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e-ASPECTS for early detection and diagnosis of ischemic stroke

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Abstract— **Ischemic Stroke is one of the major causes of human death and disability. So early stroke diagnosis is vital for patient's survival and is remained as challenge for neuro-physicians. The electronic Alberta Stroke Program Early CT Score (e-ASPECTS) software is widely used by neuro-physician to assess the extent of early ischemic changes in brain imaging for acute stroke treatment. However, despite its efficiency, e-ASPECTS suffer of some limitations because of non-contrast computed-tomography scans. This study aims to present the e-ASPECTS program limits of through a literature review of recent studies that compare between automatic performance and human performance at the level of stroke detection and assessment. The present paper highlights the recently developed Artificial-Intelligent based tools in diagnosis and treatment of stroke with a comparison with humain score.**

Keywords— Stroke, e-ASPECTS, Brain imaging, Artificial intelligence, computed-tomography, Diagnosis

I. INTRODUCTION

Ischemic stroke is an acute cerebral complication (signs appear within minutes) due to blood circulation failure at the level of the cerebral area and affects hyper delicate regions of the brain. In fact, blood vessels obstruction provokes the death of nerve cells, due to oxygen and nutrients deprivation essential for their functioning [1][2]. The harmful effects of stroke vary with person to person and depend on the affected area in brain where the stroke happens, size of stroke. Stroke may cause partial or complete disability and it a major causes of human death [3]. Lesions detected by Computed Tomography (CT) have long confirmed stroke diagnosis, and their monitoring not only determines the progressive state of the disease, but also shows therapeutic efficacy [4]. In addition, the image processing techniques can help to differentiate the abnormal brain areas in question from healthy ones and give more precise informations on stroke. The delay between the appearance of stroke and its diagnosis is of great importance and every minute lost is vital because it directly affects the brain-function and is remained as a challenge for neuro-physicians. In fact, as 120 billion neurons are lost per hour, and after 4 hours and 30 minutes, it would be too late to set up a treatment that would vascularize the brain[5]. Therefore, the human Alberta Stroke Program Early CT Score (ASPECTS) must be seen as a potential prognostic tool[6]. The ASPECTS score is a 10 point score to evaluate ischemic strokes in the middle cerebral artery (MCA) area on a brain scanner. By establishing it in the early first hours of cerebral obstruction, the therapeutic response could be predicted. However, scanning to identify early signs of ischemia by human ASPECTS is often difficult, subjective and depend on experts observation. [7][8]. Thus, to overcome these limitations, the e-ASPECTS software was introduced. This program is a commercially available, now CE-marked, standardized, and fully automated ASPECTS scoring tool based on a machine learning algorithm. [9]. It helps to detect the first scanner interpreters and it produces good results within the right time. Thus, Artificial Intelligence (AI) is suggested as a powerful tool to respond to a clinical need [10]. It ensures precision, speed and urgent hospitalization in a neurovascular department with the least risk of error. Consequently it saves the life of stroke victims and reduces the risk of residual disability thanks to a very early prevention of non-specific complications and the introduction of anti-thrombotic prevention. Recently, comparative studies have been conducted to compare between the performance of the e-ASPECTS algorithm and that of the ASPECTS score calculated manually by stroke-expert neurologists and radiologists [11][12]. Results show that it is equivalent to or superior to human performance [13][14]. Despite its performance, e-ASPECTS is not yet widely available, as consequence diagnosis of acute stroke by AI has not yet been proved [15][16]. The present study focuses on the application of e_ASPECTS software in the stroke early detection and diagnosis through a literature review of recent studies that propose comparisons between automatic performance and human performance at the level of stroke detection and evaluation. Thus, this document is organized as follows: section 2 deals with methods that includes manual ASPECTS scoring, automated ASPECTS (e_ASPECTS software) and statistical analysis. We present our results in section 3. Finally, discussion and conclusion are reported in section 4.

II. METHODS

A. *Manual ASPECTS scoring*

Stroke is an absolute medical emergency [5]. The seriousness of stroke can be understood by the fact that the only one-fourth of surviving individuals return to the normal health status. So, the delay in both diagnosis and treatment severely affects the brain function and increase the chances of mortality. Patients who have experienced a stroke will most likely be taken to a nearby hospital. Upon arriving at the hospital, medical staff will attempt to treat the patient, considering the clinical presentation together with information obtained from an emergency non-contrast computed tomography (CT) scan of the patient's brain.

MRI (Magnetic resonance imaging): It is rarely used, yet it is sometimes useful in some situation (brain stem)[1].

