introduction Stroke is a time-critical condition and one of the leading causes of mortality and disability worldwide. To decrease mortality and improve patient outcome by improving access to optimal treatment, there is an emerging need to improve the accuracy of the methods used to identify and characterise stroke in prehospital settings and emergency departments (EDs). This might be accomplished by developing computerised decision support systems (CDSSs) that are based on artificial intelligence (AI) and potential new data sources such as vital signs, biomarkers and image and video analysis. This scoping review aims to summarise literature on existing methods for early characterisation of stroke by using AI.

Methods and analysis The review will be performed with respect to the Arksey and O'Malley's model. Peer-reviewed articles about AI-based CDSSs for the characterisation of stroke or new potential data sources for stroke CDSSs, published between January 1995 and April 2023 and written in English, will be included. Studies reporting methods that depend on mobile CT scanning or with no focus on prehospital or ED care will be excluded. Screening will be done in two steps: title and abstract screening followed by full-text screening. Two reviewers will perform the screening process independently, and a third reviewer will be involved in case of disagreement. Final decision will be made based on majority vote. Results will be reported using a descriptive summary and thematic analysis.

Ethics and dissemination The methodology used in the protocol is based on information publicly available and does not need ethical approval. The results from the review will be submitted for publication in a peer-reviewed journal. The findings will be shared at relevant national and international conferences and meetings in the field of digital health and neurology.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ The use of a scoping review is an effective method to explore and map broad and diverse research questions.
⇒ This study is guided by a validated methodological framework and has a peer-reviewed search strategy.
⇒ Two reviewers will conduct the screening process to reduce selection bias.
⇒ As this work is a scoping review, no quality appraisal of included studies will be carried out.
⇒ Grey literature and studies not published in English are not included.

INTRODUCTION
Stroke epidemiology and importance of prehospital stroke care

Stroke is caused by disruption of blood flow in the brain and is a major cause of mortality and disability worldwide.[1–3] In middle-income and low-income countries, stroke has doubled in the past four decades.[4,5] In high-income countries, the majority of stroke cases (85%) are caused by occlusion of a vessel by a blood clot, called ischaemic stroke.[3,6] For 24%–46% of ischaemic strokes, the obstruction is located in the proximal part of a major intracerebral artery, referred to as large vessel occlusion (LVO).[6,7] Stroke caused by bleeding, called haemorrhagic stroke, accounts for the remaining cases (15%).[2,3] In ischaemic stroke, the clinical outcome can be improved by early reperfusion therapy with intravenous thrombolysis (IVT)[3,8] and for LVO also mechanical thrombectomy (MT); the latter is performed at specialised comprehensive stroke centres (CSCs).[3,9] Time window for reperfusion treatment may be up to 9 hours for IVT and 24 hours for MT.[10] The effectiveness of reperfusion treatment increases the earlier it can be administered to the patient after the onset of stroke.[11,12] Stroke is thus a highly time-dependent condition, and the phrase 'time is brain' emphasises that brain nervous tissue is rapidly lost as time passes, and optimal treatment should be emergently pursued.[13,14]

Patients with suspected stroke are transferred to hospital by ambulance or present directly at the emergency department (ED).[15 16] Early characterisation is thus defined as to take place in the prehospital assessment or in the ED. Emergency medical service (EMS) clinicians are the first contact with healthcare for the majority of patients who had a stroke,[17] and accurate characterisation of stroke is challenging in prehospital settings due to lack of diagnostic technology, time pressure and heterogeneous clinical presentations.[3] Stroke characterisation starts with the use of clinical stroke scales,[7] which are tests to determine whether the patient is having a stroke.

Identification of stroke is not always straightforward. Similar symptoms may develop in several medical conditions, which are commonly referred to as stroke mimics.[10] Mimics account for 5%–30% of hospital admissions for suspected stroke.[18–20] A significant proportion of patients who had a stroke mimic receive IVT and are admitted to stroke units.[10 18] It is therefore essential to distinguish stroke mimics to avoid the unnecessary use of potentially harmful and expensive treatments.[10 18] Studies from Sweden suggest that 52%–80% of stroke cases are recognised by EMS clinicians,[21–23] and a 62% accuracy in identifying stroke in the prehospital phase has been observed in the USA.[24] Thus, there is a potential to improve stroke characterisation. The term identification in this article refers to the detection of patients who had a stroke (distinguish from stroke mimics). Characterisation in this article refers to first identifying the patients at a high probability of having a stroke and specifying which subtype of stroke they have and its severeness.

