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Emerging artificial intelligence-aided diagnosis and management methods for ischemic strokes and vascular occlusions: A comprehensive review

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ABSTRACT

Large-vessel occlusion (LVO) stroke is a promising field for the use of AI, especially machine learning (ML) because optimal results are highly dependent on timely diagnosis, communication, and treatment. In order to better understand the current state of artificial intelligence (AI) in relation to LVO strokes, its efficacy, and potential future applications, we searched relevant literature to perform a comprehensive evaluation of the topic. The databases PubMed, Embase, and Scopus were extensively searched for this review. Studies were then screened using title and abstract criteria and duplicate studies were excluded. By using pre-established inclusion and exclusion criteria, it was decided whether or not to include full-text papers in the final analysis. The studies were analyzed, and the relevant information was retrieved. In recognizing LVO on computed tomography, ML approaches were very accurate. There is a shortage of AI applications for thrombectomy patient selection, despite the fact that certain research accurately evaluates individual patient eligibility for endovascular therapy. Machine learning algorithms may reasonably predict clinical and angiographic outcomes as well as associated factors. AI has shown promise in the diagnosis and treatment of people who have just suffered a stroke. However, the usefulness of AI in management and forecasting remains restricted, necessitating more studies into machine learning applications that can guide decision making in the future.

1. Introduction

The World Health Organization defined stroke in 1970[1] as ″rapidly acquired clinical symptoms of focal (or global) impairment of brain function, lasting more than 24 h or leading to death, with no clear cause other than a vascular origin″.[1] A diminished blood flow to the brain characterizes this illness, which leads to cell death. With 16 million incidents, stroke is the second most common cause of mortality worldwide. In the US population, stroke prevalence rises with age, from 2.7% in those under 20 to 6% in those over 60 to 13% in those over 80. Each year, there are around 800,000 new or recurring cases of stroke. Despite advancements, 17.5% of individuals still die, making it the fifth leading cause of death in the United States.[2] A stroke is a medical disorder characterized by cell death caused by the inadequate blood supply to the brain. There are two primary forms of stroke: ischemic, which is caused by a lack of blood flow, and hemorrhagic, which is caused by hemorrhage. Both conditions impair the correct functioning of portions of the brain 3. When a stroke occurs, it is important to seek quick immediate treatment. Long-term incapacity, permanent brain damage, and even death can result from a stroke. After a stroke, one may experience symptoms across a broad spectrum from slight weakness to complete

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Abbreviations

(LVO)	Large-vessel occlusion
(ML)	Machine learning
(AI)	Artificial intelligence
(ICH)	Intracerebral hemorrhage
(CSF)	Cerebrospinal fluid
(SAH)	Subarachnoid hemorrhage
(CT)	Computed tomography
(MRI)	Magnetic resonance imaging
(RFL)	Random forest learning
(MT)	Mechanical thrombectomy
(SVM)	Support vector machines
(CTA)	Computed tomographic angiography
(CACS)	Coronary artery calcium score
(EHR)	Electronic health record
(PACS)	Picture archiving and communication system
(RIS)	Radiology information system
(IC)	Incremental Cost
(IE)	Incremental Effect
(QALYs)	Quality-Adjusted Life Years

paralysis of the face or body. A sudden, severe headache, sudden weakness, trouble seeing, trouble speaking, or trouble understanding speech are all signs that something is wrong with the brain's ability to function in a normal physiological pattern.[3] An ischemic stroke develops when a brain-supplying artery gets obstructed or ″clogged″, reducing blood flow to a portion of the brain. Within minutes of oxygen and nutrition deprivation, brain cells and tissues begin to die.[4] Feske.[5] stated in his study that primary care practitioners are frequently challenged by cerebrovascular disorders. It is the major cause of hospitalization due to a neurologic illness. AI's impact on stroke detection and management lies in its ability to improve diagnostic accuracy, support medical decision-making, provide personalized treatment plans, and enhance research efforts. As AI technology continues to evolve, its role in stroke management is expected to grow, benefiting both healthcare providers and patients. This review focuses on the AI-based diagnosis of ischemic stroke and major vascular occlusions that result in debilitating outcomes. It also attempts to determine the potential cost-effectiveness and reviews the accuracy matrices of computer-assisted LVO identification in ischemic stroke. A study of this type could be used to provide early guidance for the development and application of AI tools by indicating their potential utility in the area of stroke management.