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After brain imaging, recent studies consider calculating the ASPECTS score (Fig. 1) as a potential prognostic tool [6]. The ASPECTS score is a 10 point score designed to rate ischemic strokes in MCA territory on a brain scanner. The design of the score is based on a territory division of the MCA into 10 regions, each of which is worth one point. Three points are allocated for deep regions or sub-cortical regions while 7 points are for superficial or cortical regions. Point subtraction is performed for each region with an early ischemic change. Thus, if the ASPECTS score = 10, it signifies a normal scanner. If the ASPECTS score = 0, it means total ischemia in the MCA territory. Additionally, if the score > 7, the situation is recoverable, and if the score $\leqslant 7$ (Fig. 2), the situation is pejorative and means permanent handicap [17]. After diagnosing brain imaging, the neurologist specifies the necessary therapy for the patients.

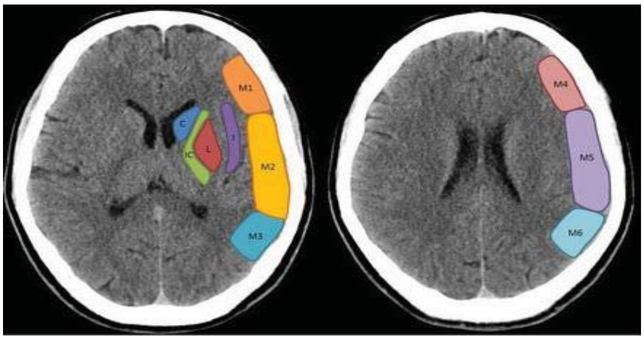

Fig. 1 The ASPECTS score with its different regions C : caudate, L : lentiform, IC : Internal Capsule, I : Insula, M1 : anterior MCA cortex, M2 : MCA cortex lateral to insular ribbon, M3 : posterior MCA cortex, {M4, M5 , M6} : anterior, lateral and posterior cortex respectively 2 cm overhead {M1, M2, M3}.[18]

It should be noted that most relevant study regarding ASPECTS as a selection tool for endovascular stroke treatment [5]. However, this tool remain subjective and time consuming. Thus, e-ASPECTS software has been developed to automate the ASPECTS scoring system for ischaemic stroke patients. The algorithm processes brain CT scans in a similar way to a human expert, applying the ASPECTS score.

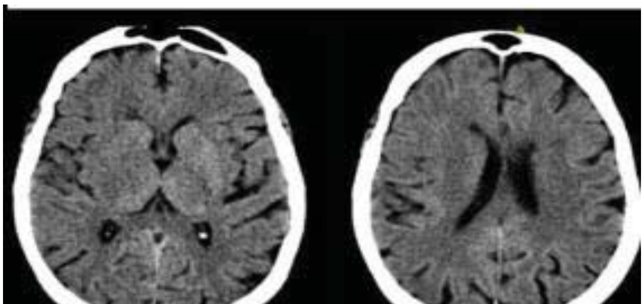

Fig. 2 A patient with an ASPECTS score = 5.

B. *Automated ASPECTS (e_ASPECTS software)*

Currently, there are four software platforms that integrate machine learning (ML): Brainomix e_ASPECTS (Oxford, UK (United Kingdom) /Olea Medical, La Cio-tat, France), Siemens Frontier (Erlangen Germany), iSchemaView RAPID (Rapid Processing of Perfusion and Diffusion; Menlo Park, California, USA (United States of America)) and Viz. ai (San Francisco, California, USA) [15]. Each of these four software platforms uses almost the same ischemia detection approach. The differentiation lies in the methods of machine learning. In fact, various algorithmic estimation methods have been used. These methods are different in terms of platform software type of. The Brainomix company declares that its e_ASPECTS software standardizes the entered Digital imaging and communications in Medicine (DICOM) images as a first step. Then, it identifies early or non-acute signs of ischemia relying on machine learning classifier using a very large database. After that, a specific segmentation of the ASPECTS regions of each patient is carried out. Finally, the Brainomix algorithm ensures the calculation of the ASPECTS output score by classifying each voxel according to the results of the voxel-wise ischemia analysis[19]. iSchemaView declares that the RAPID software performs a series of tasks to generate the ASPECTS automatic assessment. 1) It starts by importing DICOM images as input 2) It ensures the correction of the angulations of the image with removal of the base of the skull, the calvarium and areas of Cerebrospinal fluid ; 3) Applying a standardized atlas in order to create an individualized grid defines the 10 ASPECTS regions of each hemisphere; 4) calculating Hounsfield unit values with other parameters for each of the 20 regions; 5) Each region is classified as ischemic or non-ischemic using an algorithm based on machine learning and assessing which hemisphere is most likely to be the involved hemisphere; 6) reviewing plausibility and threshold; 7) generating an ASPECTS output card on a graphical interface identifying the regions concerned in red with the ASPECTS assessment[13].

