Background and Literature Review

# Medical Aspect

## Clinical definition and types of brain haemorrhage

Brain haemorrhage is defined as a bleed in or around the brain tissue. It may be spontaneous, precipitated by an underlying vascular malformation, induced by trauma or related to therapeutic anticoagulation. [1] This can be caused by a blood vessel rupturing, typically due to high blood pressure, stroke or trauma to the head. The resulting bleeding, especially within the brain tissue, results in an increase in pressure on the part of the brain near the bleed, which pressure can potentially damage the effected brain tissue. The place of the ruptured vein, the speed at which blood flows into the brain and the volume of the bleed can all be factors of the severity of the case, potentially leading to death. The region of the brain in which the bleed occurs tends to indicate what are the functions and bodily abilities the patient might lose, such as movement of one side of the body or speech. The increase in pressure in the region where the bleed occurs is since blood irritates brain tissue thus making it swell. Although high blood pressure is often one of the main causes of brain haemorrhage, haemorrhagic stroke only amounts to roughly 20% of all stroke cases.

In the cases of head trauma, traumatic brain injury (TBI) is a possible occurrence. In the case of traumatic brain injury, the bleed in the brain is a result of an external force, such as a blow to the head in instances like motor vehicle crashes. In such cases, the brain is highly likely to move within the skull, potentially hitting the dura matter, of the innermost layer of the skull, and causing contusions, or bleeding and bruising in the brain. This thus implies that in the cases of trauma, a haemorrhage may be present even if there is no visible skull fracture. Due to the nature of this form of haemorrhage, it is most common in young adults, being considered as the highest cause of death in the 15-24 age group, and the third highest, after heart disease and cancer, in other ages. [2] For patients diagnosed with brain haemorrhage, a late or wrong diagnosis can potentially lead to disabilities or death, making the quick and correct diagnosis imperative for such cases.

There are five different types of haemorrhage. These are intracerebral haemorrhage (ICH), intraventricular haemorrhage (IVH), epidural haemorrhage (EDH), subdural haemorrhage (SDH) and subarachnoid haemorrhage (SAH). [3] The location of the bleed determines what the original source was, for instance subdural and epidural haemorrhages are usually due to experienced trauma, sometimes having a scar related to them and are located towards the side of the brain, not inside. [1] Each of these types of haemorrhage have different qualities that are used to distinguish one from the other. At a basic level, a bleed can be classified as intra-axial or extra-axial. These two classifications are the broader categories, with each having more sub-categories. Intra-axial bleeds are ones which occur within the brain itself and include ICH and IVH whereas extra-axial bleeds are those occurring within the skull but external to the brain tissue and tend to be easier to treat. Extra-axial bleeds can be further classified into 3 sub-categories, namely EDH, SDH and SAH.

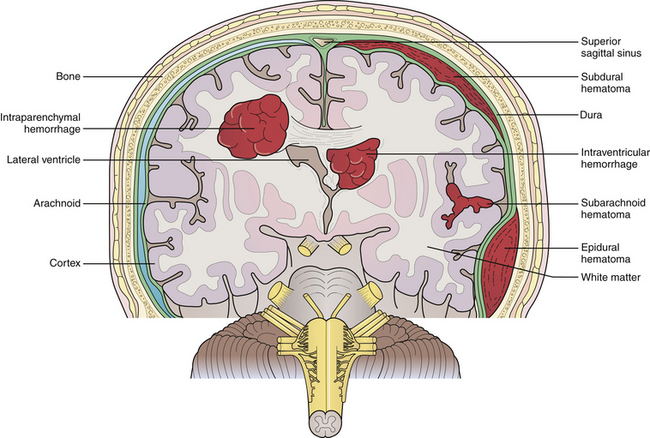


Figure 1: Diagram of hematoma locations and other parts of the human brain [4]

## Computed tomography

Computed tomography, or CT, relies on the principle of using x-rays transmitted through the body to analyse interior parts of the body in a non-invasive way, meaning without the need to operate. The underlying principle behind CT and how it works is that x-rays going through the body are absorbed to some extent, with the rate of absorption varying according to the medium it passes through. The rate of absorption is calculated by measuring the attenuation coefficient of the detected x-ray wave in comparison to the fixed emitted x-ray waves, which properties are known. The attenuation coefficient quantifies how much the detected x-ray signal is weakened after passing through a given material, and is used to calculate the density of the material. [5] This is the same principle behind conventional radiography, which is traditionally used to examine the skeletal structure for fractures and assess lung pathologies, amongst other applications [6].