2. Techniques extensively studied over the past decade

Research and development into LVO care have accelerated over the

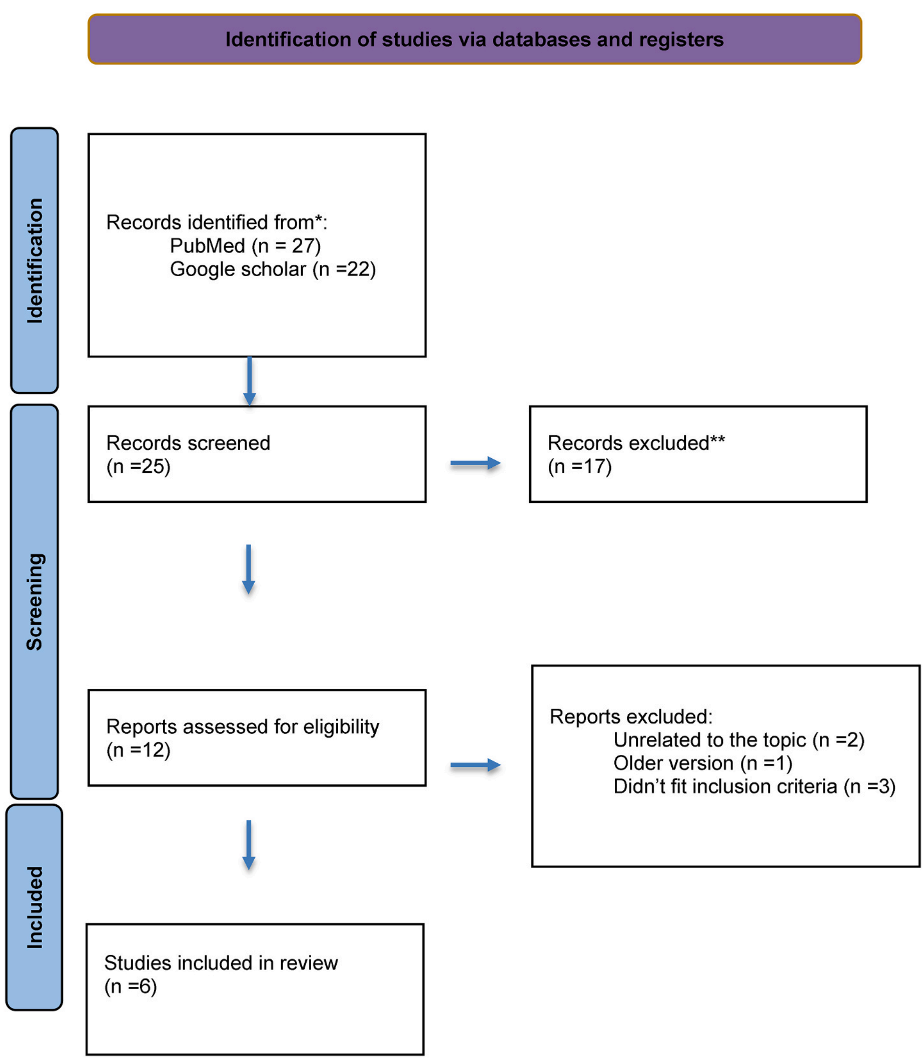

Fig. 1. Flowchart diagram of literature search.

past decade, resulting in techniques that enable earlier diagnosis and better occlusion treatment. Recent developments in mechanical thrombectomy (MT) have been significant in enhancing treatment for LVO.[6] Nicholls et al[7] reviewed sixty-two recent studies and found that LVO detection techniques were categorized into 5 groups: (a). stroke scales, (b). imaging and physiological methods, (c). algorithmic and machine learning approaches, (d) physical symptoms and biomarkers.[7] Typically, clinical presentation and the application of stroke triage measures serve as the primary means of stroke detection, followed by neuroimaging at a medical institution for confirmation. While it is generally acknowledged that computed tomography (CT) and magnetic resonance imaging (MRI) are the gold standards for validating stroke imaging, it is less apparent what the best methods for detection and triage are before neuroimaging. Moreover, this was included in the most recent AHA Guidelines (2019), which called for improved prehospital stroke detection tools but found no clear evidence to favor one approach over another.

3. Current landscape of mechanical thrombectomy in stroke management

Recent research has proposed improved scales and innovative detection approaches, such as biomarkers, new imaging modalities, clinical manifestations, and decision-oriented algorithms that combine these. These are utilized in addition to conventional stroke prediction measures. These are all utilized in addition to conventional stroke prediction measures.[7] The severity of neurological symptoms, the number of blocked arteries, the size of the infarct, and whether or not the treatment is able to maintain the infarct small are the most critical elements in determining the prognosis of patients with acute ischemic stroke.[8] The prognosis of individuals with acute ischemic stroke depends on the severity of neurological symptoms, the artery that is blocked, the size of the infarct, and whether or not therapy is successful in keeping the infarct small.[9] Patients with large vascular occlusions (LVOs) should be provided endovascular mechanical thrombectomy, with or without intravenous thrombolysis, during an extended window of up to 24 h. The suggested therapy for a patient with an LVO is one of these two options. According to the findings of a study by Fujita et al.,[9] a total of 150 people were studied, with a median age of 92. Up to a third of patients suffered from endovascular treatment (EVT) complications (32.7%; 43 had mechanical thrombectomy). The EVT group performed better than the medical management group in terms of a shorter amount of time between the beginning of the stroke and the arrival at the hospital ($p = 0.03$), a higher number of points on the Alberta Stroke Program Early CT Score ($p < 0.01$), and greater rates of therapy with intravenous thrombolysis ($p < 0.01$).[9]

