Artificial Intelligence in Stroke Imaging

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***Abstract*— Today, computed tomography and magnetic resonance imaging of the brain occupies the main place in the diagnosis of acute stroke. To improve the reliability of CT and MRI image analysis, it is advisable to develop an automated recognition system using neural networks of machine and deep learning. This article discusses the use of machine learning methods on computer and magnetic resonance imaging (CT and MRI) for the diagnosis of acute cerebral circulation disorders.**

Our goal consists of three parts: (1) to provide a brief introduction to machine learning with pointers to the main links; (2) to show how machine learning has been applied to the entire MRI and CT processing chain, from image acquisition to image acquisition, from segmentation to disease prediction; (3) provide a starting point for people interested in experimenting and possibly contributing to the field of deep learning medical imaging, pointing to good educational resources, modern open source code, and interesting data sources and problem-related medical images.

Keywords—Stroke, MRI, CT, Stroke Detection, Machine Learning, Review

I. INTRODUCTION

Acute cerebrovascular accident is a major source of global mortality, with more than 6 million deaths recorded annually, and is the second leading cause of death in all income groups worldwide, surpassing only coronary heart disease. In addition to being the leading cause of death, cerebrovascular diseases are also an important cause of morbidity. Up to 50 % of stroke survivors do not regain functional independence, and 20% need hospital treatment 3 months after the onset of stroke [1].

Stroke is a type of acute cerebral circulatory disorder (onmc) and is characterized by sudden (within a few minutes, less often - hours) appearance of focal neurological symptoms, such as motor, speech, sensory, coordination, visual and other disorders or General brain disorders, such as depression of consciousness, headache, vomiting, etc., which persist for more than 24 hours or lead to the death of the patient within a short period of time due to the cause of cerebrovascular origin. There are two clinical and pathogenetic forms of stroke: 1) ischemic stroke (cerebral infarction) due to acute focal cerebral ischemia leading to infarction (area of ischemic necrosis) of the brain; 2) hemorrhagic stroke (nontraumatic intracerebral hemorrhage) due to rupture of a cerebral vessel and penetration of blood into cerebral parenchyma or rupture of arterial aneurysm with subarachnoid hemorrhage. It also includes transient disorders of cerebral circulation, characterized by the sudden appearance of focal neurological symptoms that develop in a patient with cardiovascular diseases, such as hypertension, atherosclerosis, atrial fibrillation, vasculitis, etc., lasting several minutes, less often, but no more than 24 hours, and ending with complete recovery of impaired brain functions [2]. Every year in Kazakhstan, more than 40 thousand people suffer a stroke, of which 5 thousand die within the first 10 days. Among the patients, 53% are men and 47% are women. The highest incidence rate is observed in the age group from 41 to 60 years, followed by the age category from 61 to 70 years. Above 71 years, the level is about 28%. People aged 16 to 40 are at the lowest risk, which is 4% [3].