Streamlining prehospital stroke management is essential.[25] In many countries when stroke is suspected, the EMS clinician initiates a prenotification to the hospital, which is a telephone consultation to initiate a fast track to reduce the time to imaging[21 26] by CT or MRI.[7] Brain imaging is currently the only way to confirm stroke in clinical practice and differentiate between subtypes of stroke[3] and is only available at hospitals in most settings. However, mobile stroke units, which are specialised ambulances with built-in CT scanners, are used in some areas of the world for rapid and remote characterisation of stroke.[7 27] Furthermore, emerging point-of-care technologies may improve diagnostic capabilities in the future.[28]

Acute stroke management guidelines recommend transferring patients who had a stroke to the nearest hospital offering stroke care, but when the distance to the CSC is not too long compared with the nearest hospital, the patient should be transferred to the facility with the highest level of care.[25 29] Patients with high probability of LVO may be transported directly to the CSC, which is called the mothership strategy.[7 25] When the patient is transferred to the nearest hospital and LVO is confirmed by brain imaging, the patient should be further transported to the CSC to receive MT when time window is sufficient, called drip-and-ship strategy.[7 25] It is of fundamental importance to accurately characterise potential patients with LVO in prehospital settings, as most delays occur in the prehospital phase of acute stroke management.[14 25 30] This allows the transportation of patients to the suitable care centre in the shortest time possible. The American Heart Association (AHA) Guidelines in 2019 called for research in the prehospital procedures for triaging patients to the most appropriate centres, including bypass algorithms.[31]

Stroke assessment based on clinical stroke scales

Different clinical stroke scales are used for stroke assessment in prehospital settings, most of which are based on the National Institutes of Health Stroke Scale (NIHSS).[25 32] NIHSS is a comprehensive stroke assessment test that includes 15 items, which is a time-consuming test and not practical in the prehospital settings.[33] A commonly used scale is the Face Arm Speech Test,[34] which has a low level of specificity but a moderate-to-good level of sensitivity.[3 35–37] Apart from these scales, many scales have been developed to detect a possible LVO,[14 25] such as the Rapid Arterial Occlusion Evaluation Scale and the Prehospital Acute Stroke Severity Scale. Some of these scales identify the presence of motor symptoms and cortical symptoms (neglect, gaze and aphasia).[25] However, many LVO cases remain undetected by scales; for example, 13 scales for LVO detection were evaluated in a study, and the results showed that 20% of LVO cases were undetected.[25 38]

Stroke assessment based on clinical stroke scales alone does not provide sufficiently accurate information, causing treatment delays, transportation of ineligible patients to specialist units and additional demands on resources.[3] New methods for early characterisation of stroke and its subgroups (haemorrhagic stroke, ischaemic stroke and LVO) are emerging and can play a major role in improving the outcome for patients who had a stroke.[3] AHA also called for better prehospital characterisation tools for stroke and found no clear evidence for one tool over another.[31] Recent literature proposes novel stroke detection techniques including new imaging modalities, biomarkers and computerised decision support systems (CDSSs).[7]

Use of artificial intelligence in stroke-related decision-making

Artificial intelligence (AI) is a broad term within the field of computer science and reflects computers performing tasks that might be difficult for humans.[39] Machine learning (ML) is a subset of AI-enabling computers to solve problems by the use of data-driven rules applied on large datasets.[40 41] Our goal is to investigate different types of algorithms that have the potential to improve the early characterisation of stroke, and we therefore refer to a broad range of algorithms when using the term AI in this review.

AI has the potential to be used as decision support for patient management and treatment, to facilitate providing faster and more accurate characterisation of stroke.[42] Early characterisation of stroke could be achieved by the development of CDSSs that are based on ML algorithms,[43] which make the decision with respect to the

patient's medical history, clinical stroke scale score, vital signs and other data sources. New data sources could be biomarkers[7] and image or video-based analysis techniques to quantify facial nerve palsy or motor disorders proposed by many studies.[44] The research group Care@Distance–Remote and Prehospital Digital Health at the Department of Electrical Engineering at Chalmers University of Technology, which comprises most of the authors, consists of subject matter experts in the area of AI-based CDSSs in healthcare. The group focuses on developing CDSSs that are clinically beneficial for remote and prehospital care. AI is used as a tool to enhance patient care, by evaluating the limitations of algorithms and developing interfaces for clinical use to effectively communicate results. Adding competence to the core group, author KJ is a neurologist with clinical expertise about prehospital stroke care, author IH has expertise in computer vision and medical image analysis, and author MP's specialty lies in the digitalisation of healthcare services.

In this scoping review, we will analyse the AI-based CDSS for early characterisation of stroke and LVO detection. The goal is to identify new candidates to bring into prehospital settings.