4. Conventional stroke management

The majority of strokes are caused by artery occlusion-induced ischemic stroke. Rapid reperfusion using intravenous thrombolysis and endovascular thrombectomy, which both lessen disability but are time-sensitive, is the focus of treatment. To maximize the advantages of reperfusion treatments, it is crucial to enhance the system of care in order to avoid treatment delays. When delivered within 4.5 h of stroke onset, intravenous thrombolysis lowers disability. Thrombolysis is also advantageous for patients with perfusion imaging indications of salvageable brain tissue for up to 9 h, as well as individuals who awaken with stroke symptoms.[10] Campbell et al[10] also mentioned his study that endovascular thrombectomy decreases disability in a large cohort of patients with major artery blockage when done within 6 h of a stroke onset and in individuals chosen by perfusion imaging for up to 24 h after stroke onset. Managing cardiovascular risk in other areas of health shares many elements with secondary prevention of ischemic strokes, such as blood pressure control, cholesterol management, and antithrombotic medications. Other preventive measures are adapted to the cause of the stroke, such as anticoagulation for atrial fibrillation and carotid endarterectomy for severe symptomatic carotid artery stenosis.[10] Conversely, hemorrhagic strokes take place when a blood vessel supplying the brain bursts and bleeds into the brain tissue. When an artery bleeds into the brain, oxygen and nutrients are denied to brain cells and tissues. Additionally, pressure builds up in the surrounding tissues, causing inflammation and swelling, which can cause additional brain injury.[4] A hemorrhagic stroke is an abrupt neurologic damage that results from bleeding into the head. Two separate processes exist: bleeding directly into the brain parenchyma (intracerebral hemorrhage [ICH]) and bleeding into the cerebrospinal fluid (CSF) containing sulci, fissures, and cisterns (subarachnoid hemorrhage [SAH]).[11] Large vascular occlusion (LVO) is the blockage of large, proximal cerebral arteries and accounts for 24–46% of acute ischemic stroke (AIS) when both A2 and P2 segments of the anterior and posterior cerebral arteries are included.[2] Due to the involvement of proximal vasculature, important brain areas are frequently damaged, resulting in substantial neurological impairments.[6]

5. Methodolgy

5.1. Search strategy

To find relevant papers, an electronic literature search was conducted using the MEDLINE databases via PubMed and Google Scholar. The search was restricted to publications written in English and published between 2020 and 2023. The search terms used were (″Artificial intelligence″ OR ″AI″) AND (″Ischemic stroke″ OR ″venous occlusion″) AND (″Management), (″Artificial intelligence″) AND (″Ischemic stroke″) AND (″Management),(″venous occlusion″) AND (″AI″) AND (″Management″).

5.2. Inclusion criteria

- Studies that investigate artificial intelligence-aided diagnosis and management methods for ischemic strokes and vascular occlusions.
- Research articles written in English.
- Studies conducted on human subjects or in vitro models.
- Studies published in period of 2020–2023.
- Articles published in peer-reviewed journals.
- Studies that provide clear methodologies and data on artificial intelligence-aided diagnosis and management methods for ischemic strokes and vascular occlusions.

5.3. Exclusion criteria

- Review articles, editorials, letters, and conference abstracts.
- Studies focusing solely on all aspect of management of Ischemic stroke/venous occlusion.
- Studies that do not specifically examine the artificial intelligence-aided diagnosis and management methods for ischemic strokes and vascular occlusions:.
- Non-English articles.
- Studies with insufficient or unclear methodology and data.

5.4. Eligibility criteria

The electronic article search was followed by the evaluation of studies based on their title and abstract. Subsequently, the full text of the selected articles was carefully assessed, taking into account specific inclusion and exclusion criteria. Only articles that met the inclusion criteria were chosen for the study.

5.5. Outline of the data extraction process

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6. Role of artificial intelligence as an aid in management