The main difference between these two types of scans is that in CT a more sensitive detection system, typically making use of glass or crystal detectors as opposed to photographic film which is used in conventional radiography. This increased sensitivity gives the ability of detecting smaller changes in the absorption values can be detected, which in turn implies that finer detail, such as the distinction of density gradation within soft tissues can be observed. The detection system is connected to a computer, which is used to visualise these results, as opposed to traditional radiography which relied mainly on photographic film. [7] Another important distinction between conventional radiography and CT is that while in the former a fixed x-ray tube is used, CT uses a motorised x-ray source that rotates around the circular opening through which the patient is passed, referred to as the gantry. [8]

### How CT works in general

When a CT scan is to be performed, the patient is placed such that the part to be examined is within the gantry, within which the x-ray emitter tube and detector are enclosed, opposite one another. [9] As the patient is passed through the gantry, the emitter and detector are quickly rotated, with the emitter producing a narrow x-ray beam. For every rotation, the data collected forms a cross-sectional image, known as a section or ‘slice’. The typical thickness of each section is between 1 and 10mm. Given that multiple rotations are performed, a number of adjacent sections are obtained, which can then be digitally stacked to form a 3D image of the patient. The 3D image can in turn be used to identify the location of basic structures and any abnormalities in an easier way. [8] The operator of the CT machine decides the thickness of each section, considering the trade-off between accuracy and number of sections, according to the case at hand.

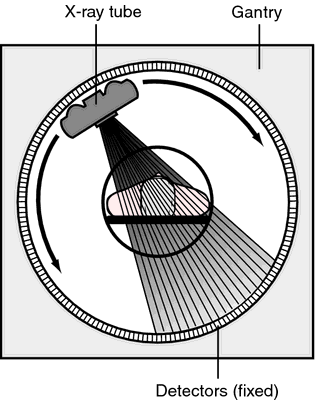
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Figure 2: Principle of CT [10]

There are two main ways of scanning, which are the slice-by-slice, conventional CT scanning and the volume acquisition scanning, which is also referred to as ‘spiral’ or ‘helical’. [7] In conventional slice-by-slice scanning, the patient is in a fixed position while a section is being scanned. In this way, the thickness of each section can be defined by how much the patient is moved between one complete scan and the next, and the position is defined by the position from which scanning starts. [11] The main drawbacks of this form of scanning are that it takes a longer time to scan the body section of interest, which can prove to be challenging with children and people who cannot hold still for a long time, and that the sections’ position and thickness are fixed while scanning and cannot be changed afterwards. In spiral scanning, the patient is constantly moved through the scanner, while the x-ray emitter and detector move continuously in one direction such that it traces a spiral path, collecting data continuously. In this way, a shorter time is taken to scan the section in question, thus eliminating inconsistencies due to breathing or slight movements. The data collected is stored as a volume, thus any required position within the body section can be obtained from the da`ta set, either because it was scanned at that position or via reconstruction. Furthermore, spiral scanning facilitates the reconstruction in 3D form and the possibility of reconstructing the image in a different plane. [7] [11]

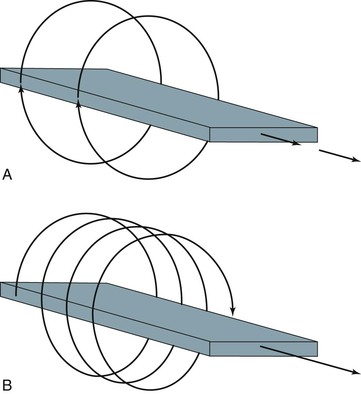


Figure 3: slice-by-slice conventional CT scanning (a) and spiral CT scanning

### Brain CT – how it works, what effects and under what circumstances it is to be used

For the vast majorities of neurological disorders, CT or Magnetic Resonance Imaging (MRI) are used, since both give more information when compared to conventional radiography. [7] In CT scanning, there are three planes along which a scan is performed, which are the axial, coronal and sagittal planes. With regards to brain CT scans, the most common axis chosen is the axial plane. Should other planes be required, in some cases they can be reconstructed from the axial plane result set.