Classic symptoms that indicate the development of intracranial hemorrhage in a patient with acute cerebral circulation are well known. However, an accurate diagnosis of hemorrhage is possible only on the basis of tomographic data. The development of modern diagnostic equipment, the introduction of computed tomography (CT) and magnetic resonance imaging (MRI) into clinical practice have opened up new opportunities for in vivo research of changes in the structure of brain tissue and blood vessels in stroke. However, the problem of stroke remains relevant today, and the incidence of this nosology is constantly growing. In recent years, advances in CT and MRI have made it possible to assess more deeply and subtly the extent of brain tissue damage in vascular diseases. Neuroimaging is one of the important components of assessing structural changes in the brain in the acute period of ischemic stroke (the first 6 hours from the onset of the first symptoms of the disease). For a long time, the role of radiation diagnostics methods was reduced to the exclusion of pathological conditions that mimic an ischemic stroke: intracerebral hemorrhages, tumors, etc. The timing of computed tomography for suspected ischemic stroke was not decisive, since the data obtained were not related to therapeutic tactics. Moreover, it was proposed to examine a patient with ischemic circulatory disorders no earlier than 24 hours after the disease, since the picture of changes in the brain parenchyma during these periods was considered radiologically negative. Recently, the role of neuroimaging has changed radically. In this regard, it became necessary to quickly and accurately diagnose cerebral changes in order to determine the indications for medical measures, evaluate the effectiveness of treatment and predict the likely complications of stroke. Currently, there are many methods for visual diagnostics of ischemic brain lesions, but the time frame determined by a narrow therapeutic window makes it necessary to focus primarily on computed tomography, which is widely used and available in emergency situations [4]. Intracranial non-traumatic hemorrhages belong to the group of urgent neurological pathology, in which the timely and correct choice of treatment tactics is mainly determined by the data obtained during tomographic (CT and MRI) examination of the brain. Effective methods of CT and MP angiography have also been developed, which successfully compete with direct x-ray angiography, in particular in the diagnosis of vascular changes in intracranial non-traumatic hemorrhages. Acute intracranial hemorrhages are of the same type and have distinct signs in images obtained by x-ray computed tomography. In the first hours of intracerebral hemorrhage, a clot is formed, in which a seal occurs due to retraction with the release of the liquid part of the blood to the periphery of the brain substance. During this period, a CT scan reveals a blood clot in the form of a high-density formation (55-90 units), around which there is a hypointensive band corresponding to the liquid part of the blood displaced to the periphery when the clot is retracted. CT is widely used to differentiate the nature of brain stroke, which is associated with reliable and accurate detection of hemorrhages by this method, especially in the first days. CT remains the method of choice for diagnosing intracranial hemorrhages in the acute period, but during the transition to the subacute and especially chronic stage, the diagnostic value of this method is significantly reduced, and the benefit of MRI increases. Currently, x-ray computed tomography (CT) of the brain is an international standard in the diagnosis of hemorrhagic stroke, which allows not only differential diagnosis of the nature of cerebral circulation disorders and its localization, but also to identify the presence of a possible cause in the patient. Magnetic resonance imaging does not always detect small aneurysms and vascular malformations, but it is more sensitive than computed tomography when cavernous malformations are detected [5].

II. Methods

A. Computed tomography (MSCT) of the brain and skull

Computed tomography of the brain and skull is an indispensable and most informative and reliable diagnostic study in modern medicine. A high degree of resolution in computed tomography of the skull determines the quality of diagnosis of brain diseases, detected even with the most minimal pathological changes in the structure of nervous tissue.

Most often, CT scans of the brain and skull are required for the diagnosis of diseases such as:

- traumatic brain injuries (bruises, concussions),
- discharge of cerebrospinal fluid in fractures of the base of the skull,
- primary and secondary brain tumors,
- tumors of the meninges,
- vascular aneurysms and arteriovenous anastomoses,
- brain cysts, hematomas,
- hemorrhagic stroke.

Computed tomography of the brain and skull will allow you to evaluate complex bone structures (cranial arch, temporal bones, base of the skull, sinuses), soft formations, abdominal structures, vessels of the brain and skull (arteries, veins, sinuses).

With computed tomography, bone structures are better visualized, with contrast-blood vessels, and with MRI (magnetic resonance imaging)-brain tissue, soft tissues, and blood vessels.

When performing a CT scan of the brain, you may need to inject a contrast agent. The decision is made by the radiologist during the CT scan and the attending physician. This should be taken into account when planning the study.

Computed tomography can detect not only structural, but also qualitative changes in head injuries.