Aim and objectives

The aim of this study is to identify and summarise existing literature on early characterisation methods for stroke using AI. To fulfil the aim, the following objectives have been established:

1. To summarise the state-of-the-art methods in using AI in the characterisation of stroke in the prehospital setting and/or in the ED, highlight the promising methods and investigate the possibility of using them as decision support in stroke assessment and decision-making, with focus on patients with LVO.
2. To study the accuracy of AI-based CDSSs in terms of common evaluation metrics such as sensitivity, specificity and area under the curve.
3. To identify new data sources and variables that could be used in the early characterisation of stroke such as vital data, observations by EMS clinicians, biomarkers, sensors, video analysis, etc.

METHODS AND ANALYSIS

According to Arksey and O'Malley,[45] a scoping review is a type of literature review with the aim of mapping relevant literature in the addressed research field. Broader research questions are typically covered in scoping reviews as compared with systematic reviews and meta-analyses, and it allows the inclusion of a wider range of study designs.[45] This review will be guided by the Arksey and O'Malley's framework. The model includes a five-stage methodology:

1. Identifying the research question.
2. Identifying relevant studies.
3. Selecting studies.
4. Charting the data.

5. Collating, summarising and reporting the results.

Consultation exercises, which is an optional stage, will not be performed in this review since it might be difficult for practitioners to provide judgement of new AI-based CDSSs because of the complex nature of the algorithms and methods.[46] One of the authors is a clinical expert in neurology and can provide insights into the potential for clinical usability. The scoping review is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses Protocols (PRISMA-P) reporting guideline.[47] The PRISMA-P is primarily developed for the systematic review protocol, all items will therefore not be covered (see online supplemental file 1: PRISMA-P checklist).

Stage 1: identifying the research questions

We have carried out a preliminary review of the literature on stroke characterisation by using AI-based CDSSs. The following research questions have been identified, and we aim to provide answers for them in the review:

1. What is the potential clinical effectiveness of using AI-based CDSSs for early characterisation of stroke in terms of identifying patients who had a stroke, specifically the type of stroke and its severeness. What are the promising AI-based CDSSs?
2. Could AI improve the precision of decisions (eg, in terms of accuracy of the AI-based CDSSs) for where to transport patients who had a stroke and help refine treatment strategies such as mothership and drip-and-ship?
3. What new variables and data sources could be used in early characterisation of stroke (eg, biomarkers, sensors, etc)?

Stage 2: identifying relevant studies

To answer the identified research questions, a search strategy was developed by the research team. The following databases will be searched to provide a systematic search for the relevant studies: PubMed, Scopus, IEEE Xplore, Web of Science, Cochrane Library, Embase, CINAHL, ProQuest, PsycINFO and Google Scholar as they have been used by related studies.

It is essential to select appropriate search terms. There is a variation in the terminology used for the methods that characterise the patients at high probability of having a stroke. Terms such as "characterize", "assess", "detect", "predict", "identify", "recognize" and their variations (characterization, assessment, etc) are used interchangeably in the literature. The search keywords that are used in the scoping review are presented in online supplemental file 2 (search strings). Further search terms might be added later if necessary to comprehensively cover the intended scope. These keywords will be systematically combined using Boolean operator (AND, OR) to capture relevant studies, and the search strings will be defined and adapted for each database (see online supplemental file 2: search strings).

Table 1 Eligibility criteria based on modified PICO[56] (PICO element 'comparator' is not relevant)

	Inclusion criteria	Exclusion criteria
Patient	Patients with suspected stroke	Phases of stroke care not related to initial diagnosis and treatment, for example, rehabilitation
Intervention	AI-based CDSS	The early characterisation method depends on mobile CT scanning Stroke detection image techniques that cannot be used or adapted to the prehospital setting
Outcomes	Study reports accuracy and/or qualitative evaluation	No results for stroke characterisation are reported
Publication type	Peer-reviewed articles and peer-reviewed conference papers	Book reviews, editorial articles, conference abstracts and commentaries
Study design	Qualitative and quantitative studies	Cost-effectiveness and acceptability studies
Publication date	January 1995–April 2023	Full article cannot be obtained
Language	English	Articles not written in English

AI, artificial intelligence; CDSS, computerised decision support system; CT, computerized tomography; PICO, patient/population, intervention, comparator and outcomes.

To identify further articles that might be relevant to this review, the snowballing approach described by Wohlin[48] will be used. Snowballing refers to identifying additional studies by using the reference list in each included article (backward snowballing) and/or the citations to the article (forward snowballing).[48] Both forward and backward snowballing will be used in our search strategy. The cited papers will be searched for in online databases such as PubMed, IEEE Xplore and Google Scholar. The same search process will be repeated until no new articles are found.