Artificial intelligence (AI) is a groundbreaking technology that uses computer algorithms to analyze complicated data. Diagnostic imaging is one of the most promising clinical uses of artificial intelligence, and growing emphasis is being placed on establishing and enhancing its performance to make it simpler to identify and quantify a wide range of clinical problems. Studies using computer-assisted diagnostics have proven high specificity, sensitivity, and accuracy for the diagnosis of small radiographic abnormalities, which has the potential to improve public health. The optimal outcomes that can be achieved after a stroke caused by a large-vessel occlusion (LVO) are highly dependent on timely diagnosis, effective communication, and treatment. Because of this, LVO is a promising application area for artificial intelligence (AI), and machine learning (ML). The number of people who have an acute ischemic stroke (AIS) is still very high, which makes it the leading cause of death and disability around the world.[12] Large-vessel occlusion, also known as LVO, accounts for 29.3 percent of all instances of AIS and affects 24 out of every 100,000 individuals annually. The frontal circulation is the location of the majority of these occurrences.[13] Large vascular occlusions (LVOs) which are acute ischemic strokes must be diagnosed as soon as possible during pre-hospital triage like electrocardiograms are being used to detect acute myocardial infractions.[9] Endovascular thrombectomy (ET) and LVO verification in the hospital are important ways to reduce morbidity and mortality.[14] Increasingly, commercially available platforms providing automated information about various components of the acute stroke triage pathway are being integrated into routine clinical practice and clinical trials. These tools offer fast and efficient analyses that seek to optimize the delivery of stroke care at spoke and hub hospitals and reduce turnaround times in the clinical workflow.For Instance, Aidoc stroke triage mobile interface provides a notification alert, a study list of cases, NCCT of an acute stroke, and a text messaging system. Avicenna.AI DL-based ASPECTS tool demonstrates identification of ASPECTS and a heat map overlay. Brainomix e-CTA tool demonstrates identification and localization of an LVO of the right MCA, collateral score and collateral vessel attenuation, and a heat map of the collateral deficit.[15]Scaling systems also aid in various ways. The modified Rankin Scale for a single patient with an LVO ranges from 0 to 6 which is measured for the number of patients required to be treated to achieve at least a one-level improvement.[16] The Alberta Stroke Programme Early CT Score can be used to detect LVOs using non-invasive cerebral angiography and perfusion investigations that also evaluate infarct core and penumbral volume mismatch. These studies aid in determining which patients should be considered for acute ET.[17,18] Artificial intelligence (AI) is being promoted as a means of meeting this need. Recently, AI has been used to develop norms for identifying LVO strokes. The AI functionality in stroke imaging software packages varies, and the majority of it is still proprietary. In artificial intelligence (AI), machine learning (ML) is a subfield which focuses on the development and exploration of methods for extracting useful knowledge from large data sets in order to inform decisions. LVO stroke detection algorithms are an example of ″narrow AI,″ or AI that excels only at a limited set of tasks due to its reliance solely on ML and a small amount of tailored data.A few supervised ML and DL techniques have been proposed that can be of interest for specific stroke analyses.**Imaging triage and workflow**. DL algorithm of Al is able to preprocess, interpret, and alert physicians of urgent findings many times faster than humans. Additionally, the urgent cases appear at the top of the worklist earlier through the automated prioritization system. For image prioritization and overall workflow management using a traditional ML algorithm for stroke detection in non-contrast CT datasets has also been investigated.This algorithm can function as a rapid screening tool for alerting physicians.[19] **Image optimization** Another area in which AI has shown incredible progress lately is image optimization and quality improvement. These processes, which include fast image acquisition and reconstruction, denoising, artifact reduction, and resolution improvement, have considerable overlap in some instances. **Image analysis** Given the vast amount of data, time-sensitive nature of stroke, and potential for immediate clinical impact, image analysis has become arguably the most promising application of AI for stroke imaging. Image analysis encompasses detection and segmentation, classification, and prediction of stroke outcome using AI methods. Supervised AI techniques have shown great promise for the support of image-based diagnosis support in acute ischemic stroke patients.The main goal of any AI or ML system in strokes to determine accurately whether or not a large vascular occlusion (LVO) is present in three-dimensional tomographic images. This can be accomplished in a number of ways. However, there are several potential paths to take in order to achieve this goal using ML methodologies. The terms of input abstraction are different (i.e., image input manipulation, whether as manually engineered image abstract feature representations or non-abstract pixel intensities), function approximation (i.e., an algorithmic method of estimating or fitting the value of different image data states with similar features; this includes methods such as a support vector machine, random forest learning (RFL), or deep neural network), and final algorithm output format. The manipulation of the input image is referred to as input abstraction.[20] Before the next stage can be considered successful, the results of the early health technology evaluation must be validated in clinical settings. As the number of AI tools used in clinical settings increases, it is critical to assess the impact of these tools on our nation's healthcare system. Real-world result measurements should be used to gain insights into how to implement AI technologies responsibly and safely. This precondition must first be met in order to establish the claim that AI is improving and lowering the cost of healthcare.[21]

6.1. Machine learning methods for detection of occlusions

Artificial intelligence (AI), a wide term referring to the use of computers to do difficult tasks, has recently been applied to LVO care and research to overcome these issues. Machine learning (ML), a subset of artificial intelligence (AI) involving computer problem-solving using data-driven algorithms derived from large data sets without explicit human programming, has gained prominence due to the potential for rapid automatic evaluation of patients with stroke and selection for mechanical thrombectomy (MT). Input abstraction: Relying on inference from low-dimensional signals extracted from high-dimensional volumes opens the door for domain expertise to be incorporated. Thus, many people agree that hand-crafted aspects make this technique more ″interpretable,″ however this type of input frequently limits the effectiveness of ML algorithms.[21] Function Approximation: Humans are tasked with identifying a function within a strongly outlined class that closely approximates a given target function in a function approximation problem. When the precise value of a function for a set of inputs is prohibitively expensive, an approximation functional form is required. The kernel trick is a method for implicitly mapping inputs to a higher dimensional feature domain in order to transform a linear learning model and its corresponding training procedure into a non-linear one. Support vector machines (SVM) use numerical characteristic vectors, or feature vectors, to represent the object of interest in the images. All of the feature vectors for all of the pictures define an n-dimensional vector space, also known as a feature space. Weights are assigned to feature values when creating a linear predictor function. In practice, SVM works well if n is small, that is, if the feature space is abstracted down to a small number of dimensions.[21] Because the output is confined to the instance level, the ML method performs heavy dimensionality reduction. Because of the dimensionality reduction, the learning process may be more susceptible to overfitting. Supervisory signal: In the absence of labels that reflect the contextual information and can be used for training, learning models may still be trained by optimizing for encodings that, for example, create clusters in the encoded domain or can be decoded to replicate the input.