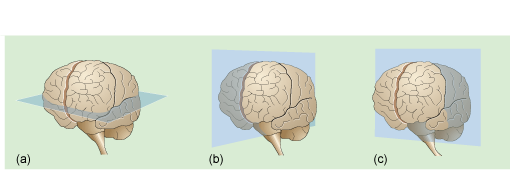


Figure 4: axial (a), sagittal (b) and coronal (c) planes [12]

When analysing a CT scan for abnormalities, there are three main signs that one is present. These are abnormal tissue density, mass effect and enlargement of ventricles. Abnormal tissue density refers to areas in the brain tissue that have higher or lower densities, thus are seen as lighter or darker, when compared to the rest of the brain. The mass effect is the displacement of the brain’s soft tissues due to an intracranial lesion [13] that was not always present and is taking up space, such as a bleed or a tumour. This can be seen in the scan as a compression or displacement in the lateral ventricles and shift in midline structures of the brain [7]. Finally, an enlargement of ventricles can be due to an increase in the volume of cerebrospinal fluid (CSF) in the brain. This can be easily noted in the scan when comparing the size of regular and abnormal lateral ventricles.

In CT scans, a fresh bleed is characterised by an area of very high intensity, and possibly surrounded by a low-density area, known as oedema, which is caused by swelling [7]. The importance of correct diagnosis of the case based on the scan is vital in determining whether the patient requires immediate surgery or not, since in some cases operating the patient could potentially be harmful. CT scans, albeit being the best initial way of detecting these bleeds, can only visualise the largest aneurysms, which are usually the source of such bleeds.

ICH in CT scans can be easily seen as a hyperdense area, or a white patch, within brain tissue, and thus gives little difficulty in diagnosis provided the bleed is large enough to detect. IVH in CT has the similar hyperdense property but the location of the bleed is within one or both brain ventricles. EDH is usually lens-shaped, distinct, hyperdense area and usually associated with a skull fracture. Its shape is heterogeneous, meaning it is not uniform. SDH classically appears as hyperdense crescent-shaped area and is situated over the surface of a cerebral hemisphere, with a skull fracture potentially present but not necessarily so. SAH is the most difficult to detect, since generally the bleeds are small and dispersed. [14]

# Computer aided diagnosis – brief overview and developments

Computer aided diagnosis (CAD) is a research area which bridges the gap between technology, more specifically Artificial Intelligence (AI) and the medical world. CAD can be currently considered as a major research area in medical imaging, technology and radiology. The background idea behind CAD is for the computer to analyse a medical case in a particular field and offer a “secondary opinion” to the radiologist, who is the person taking the final decision on the case. This thus implies that the computer, using a suite of tools in multiple areas, such as image processing and classification, can reach a conclusion on whether or not there is the pathology being tested for. With the use of such software, there can be cases where the radiologist did not spot a problem, yet the computer detected a region of concern, thus possibly giving a better diagnosis. Considering the way CAD works, one can note that the concept of the system is to put equal weight on the computer result and the role of physicians and radiologists, without having one undermining the other, to reach a conclusion on whether the pathology being tested for is present or not. This alleviates some pressure from the performance of the system itself, in the sense that it is not necessary for the system to have a performance which is superior to that of the radiologist, but rather it being comparable and complimentary [15].

Although CAD has been popularised as a research area only recently, it has been around, in different forms, for quite some time. The history of computers as tools for diagnosis dates to the 1960s, where the idea of automated computer diagnosis started to emerge. The notion behind this movement was the general assumptions that computers can completely replace radiologists and physicians in identifying and diagnosing certain pathologies, given that the computer was proven to be superior to humans in other areas. This did not work out due to several factors, including the lack of sufficient computing power at the time, lack of advanced image-processing techniques and the lack of access to digital medical images. Overall, at the time, too much was being expected from computers, which led to the notion losing popularity and being deemed as unfeasible and impossible.