For example, computed tomography of the skull allows you to confirm not only the violation of the integrity of the bone, but also to determine the direction and depth of the wound channel, the presence of foreign bodies that fill the channel with blood, cerebrospinal fluid or air. In addition, thanks to the CT scan, you can detect and evaluate:

- degree of brain edema,
- displacement of structures, the magnitude of the degree of displacement of the ventricles of the brain and basal cisterns, the quality of the subarachnoid space,
- presence of small-focal hemorrhage,
- large subdural and epidural hematomas and their external and internal coverings, post-traumatic inflammatory processes (encephalitis, arachnoiditis),
- accumulation of pus in the subdural and epidural spaces.

Also, computer tomography images of the brain and skull clearly visualize cysts and tumors of various tissues: bones, cartilage, and soft tissues of the brain [6].

B. Brain MRI

MRI of the brain is a non-invasive study that involves the use of powerful magnetic fields, high-frequency pulses, a computer system and software that allows you to get a detailed image of the brain. X-rays are not used in MRI. That is why today MRI is one of the safest and, moreover, very accurate studies. The quality of imaging using MRI is significantly better than using x-ray or ultrasound, computed tomography. Magnetic resonance imaging can detect tumors, aneurysms, and other vascular pathologies, as well as some problems of the nervous system. In short, the possibilities of this method are very wide. High information content, safety and affordable price make MRI a very common diagnostic method. Indications for MRI of the brain are:

- diseases and pathologies of brain vessels;
- bruises and injuries of the brain, accompanied by internal bleeding;
- brain tumor;
- hearing loss and speech disorders;
- tumors of the bridge of the cerebellum;
- infectious diseases of the nervous system (meningitis, abscess, HIV infection);
- paroxysmal States;

- abnormal development of vessels of the head (aneurysm, thrombosis);
- epilepsy;
- pituitary adenoma;
- persistent headaches of unknown origin;
- sclerosis;
- sinusitis;
- pathology of the skull base;
- neurodegenerative diseases [7].

C. *Analysis*

The analysis of the use of computer and magnetic resonance imaging of patients ' brains in early studies of scientists in the diagnosis of stroke was carried out. Table 1 below shows a comparative analysis of the use of CT and MRI for detection.

TABLE I. COMPARATIVE ANALYSIS OF CT AND MRI USED TO DETECT STROKE

Reference	Database (number of patients)	Diagnosis method	Year
[8]	2176	CT	2016
[9]	1256	CT	2012
[10]	CT=204 MRI=141	CT, MRI	2013
[11]	1107	CT	2013
[12]	34	CT or MRI	2013
[13]	203	MRI	2019
[14]	474	MRI	2019

It was found that the use of MRI and CT depends on the patient's condition, so each method has its own research area. In one large study in particular, which was revised for guidance, stroke was accurately detected in 83 percent of cases using MRI versus 26 percent of cases using computed tomography [15-16]. The combined study shows the highest accuracy rate for detecting different types of stroke in patients, but the combined study shows a high risk of death.

D. *Applying Machine Learning in Stroke Detection*

Although machine learning techniques have been successfully applied to medical imaging from the second millennium, they suffer from several limitations. These methods relied heavily on manual functions developed by experts in the field. Since observed data vary from patient to patient, and interpretation of data depends on the experience of those skilled in the art, this can lead to errors within and between observers. On the other hand, deep learning in medical imaging has made significant progress in capturing latent representations and automatically extracting functions from them. Therefore, it can facilitate better data interpretation and observation, which can effectively help clinicians.

Deep learning models will never replace doctors and radiologists. But this can have a huge impact on automating the image processing and analysis process. Computer - based methods for analyzing medical images have expanded significantly recently, making medical research and clinical application easier. Recent advances in deep learning have shown continuous optimization of the process of segmentation of stroke areas of the brain. This study was aimed at observing the improvement and growth of the deep learning architecture in the identification and segmentation of stroke lesions over the past few years. Despite these achievements, there are still some limitations and therefore room for further improvements. This model of progressively improving segmentation of the stroke area could be a scientific revolution if doctors and radiologists also participate in the conceptualization and creation of deep learning models.