6.2. Artificial intelligence software for occlusion detection

LVO detection capabilities are available in a variety of AI software systems. While not all are available in the United States, these have varying degrees of automated perfusion, angiographic vascular image processing, and artificial intelligence recognition of acute stroke characteristics on imaging. Artificial intelligence has the potential to standardize and improve care when applied to stroke diagnosis and LVO detection. The number of randomized controlled trials comparing various types of AI software is still quite low. Validation and evaluation of this type of tool necessitate the development of procedures that are both systematic and standardized. Blood tests, computerized tomography (CT) scans, magnetic resonance imaging (MRI), carotid ultrasound, cerebral angiogram, and echocardiogram are all used to diagnose LVO. When it comes to AI in LVO, the application has also been used to analyze the plaque occluding the vessel as well as the morphology of its component. The standardized assessment is performed using a computed tomographic angiography (CTA) scan, which determines whether the plaque is calcified or noncalcified. The coronary artery calcium score is one method of assessing calcification (CACS). Moreover, it is a time-consuming and tedious process that is rarely used. AI has aided in the evaluation of coronary calcium scores.[22] (CAC) score is a surrogate measure of atherosclerotic plaque burden within the coronary arteries that has been shown to predict CAD events.CAC is traditionally assessed non-invasively using electrocardiogram-gated computed tomography (CT) imaging of the heart, without the need for intravenous contrast. Automated models for CAC assessment using cardiac CT have been reported, including rule-based, machine learning, and deep learning approaches. Fully automated identification and quantification of CAC that requires very little or no human analysis can potentially decrease the workload of human operators, be more time-efficient, reduce costs, and play a role in large-scale screening strategies or epidemiological studies.In one study,[23] fully convolutional neural networks for automated CAC scoring were developed and trained on 2439 cardiac CT scans and validated using 771 scans. The model was tested on an independent set of 1849 cardiac CT scans. This artificial intelligence–based fully automated CAC scoring model shows high accuracy and low analysis times. A study caried out to evaluate an artificial intelligence (AI)-based, automatic coronary artery calcium (CAC) scoring software, using a semi-automatic software as a reference.[24] This observational study included 315 consecutive, non-contrast-enhanced calcium scoring computed tomography (CSCT) scans. There was an excellent correlation and agreement between the automatic software and the semi-automatic software for three CAC scores and the number of calcified lesions. Risk category classification was accurate but showing an overestimation bias tendency. Also, the automatic method was less time-demanding. So, research to date on applying AI to CAC scoring has shown the potential for automation and risk stratification, and, overall, efficacy and a high level of agreement with categorisation by trained clinicians have been demonstrated. However, research in this field has not been uniform or directed. Table 1 details a list of studies that tested accuracy matrices of different methods and softwares in the recent years.

6.3. Artificial intelligence: a feasible economic option

According to a survey of 511 patients, male and female AI patients had diagnosis accuracy rates of 94.3% and 92.3%, respectively. The researchers also discovered that the deep learning process produced results in just 2.7 s on average. Given that it has been confirmed by an observer, the idea of using it in CACS appears feasible, given its high accuracy and short median time.[22] According to one study, using the base case assumptions (6% missed LVO diagnoses by clinicians, \$40 for an AI analysis, and a 50% reduction in missed LVOs by AI) resulted in cost savings and incremental QALYs over the projected lifetime (IC: \$156, 0.23%; IE: +0.01 QALYs, +0.07%) per suspected ischemic stroke patient (IC: \$156, 0.23%; IE: +0.01 QALYs, +0.07%). This translates into annual cost savings of \$11 million for each patient cohort in the UK.

Table 1
Latest advances in artificial intelligence methods and softwares along with their respective accuracy matrices.

Study	Aim	Study Type	AI method and software	Accuracy matrices	N
(Rava et al, 2021)[25]	To evaluate an application's capacity to detect and locate LVOs in AIS patients.	Retro prospective	CTA	Accuracy = 81% Sensitivity = 73% Specificity = 98%	303
(Adhya et al, 2021)[26]	Utilize emerging approaches for diagnosis of anterior circulation artery blockages by assessing relative vascular densities.	Prospective	RAPID-CTA	Sensitivity = 80% PPV = 87%	310
(Morey et al, 2021)[27]	To reduce time-to-treatment and improving clinical outcomes.	Retrospective	Viz.ai LVO	Sensitivity = 82% Specificity = 94%	55
(Meng et al, 2022)[28]	Use deep learning pipeline to detect large vascular occlusion (LVO) and predict functional outcomes based on CTA images to optimize LVO patient care.	Retrospective	Inception-V1 I3D	Sensitivity = 89% Specificity = 66% Accuracy = 96%	8650
(Matsoukas et al, 2022)[29]	Evaluate the precision of AI software in a multihospital stroke network.	Prospective	Viz LVO	Sensitivity = 91.1% Specificity = 93.8% Accuracy = 91.2%	1822
(Bathla et al, 2022)[30]	LVO identification at the level of the picture to speed patient triage for mechanical thrombectomy.	Retrospective	4D-CTA/CT perfusion (CTP) images using neural network (NN) models	Sensitivity = 86.5% Specificity = 89.5% Accuracy = 85.5%	306