In the 1980s however, a different approach to automated computer diagnosis was introduced, where the system output can be used by the radiologist to help in the decision-making process, but not replace them. This system, dubbed as Computer-Aided Diagnosis was widely accepted as a concept and research interest in the area grew widely and rapidly. This was due to multiple factors, including the reduced performance expectations since the computer program’s output is combined with, rather than replacing, the radiologist’s expertise. This is not the case for automated computer diagnosis, where computer performance is of utmost importance given that the result is being issued solely by the computer. Performance in such cases is measured by specificity and sensitivity. For automated computer diagnosis, both of these factors are required to be very high, that is comparable or higher than that of radiologists, but given that the performance level of radiologists and physicians is much higher than that of a computer, in CAD lower specificity and sensitivity is allowed, since it is being combined with the radiologist’s knowledge. [15]

CAD is currently being researched extensively in the medical imaging realm. It has proven to be a very useful tool in the industry, particularly when it comes to the detection of breast [16] [17] and lung [18] [19] cancers. These areas were of great interest since lots of screening tests are performed to check for these pathologies. Given that most screened cases are normal, it may be tedious and time-consuming for the radiologist to go through each result, thus with CAD, these results can be fed through the system, and the computer flags which results have areas of concern. Such systems are nowadays available for clinical use.

# Pre-Processing, haemorrhage detection and segmentation

SUMMARY OF BELOW POINTS!

Once the CT scan images are obtained, the following steps would be processing these images such that it can be detected if a bleed is present or not. With such techniques, one can determine if there is a region within the section which is suspected to contain the pathology in question, which is haemorrhage for the problem being tackled. The three main processes to detect whether there is a haemorrhage present in a CT image are pre-processing, segmentation and detection.

Show process of how image is segmented – overview of what john did

* Noise removal
  + bilateral filter with 5 pixel neighbourhood, colour standard deviation of 10 and space standard deviation of 2.5 used. More details re how it was chosen in john’s work
* Segmentation
  + thresholding and contours are used in order to segment the brain from the head and skull.
  + Erosion and dilation techniques were also incorporated in order to achieve better results.
  + practical to implement as well as effective in achieving segmentation of both the brain and haemorrhagic regions.
  + The first step in segmenting the brain is removing the head tissue from the skull Once this step was completed, morphology operations were applied. The morphology operations used in the segmentation process consisted of dilation and erosion
    - Dilation is a process which involves convoluting an image with a kernel which has a defined anchor point. This anchor point is usually situated at the centre of the kernel. The dilation operation was required in order to join the disconnected bone structures
    - The erosion process is very similar but in this case the anchor point is replaced by the minimum value overlapped by beta, causing bright areas in an image to shrink.
  + The segmentation procedure used the largest contour as a binary mask and applied it to the original image by setting any pixels outside the mask to black and keeping the original value of any pixels within the mask.
* Detection:
  + clustering, thresholding and contour techniques would be combined to produce a functional and effective haemorrhage detection algorithm
  + clustering and thresholding:
    - pixel intensities of the image were grouped into 4 clusters. Cluster C1 represents CSF, cluster C2 represents GM and WM, cluster C3 represents partial volume pixels of haemorrhage and brain parenchyma pixels whilst C4 represents the haemorrhage pixels. The lower threshold was selected to be an intensity value found half way through the third cluster. Through testing, the upper intensity threshold was found to be 40 intensity levels greater than the lower threshold.
  + contour finding algorithm is used to obtain all the contours of joined pixel masses. From all the obtained contours the one with the largest area is selected, as whenever it is present, the haemorrhagic region forms the largest pixel mass.
  + Removing false positives:
    - pixel mass must have an area greater than 3788 pixels
    - contour area corresponding to possible haemorrhage must be at least 10,000 pixels smaller than the contour area of the original brain to ensure gray matter and white matter are not mistaken for the haemorrhage should the skull be incorrectly segmented.
    - Perimeter of the contour being considered must be at least one and a half times smaller than the perimeter belonging to the contour of the segmented unthresholded brain.
    - a contour with a closed perimeter of less than 2000 pixels must have a contour area between 2800 and 15000 pixels and the contour perimeter of the original brain must be at least 4000 pixels longer than that of the haemorrhage contour.
    - Volume - brain haemorrhage was present in at least four consecutive CT slices. If counter for consecutive slices is less than 4, than case is considered free of pathology.