Regarding the eligibility criteria outlined in table 1, the scope of this review includes peer-reviewed articles and peer-reviewed conference papers that examine the use of AI-based CDSSs and/or report new data sources for stroke characterisation in prehospital and/or ED settings. Studies that focus on mobile CT scanning will be excluded because they are still expensive solutions and focus on a different concept.[49 50] Since potential clinical effectiveness is not determined by accuracy of algorithms alone, but also relates to the usability of the algorithms in clinical context, both qualitative and quantitative studies are included. The search is limited to articles published between 1 January 1995 and 30 April 2023. The rationale for excluding articles before 1995 is that it was around this time that effective ischaemic stroke treatments became widely available.[51] Quality appraisal or quantitative synthesis will not be conducted for this scoping review.

Stage 3: study selection
After identifying relevant studies from the selected databases and search engines, there is a need for a systematic method to decide what papers to include in the study in a consistent way. The study selection workflow is presented in figure 1. The retrieved articles will be exported into a referencing software, Zotero Reference Manager,[52] to remove duplicate studies. Title and abstract screening will then be done to assess the relevance of the

articles. To avoid any bias among the reviewers, two of the reviewers (authors HJ and MS) will use Rayyan (Rayyan Systems, Massachusetts, USA)[53] to independently review the articles, blinded from other reviewers' decisions or comments. Rayyan is a free tool to help reviewers with the initial screening of titles and abstracts to filter searches for eligible studies for systematic reviews.[54]

The full text of the relevant studies will then be screened following the same independent double-screening process used for the initial screening. To decide whether to include or reject the retrieved studies, the eligibility criteria will be applied (table 1). In case of disagreement about certain studies, an additional reviewer will be involved. All reviewers will use the same criteria when voting for whether to include an article. Final decision will be made based on majority vote.

Stage 4: charting the data
Studies and articles that pass the full-text screening will be summarised and charted at this stage. An Excel sheet will be used for data extraction. We will include the information outlined in table 2 in the data extraction of every included study, and the data will be categorised and sorted accordingly.

To ensure that the presented framework is suitable and can be applied consistently, at least two reviewers will test it on a sample of included articles. The charting categories will be modified if needed, and the data extraction framework can be revised accordingly. Any modifications will be presented and explained in the review.

Stage 5: collating, summarising and reporting the results
We will identify, analyse and summarise research evidence, and an overview of the reviewed literature will be presented at this stage. A PRISMA flow chart will be presented, and we will describe the methodology in detail. A descriptive summary and a thematic analysis will be provided from the analysis of the collected data, which
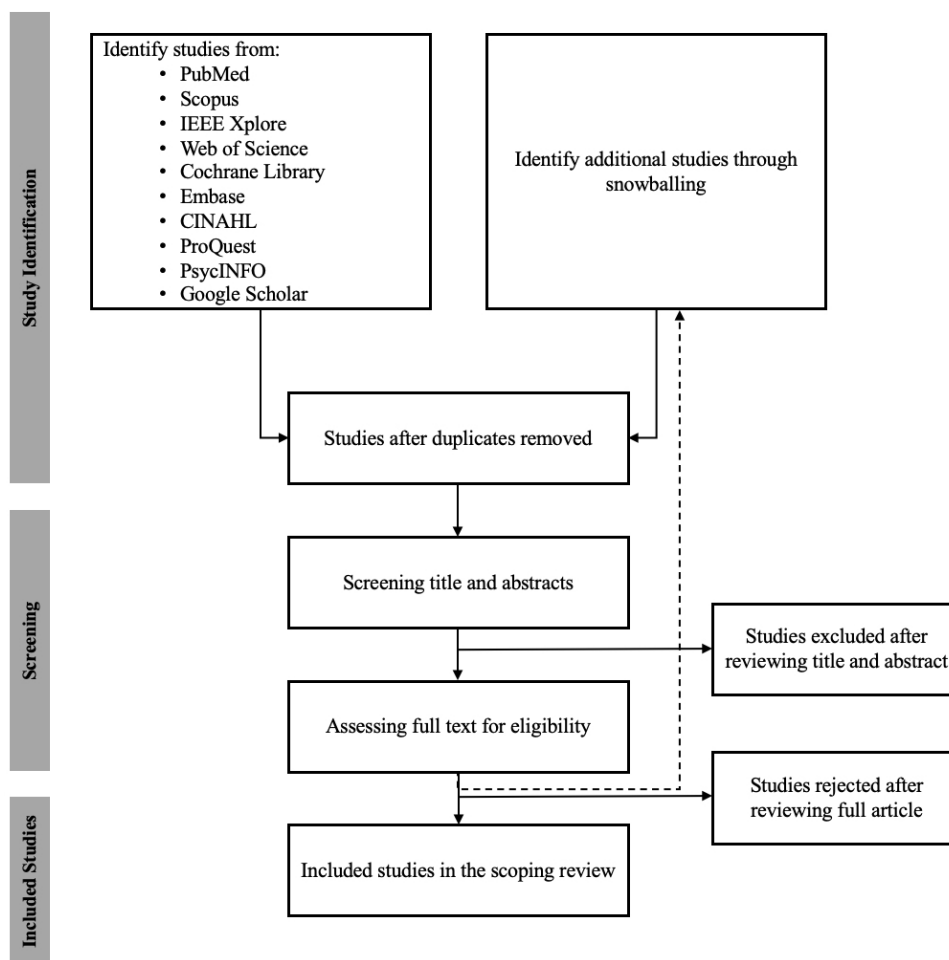
Figure 1 Study selection workflow.