The use of AI in emergency care for LVO identification has the potential to improve patient outcomes while also lowering costs.[21]

7. Hurdles to artificial intelligence

Even so, using AI has its own set of drawbacks. One is the requirement for large, systematic, and accurate data, which takes a significant amount of time and money when compared to other methods, which are known to be less expensive and faster. Overfitting is another disadvantage. In this case, an artificial intelligence (AI) system detects noise rather than a signal which is often critical to the diagnosis. This incorrect detection distorts the results and may result in false positive findings. It is essential to acknowledge the shortcomings and challenges that prevent generalizability and clinical implementation of supervised AI techniques, despite the fact that these techniques have demonstrated a great deal of promise for the support of image-based diagnosis in acute ischemic stroke patients. In this part, we will discuss the primary concerns from three different points of view: data-related, medicolegal, and ethical. **Data limitations:** Many of the aforementioned studies are supervised machine learning techniques that depend on existing data and collecting these datasets in a centralizing location, which is primarily limited due to medicolegal and ethical considerations. In reality, existing datasets are not only decentralized but also small, often with only tens of patients in each center. Additionally, these trained datasets may reflect underlying human biases, such as decision making factoring in ethnicity, which is a common problem in medicine in general [89]. Another concern regarding datasets is the lack of knowledge of how these AI tools actually process these training data, leaving room for potential research but also an area of vulnerability. **Medicolegal:** With promising results in specific areas of radiology, including and especially neuroradiology, supervised AI techniques have understandably garnered considerable enthusiasm. However, there are many medicolegal concerns that must be addressed that currently limit widespread implementation. Challenges include what the definition of AI exactly entails, whether AI products would be considered medical devices, how to assess for innovation moving forward, and whether the decisions they ultimately render regarding regulation are, in fact, even timely. **Ethical:** Data protection in particular has become another point of contention in the AI community. Datasets used as training, validation, and testing sets in AI techniques contain sensitive patient information.This might lead to creation of datasets that may be obtained illegally or simply by accident that compromise patient confidentiality. With AI being a data-driven endeavor, cybersecurity has become a concern as well. Since these technologies spread sensitive data at fast rates, data protection has become challenging, leaving patients and institutions vulnerable to cyberattacks. This, coupled with the lack of knowledge of the inner workings of these tools, creates ethical, medicolegal, and regulatory challenges.

7.1. Future prospect of artificial intelligence

In this overview of artificial intelligence, we've talked about a number of ways AI could be used to help diagnose and treat ischemic stroke. In spite of this, there is a lot of opportunity for progress, and the future holds many interesting prospects in this sector. In the current climate, the most important questions to ask are about the incorporation of these AI platforms into clinical practice and the way in which these platforms influence the workflow of neuro-radiologists. AI integration with the electronic health record (EHR), picture archiving and communication system (PACS), and radiology information system (RIS) at the individual, institutional, locoregional, national, and international levels are promising future research areas. In addition, as mentioned earlier, the validity, generalizability, and legality of these technologies are critical considerations that have a significant impact on integration. In order for AI to continue to act as an auxiliary to a neuroradiologist's workflow, there must be a continual emphasis on the validation of these tools through rigorous clinical research, as well as an emphasis on their integration. In addition, we must acknowledge that these powerful platforms will continue to radically alter the delivery of healthcare, particularly in fields such as radiology, for decades to come. However, they are likely to improve the workflow and clinical management of stroke patients and will aid physicians in diagnosis and treatment decision-making. LVO is a subtype of AIS that is particularly significant for AI applications because to the high morbidity and fatality rates associated with it in comparison to other kinds of AIS. Patients diagnosed with LVO stroke may benefit from faster triage, diagnosis, patient selection, and prognostication thanks to the application of machine learning (ML) techniques and deep learning. In this study, we examine the existing body of evidence and offer a systematic evaluation regarding the use of AI in the triage, diagnosis, patient selection, and outcome prediction of LVO.

8. Conclusion

Although artificial intelligence continues to be a useful technology in the medical field, it has yielded some promising results in research settings. AI has been found to be useful in stroke prompt detection, patient selection, and outcome prediction. Thus, many studies have demonstrated high accuracy in diagnosis and have also been estimated to be financially viable. While there is an initial cost it is beneficial in the long run as an efficient tool. More studies validating the same are required before it can be widely used in a conventional setting.