While deep learning has brought significant advances in the field of medicine, there are remarkable research prospects in using the above methods and deep architectures to solve complex image segmentation problems. Currently, deep learning segmentation algorithms are limited by factors such as retraining due to lack of data, training time and resources, and so on. If effective methods are developed to overcome these limitations, deep learning can certainly create several breakthroughs in biomedical imaging.

The analysis of the use of machine and deep learning algorithms in early research of scientists in the diagnosis of stroke was carried out. Table 2 below shows a comparative analysis of the use of algorithms for detecting stroke and the result of using algorithms.

It was found that the combined use of algorithms for MRI and CT images demonstrates the highest accuracy of detecting different types of stroke in patients.

TABLE II. COMPARATIVE ANALYSIS OF CT AND MRI USED TO DETECT STROKE

Reference to article	Base of research	Input data (number of patients)	Algorithms used	Algorithms with a high rate of stroke detection	Methods of use	Result
[17]	Hospitals of Taiwan	256 images of patches for recognizing ischemic stroke. CT and MRI images of brain stroke	CNN (convolutional neural network) CAROI	More than 90%	Data Augmentation	The method proposed in this article can provide a diagnostic stroke index for the doctor; in addition, the system can also help the doctor quickly and accurately make a diagnosis and prescribe a prescription, as well as give patients immediate and appropriate treatment.

[18]	ILSVRC, COCO, JFT	420 CT images	CNN, Bayesian classifier, multi-layer perceptron, nearest neighbor, random forest and support vector machines	CNN methods in combination with all algorithms - about 100%	The structure of the IoT for the classification of stroke, component method	All GCN architectures for DICOM images were able to achieve 100% accuracy, F1 score, re-call, and accuracy in various combinations with the classifiers used, with the exception of the Bayesian classifier.
[19]	General	Neuroimaging images, 3D patches	CNN, DN, 3DN, random forest architecture families	3D-CNN-average bone ratio 0.31 ± 0.240.	Deep learning methods	Deep learning tools, thanks to the speed and power of the results they can provide, will become more and more the standard tool in the Arsenal of the modern stroke specialist for delivering personalized medications to patients with ischemic stroke.
[20]	BDEMS with about 800,000 patients		DNN, GBRT, LR, SVM	High prediction accuracy (95%) in contrast to DC and SVM	Machine learning methods	In this assessment of the application of ML methods using EMC from the outpatient Department, algorithms based on VT and BEER can achieve high CPK and AUC to predict the future occurrence of stroke. Using longer periods of EMC data can help improve the predicted power
[21]	741 subjects	CT, MRI	Frame with two CNN, SVM, RF	DNN - 88%, SVM – 88%, RF+GACr=0.879	Deep and machine learning methods	Machine learning applications are expanding in the medical field for diagnostic and therapeutic purposes, and the rapidly expanding and increasingly neuroimaging-dependent field of AIS is proving to be fertile ground.

Conclusion

This paper describes the possibilities of using CT and MRI diagnostics to detect blood supply disorders in the brain. Recent research on endovascular intervention has repeatedly shown the importance of selecting patients based on neuroimaging. The use of combined CT and MRI methods gives a high result in detecting stroke. However, any diagnostic methods are not always suitable for a certain class of patients. Thus, each method has its own main group of patients to diagnose for different levels of stroke. Choosing the right method for the patient's risk group for stroke will speed up the process of rapid detection of stroke for further treatment.

In addition, the paper describes the possibilities of machine and deep learning algorithms for detecting acute blood supply disorders in the brain. Recent research on endovascular intervention has repeatedly shown the importance of selecting patients based on neuroimaging. However, the use of combined algorithms for CT and MRI give a high result in detecting stroke. Thus, machine and deep learning tools, thanks to the speed and power of the results they can provide, will become more and more a standard tool in the Arsenal of the modern stroke specialist to quickly detect stroke and deliver personalized medications to patients

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