A literature review was introduced (Table I). It summarizes the different recent studies that compare between the automated results and the human results of ASPECTS (January- December 2019).

C. *Statistical Analysis*

The Comparisons were quantified as raw agreement. The weighted Kappa statistic and the prevalence- adjusted and bias-adjusted kappa (PABAK) evaluate the agreement of ASPECTS rating with ground truth ASPECTS. More precisely, it defined as follows: poor agreement ($\kappa < .20$), fair agreement ($.20 \leq \kappa \leq .40$), moderate agreement ($.40 < \kappa \leq .60$), good agreement ($.60 \leq \kappa \leq .80$), and excellent agreement ($.80 \leq \kappa \leq 1.00$) [14].

Additional assessments were measured like Sensitivity, Specificity, Positive Predictive Value (PPV) and Negative Predictive Value (NPV). They were calculated individually over all ASPECTS regions from human score and automated score[10].

$$\text{Sensitivity} = \frac{\text{True Positive(TP)}}{\text{True Positive(TP)+ False Negative(FN)}}$$

$$\text{Specificity} = \frac{\text{True Negative (TN)}}{\text{True Negative (TN)+ False Positive(FP)}}$$

$$\text{PPV} = \frac{\text{True Positive (TP)}}{\text{True Positive(TP)+ False Positive(FP)}}$$

$$\text{NPV} = \frac{\text{True Negative (TN)}}{\text{True Negative(TN)+False Negative(FN)}}$$

TABLE I. the different studies that compare between the automated results and the human results of ASPECTS (January- December 2019)

Study	Software	AI method	Manual Score	Results	
				Performances (+)	***Limits (-)***
A. Neuhaus and al (décembre 2019) [12]	Brainomix	RFL	2 neuroradiologists + reader	Regional agreement k = 0.094-0.555, PABAK = 0.483-0.888, with high performance.	Median ASPECTS = 9 vs e_ASPECT = 8.5
C. Maegerlein and al, (décembre 2019) [13]	RAPID	RFL	2 neuroradiologists	Kappa human consensus : ~ 0.57, AI : 0.90	e-ASPECTS not analyzed 20% of the CT data sets
F. Austein and al (may 2019) [16]	RAPID + e-ASPECTS	RFL	Expert Consensus (EC)	e-ASPECTS version7 kappa : 0.29 vs EC : 0.26	e-ASPECTS is more sensitive and less specific vs EC (cortical areas), but less sensitive and more specific (subcortical areas).
					e- ASPECTS did not identify any IC strokes vs EC (4% cases) and RAPID(21% cases)
A. Chatterjee and al (30 janvier 2019) [20]	Viz.ai	CNN	Radiology report	Specificity 94%, Sensitivity 82%, NPV 95%, PPV 77%	41 cases were not processed.
F. Seker and al (janvier 2019) [14]	Brainomix	RFL	4 radiologists	e-ASPECTS kappa : 0.92 vs residents : ~ 0.75	Quality of image affected the performance of e_ASPECTS

III. RESULTS

Machine learning uses different methods in the functions approximation. The value of different image data states that have similar features were estimated by these methods. Random forest learning (RFL)[21] and convolutional neural networks (CNN) [22] are the most popular methods. Starting in January 2019, F. Seker and al [14] have used the RFL method which is characterized by its robustness and efficiency. The aim is to compare Brainomix software by four radiologists with different CT postprocessing reconstruction. RFL has produced results that are more effective than the human consensus. Indeed, the varied reconstructions of CT scan from the same patient was performed better by e-ASPECTS than radiologists (e-ASPECTS kappa : 0.92 versus residents kappa: 0.75). A .Chattergie and al [20] compared the radiology report and the performance of the CNN method of the Viz.ai application at the large vessel occlusions detection level. The results are the following: specificity: 94%, sensitivity: 82%, NPV: 95% and PPV :77%. This means that the CNN method has a higher ability to detect hypo-density (ischemia) with high accuracy. In May 2019, F. Austein and al[16] used the RFL method at two automated ASPECTS application level (RAPID/ e-ASPECTS). The goal of this study is to compare the agreement of both the total ASPECTS and region-based scores from two automated ASPECTS software packages and an Expert Consensus (EC) reading. RFL has produced results that are more effective than the Expert Consensus (EC)(e-ASPECTS version7 kappa: 0.29 versus (EC) kappa : 0.26). In December 2019, C. Maegerlein and al[13] compared between the results of RAPID application and the results of manual ASPECTS defined by two neuroradiologist. The software used RFL method. It found kappa: 0.90 versus the human consensus kappa: ~0.57. The results confirmed that RAPID software has better agreement to consensus score than independent neuroradiologists. From A. Neuhaus and al[12], the purpose is to compare Brainomix software with human ASPECTS for all 10 individual ASPECTS region. The software used RFL method. The results confirmed the superiority of automated performance over independent neuroradiologists. Indeed, the Regional agreement varied from κ=0.094 (M1) to κ=0.555 (lentiform), with high performance in deep regions. After correction for the low number of infarcts in any given region, PABAK ranged from 0.483 (insula) to 0.888 (M3) with greater agreement for cortex regions.