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Data availability declaration

The authors confirm that all data used in the study are available upon request from the corresponding author and can be shared with interested parties. The authors further declare that the data used in the study has been properly documented and stored in accordance with the ethical and legal requirements.

CRediT authorship contribution statement

G.A.U.R.I. Parvathy: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **B.A.L.A.K.R.I.S.H.N.A.N. Kamaraj:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **B.I.K.I.K.U.M.A.R. Sah:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **A.A.K.A.N.S.H.R.A.H.U.L. Maheshwari:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **A.I.S.W.A.R.I.Y.A. A.N.N.A. Alexander:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **V.I.N.D.H.E.S.H. Dixit:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **H.A.S.S.A.N. Mumtaz:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **M.U.H.A.M.M.A.D. Saqib:** Writing – review & editing, Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements Declaration

None.

References

1. Aho K, Harmsen P, Hatano S, Marquardsen J, Smirnov VE, Strasser T. Cerebrovascular disease in the community: results of a WHO Collaborative Study [Internet] *Bull World Health Organ*. 1980;58(1):113. Available from:/pmc/articles/PMC2395897/?report=abstract . Accessed November 7, 2022.
2. Rennert RC, Wali AR, Steinberg JA, et al. Epidemiology, natural history, and clinical presentation of large vessel ischemic stroke [Internet] *Neurosurgery*. 2019 Jul 1;85 (Suppl 1):S4. Available from:/pmc/articles/PMC6584910/ . Accessed November 7, 2022.
3. NIH [Internet]. *Stroke - what Is a Stroke? | NHLBI*. NIH; 2022 [cited 2022 Nov 7]. Available from: https://www.nhlbi.nih.gov/health/stroke.
4. Johns Hopkins Medicine. Types of strokes [Internet]. Johns Hopkins Medicine *Johns Hopkins Medicine*; 2022 [cited 2022 Nov 7]. Available from: https://www.hopkinsmedicine.org/health/conditions-and-diseases/stroke/types-of-stroke.
5. Feske SK. Ischemic stroke. *Am J Med*. 2021 Dec 1;134(12):1457–1464.
6. Minhas JS, Wang X, Lindley RI, et al. Comparative effects of intensive-blood pressure versus standard-blood pressure-lowering treatment in patients with severe ischemic stroke in the ENCHANTED trial [Internet] *J Hypertens*. 2021 Feb 1;39(2), 280–5. Available from https://pubmed.ncbi.nlm.nih.gov/33031175/. Accessed November 7, 2022.
7. Nicholls JK, Ince J, Minhas JS, Chung EML. Emerging detection techniques for large vessel occlusion stroke: a Scoping review. *Front Neurol*. 2022 Jan 6;12:2477.
8. González RG. Clinical MRI of acute ischemic stroke [Internet] *J Magn Reson Imaging*. 2012 Aug;36(2):259. Available from:/pmc/articles/PMC3400122/ . Accessed November 7, 2022.
9. Fujita K, Tanaka K, Yamagami H, et al. Outcomes of large vessel occlusion stroke in patients aged ≥90 Years [Internet] *Stroke*; 2021, 1561–9. Available from: https://www.ahajournals.org/doi/abs/10.1161/STROKEAHA.120.031386. Accessed November 7, 2022.
10. Campbell BCV, De Silva DA, Macleod MR, et al. Ischaemic stroke, 2019 51 [Internet] *Nat Rev Dis Prim*. 2019 Oct 10;5(1):1–22. Available from: https://www.nature.com/articles/s41572-019-0118-8. Accessed November 7, 2022.
11. Smith SD, Eskey CJ. Hemorrhagic stroke [Internet] *Radiol Clin*. 2011 Jan 1;49(1): 27–45. Available from: http://www.radiologic.theclinics.com/article/S0033838910001375/fulltext. Accessed November 7, 2022.
12. Feigin VL, Forouzanfar MH, Krishnamurthi R, et al [Internet]. *Global and Regional Burden of Stroke during 1990-2010: Findings from the Global Burden of Disease Study 2010*. vol. 383. London, England: Lancet; 2014, 9913):245–55. Available from: https://pubmed.ncbi.nlm.nih.gov/24449944/. Accessed September 29, 2022.
13. Pal M, Mengstie F, Kandi V. Epidemiology, diagnosis, and control of Monkeypox disease: a comprehensive review. *Am J Infect Dis Microbiol*. 2017;5:94–99 [Internet]. 2017 May 22 [cited 2022 Oct 4];5(2):94–9. Available from: http://pubs.sciepub.com/ajidm/5/2/4/index.html.
14. Goyal M, Menon BK, Van Zwam WH, et al [Internet]. *Endovascular Thrombectomy after Large-Vessel Ischaemic Stroke: A Meta-Analysis of Individual Patient Data from Five Randomised Trials*. vol. 387. London, England: Lancet; 2016 Apr 23, 10029): 1723–31. Available from: https://pubmed.ncbi.nlm.nih.gov/26898852/. Accessed September 29, 2022.