Table 2	Data extraction form
Data items	**Associated questions**
Title	What is the title of the study?
Author(s)	Who carried out the study?
Year of publication	What year was the study published?
Country of origin	Where was the study performed?
Type of study	What type of published literature was the source? Journal or conference paper?
Study aims	What were the aims of the study?
Study population	What stroke type(s) were studied? What was the demographic distribution of the studied population?
Study design	What was the design of the study (eg, retrospective or prospective)? How was the ML method validated?
Study size	What was the sample size?
Method of characterisation	How does the characterisation method work? What algorithms and variables were used?
Main findings and measures	What is the reported accuracy in terms of sensitivity, specificity, positive predictive value and AUC? What other evaluation metrics are reported in the study? What novel datasets or variables were investigated?
Advantages and limitations of the study	What advantages does the method offer? What are the limitations of the study?
AUC, area under the curve; ML, machine learning.	

will contain common characteristics of the included studies by applying a consistent approach on every study. We will compare included studies and present the key findings necessary to characterise stroke using AI-based CDSSs. The results will be reported with respect to our research questions and main findings and measures in table 2, for example, clinical effectiveness, reported accuracy and new data sources. A table will be compiled based on the data extraction, which will provide key information about the studies including study year, method, study design, limitations, etc. Any additional details will also be included to assist in the understanding of studies and performing a comprehensive analysis.

Patient and public involvement
None.

ETHICS AND DISSEMINATION
Ethical approval is not needed for this study as it will include information from articles already published. The scoping review results are expected to be disseminated in a peer-reviewed scientific journal in 2023. The results will be disseminated through national and/or international conference presentations and meetings in the fields of digital health and neurology. Any amendments to this protocol will be explained in the final review.

DISCUSSION
Stroke is a leading cause of mortality and disability worldwide, and early stroke characterisation methods are emerging to improve stroke management and facilitate access to comprehensive care for more patients with LVO. Early identification and characterisation of stroke are challenging, and the use of AI models to support decision-making has potential for improving the precision of decisions in prehospital and ED settings. Improving stroke care with AI combined with human interpretations will be critical to create CDSSs that work rapidly, reliably and accurately in clinical settings.

This protocol provides an approach to synthesising a variety of research evidence of early stroke characterisation. The results will report novel information about the current state-of-the-art of stroke characterisation, identify potential new data sources and highlight the research gaps in the literature. This scoping review will contribute to the research field by a systematic description of the current literature, covering the effectiveness and accuracy of data and AI usage in stroke prehospital decision-making. The work will hopefully help researchers in engineering and healthcare sciences to identify research gaps, and to make relevant research initiatives and effective study designs. By synthesising existing research on AI-based CDSSs, a scoping review can help identify best practices for the design of these systems. This can lead to more effective and user-friendly systems that can improve communication and coordination between EMS, hospitals and stroke

centres so that more eligible patients can be transported according to the mothership strategy. Furthermore, the review can bring insights to all actors within stroke care regarding what variables are valuable to collect, factors that influence if the CDSS fails or succeeds, and specific requirements that should be considered during the design of the CDSS. The results will also assist in our upcoming work of co-creating[55] an AI-based CDSS for the early characterisation of stroke.

Given that this is a scoping review, one of the limitations is that no quality assessment and quantitative data synthesis will be carried out. Grey literature is not included in this study and only articles published in English will be included, potentially relevant articles may thus be missed. We will acknowledge any additional limitations identified during the review process in the publication of the scoping review.

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