However, despite the high ability of e_ASPECTS to provide effective results, the diagnosis of acute stroke by its has not yet been proved, and errors continue to occur. Brainomix throughout its functioning mainly uses the RFL method[21] which, despite its quickest recognition, is difficult to interpret and improve. Indeed, the study carried out by F.Austein and al[16] approves that e-ASPECTS is more sensitive and less specific compared to the Expert Consensus (EC) in the cortex regions. Moreover, it is less sensitive and more specific in deep regions. In addition, C.Maegerlein and al [13] have used RFL method, they confirm that about 20% of all CT dataset could not be analyzed using the e_ASPECTS. Added to that, A. Neuhaus and al [12] found that the median ASPECTS of human score = 9 while median e_ASPECT =8.5 i.e the majority of cases have limited ischemic changes. Consequently, RFL not improve the accuracy. It can work well all the time, but it rarely give excellent results.

Concerning the CNN method [22], it does not encode the position and orientation of the object into their predictions. They completely lose all their internal data about the pose and the orientation of the object and they route all the information to the same neurons that may not be able to deal with this kind of information. It is, therefore, not occasionally optimal. A. Chatterjee and al [20] approved this procedure, as they found that 41 of the cases were not processed.

Other limits include scanner artifacts that can cause a misinterpretation of an image that may not translate a true lesion. The e_ASPECTS software can cause errors and not accurately detect actual lesions due to CT images at low spatial resolution. A.Chatterjee and al [20] found that 41 cases were not processed besides drawbacks of the method CNN, its due also to metallic artifacts, inadequate contrast, motion artifacts, or excessive spacing variability. In addittion, F. Seker and al [14] affirmed that the quality of image affected the performance of e_ASPECTS software. Thus, this software still lacks a tool to improve the contrast of stroke images in order to promote the detection of signs and ensure confidentiality.

Moreover, the use of ASPECTS is limited to the MCA territory. Thus, it will not be effective to use this software for the infarction of the anterior cerebral artery or vertebrate-basilar i.e among the limitations of MCA territory, the focal infarction of the Internal Capsule (IC) sometimes extends to vascular territories other than MCA. Consequently, the limitation of MCA territory can provoke poor functional prognosis. Indeed, F. Austein and al [16] have confirmed that e-ASPECTS did not identify any IC strokes in your datasets, however Expert Censensus (EC) scoring IC as ischemic in 4% of cases and RAPID scoring it in 21%. Then, we can suggest at the level of e_ASPECTS software to ask for the scanner of the MCA and the anterior cerebral artery or vertebrate-basilar to ensure the right prognosis.

IV. Discussion and CONCLUSIONS

Medical image processing lead to a greater improvement of patient care. The modeling of CT-scan allows a better diagnosis. Simulation offers the optimal opportunity to train the surgical gesture before carrying it out [23]. In fact, establishing the e_ASPECTS software in the first hours of cerebral obstruction, can help to detect the early signs of ischemia. Among the advantages of the e-ASPECTS software is that it could be improved. Therefore, by obtaining our objective of uncovering limits, we help to fix them and subsequently improve the application and the use of the software. The e-ASPECTS software is characterized by faster stroke pathology detection and evaluation compared to neurologists. In fact, instead of waiting for the neurologist's assessment, which takes 32 minutes, we can reach our target in two minutes, which allows us to save patients' lives and protect more neurons [24][15]. This makes this application so crucial and must be developed and improved in order to achieve more efficient, accurate and fast results and minimize the human intervention.

Here, we found that Artificial Intelligence offers technology solutions with high precision and accuracy for the diagnosis of stroke, its severity as well as prediction of functional outcomes.

As a future project, we suggest to solve the problem dealing with stokes missed by e-ASPECT software.

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