15. Ihdayhid AR, Lan NSR, Williams M, et al. Evaluation of an artificial intelligence coronary artery calcium scoring model from computed tomography. *Eur Radiol*. 2023;33(1):321–329. https://doi.org/10.1007/S00330-022-09028-3.
16. Nogueira RG, Jadhav AP, Haussen DC, et al. Thrombectomy 6 to 24 hours after stroke with a mismatch between deficit and infarct [Internet] *N Engl J Med*. 2018 Jan 4;378(1):11–21. Available from: https://www.nejm.org/doi/full/10.1056/nejmoa1706442. Accessed September 29, 2022.
17. Del Zoppo GJ, Saver JL, Jauch EC, Adams HP. Expansion of the time window for treatment of acute ischemic stroke with intravenous tissue plasminogen activator: a science advisory from the American Heart Association/American Stroke Association [Internet] *Stroke*. 2009 Aug;40(8), 2945–8. Available from: https://pubmed.ncbi.nlm.nih.gov/19478221/. Accessed September 29, 2022.
18. Albers GW, Marks MP, Kemp S, et al. Thrombectomy for stroke at 6 to 16 hours with selection by perfusion imaging [Internet] *N Engl J Med*. 2018 Feb 22;378(8), 708–18. Available from: https://www.nejm.org/doi/full/10.1056/nejmoa1713973. Accessed September 29, 2022.
19. Lee EJ, Kim YH, Kim N, Kang DW. Deep into the brain: artificial intelligence in stroke imaging. *Journal of Stroke*. 2017;19(3):277–285. https://doi.org/10.5853/JOS.2017.02054.
20. Murray NM, Unberath M, Hager GD, Hui FK. Artificial intelligence to diagnose ischemic stroke and identify large vessel occlusions: a systematic review [Internet] *J Neurointerv Surg*. 2020 Feb 1;12(2), 156–64. Available from: https://jnis.bmj.com/content/12/2/156. Accessed September 29, 2022.
21. van Leeuwen KG, Meijer FJA, Schalekamp S, et al. Cost-effectiveness of artificial intelligence aided vessel occlusion detection in acute stroke: an early health technology assessment [Internet] *Insights Imaging*. 2021 Dec 1;12(1):1–9. Available from: https://link.springer.com/articles/10.1186/s13244-021-01077-4. Accessed September 29, 2022.
22. Martin SS, van Assen M, Rapaka S, et al. Evaluation of a deep learning–based automated CT coronary artery calcium scoring algorithm. *JACC Cardiovasc Imaging*. 2020 Feb 1;13(2):524–526.
23. Sandstedt M, Henriksson L, Janzon M, et al. Evaluation of an AI-based, automatic coronary artery calcium scoring software. *Eur Radiol*. 2020;30(3):1671–1678. https://doi.org/10.1007/S00330-019-06489-X.
24. Soun JE, Chow DS, Nagamine M, et al. Artificial intelligence and acute stroke imaging. *AJNR: Am J Neuroradiol*. 2021;42(1):2. https://doi.org/10.3174/AJNR.A6883.
25. Rava RA, Peterson BA, Seymour SE, et al, 101177/1971400921998952 [Internet]. *Validation of an Artificial Intelligence-Driven Large Vessel Occlusion Detection Algorithm for Acute Ischemic Stroke Patients*. vol. 34. 2021 Mar 3, 5):408–17. Available from: https://journals.sagepub.com/doi/abs/10.1177/1971400921998952. Accessed September 29, 2022.
26. Adhya J, Li C, Eisenmenger L, et al, 101177/19714009211012353 [Internet]. *Positive Predictive Value and Stroke Workflow Outcomes Using Automated Vessel Density (RAPID-CTA) in Stroke Patients: One Year Experience*. vol. 34. 2021 Apr 28, 5): 476–81. Available from: https://journals.sagepub.com/doi/10.1177/19714009211012353?icid=int.sj-abstract.similar-articles.1. Accessed September 29, 2022.
27. Morey JR, Zhang X, Yaeger KA, et al. Real-world experience with artificial intelligence-based triage in transferred large vessel occlusion stroke patients [Internet] *Cerebrovasc Dis*. 2021 Jul 1;50(4), 450–5. Available from: https://www.karger.com/Article/FullText/515320. Accessed September 29, 2022.
28. Meng S, Tran TML, Hu M, et al. End-to-end artificial intelligence platform for the management of large vessel occlusions: a preliminary study. *J Stroke Cerebrovasc Dis*. 2022 Nov 1;31(11), 106753.
29. Matsoukas S, Morey J, Lock G, et al. AI software detection of large vessel occlusion stroke on CT angiography: a real-world prospective diagnostic test accuracy study [Internet] *J Neurointerv Surg*; 2022 Jan 27 [cited 2022 Sep 29]; neurintsurg-2021-018391. Available from: https://jnis.bmj.com/content/early/2022/01/26/neurintsurg-2021-018391.
30. Bathla G, Durjoy D, Priya S, Samaniego E, Derdeyn CP. Image level detection of large vessel occlusion on 4D-CTA perfusion data using deep learning in acute stroke. *J Stroke Cerebrovasc Dis*. 2022 Nov 1;31(11), 106757.