# Technological Aspect

## Machine Learning

Machine learning is defined as “an application of Artificial Intelligence (AI) that provides systems with the ability to automatically learn and improve from experience without being explicitly programmed” [21]. In this area of computing, the main aim is to design software that uses a given dataset to learn and adapt itself without being hardcoded to do so. A machine learning algorithm is thus designed with the aim of finding patterns in the data given and alter the internal workings to make better decisions based on the training set provided. Machine learning algorithms can be divided into three main categories, which are supervised learning algorithms, unsupervised learning algorithms and reinforcement algorithms.

In supervised machine learning algorithms, the training dataset is clearly labelled, in the sense that for a given set of input parameters, the expected produced output is known. When the training data is fed to the algorithm, the learning algorithm develops a function that produces predictions of the output values. These predictions are then compared to the expected outputs to find errors and correct the developed model accordingly. This model is more widely used, and the majority of practical machine learning techniques use supervised learning.

In unsupervised machine learning algorithms, on the other hand, the training dataset is neither classified nor labelled. When this training dataset is fed to the algorithm, there is no right or wrong answer that is produced. This means that for the input training set, there is no expected output defined. The algorithm is designed to find similarities in the provided dataset and derive a function that defines the hidden structure within the unlabelled data, thus this technique is mainly used to learn more about the data being fed to the system.

In real applications however, the vast majority of machine learning systems incorporate a combination of these two techniques. In these applications, which are referred to as semi-supervised learning, there is a large volume of input data, with only a small subset being labelled. These applications were built given that the process of labelling all the input data is highly time-consuming and can potentially be expensive if the data labelling process requires he help of experts in the domain, while on the other hand, unlabelled data is cheap and easy both to collect and store. In some applications, and for the problem being tackled, a small dataset of labelled data can be used to train the application such that when feeding unlabelled data, a better prediction can be made based on the modifications to the model made via the labelled training data. The newly labelled data can then be fed back to the supervised learning system to further adjust the model for new unlabelled data [22].

The fourth type of machine learning algorithms is reinforcement learning. In this approach, machines and software agents determine the ideal behaviour based on the context that the application is being used for by interacting with the surrounding environment, producing an action and discovering if the said action causes a reward or error via the reinforcement signal. In these cases, machines and software agents learn, through trial and error, which is the optimal decision based on the context to provide maximum performance [21].

## Classification

Classification is the task of labelling data from a set into one of many subsets or classes. This technique can be applied to different data types, such as images, audio and text. While classification is considered to be a relatively easy task for the human being, it has probed to be quite a challenging task for machines, given the complexity of the problem in itself. However, with the increase of programming power, classifiers have gained more popularity and performance power, which is leading to them being used in more applications.

Image classification, in particular, refers to the task of extracting information from a raster image, and categorising all pixels in an image into one of multiple classes. The whole concept of image classification is mapping regions of an image to particular predefined classes, and with sufficient training this can be achieved quite accurately. Given that image classification is a subset of machine learning, all forms of learning algorithms can be applied to the problem. Some of the most common image classification techniques include support vector machines (SVMs) and Neural Networks (NNs).

In most applications, supervised classification algorithms are applied, either on its own or as the training potion of the classifier design. These algorithms include Nearest Neighbour Algorithms, SVMs and NNs. In supervised classification, each case within a class tends to have common characteristics, such as the mean, covariance matrix and the minimum and maximum grey levels in the applicable class, which values are obtained by calculations during the image processing stage.

There are various classifier types that can be used for this application. The main types of classifiers can be divided into different categories such as linear classifiers, such as Naive Bayes, statistical such as logistic regression, decision trees, SVMs and NNs. The choice of which classifier to use depends on multiple factors, such as the number of cases available to train the classifier, previous knowledge of class probabilities and exactness of such knowledge, and computation complexity requirements.

Apart from choosing the classification algorithm, another decision needs to be made with regards to the evaluation methods. These methods give an estimate to the performance of the classifier by measuring the error rate. These methods describe how to use the currently available dataset to train and test the classifier. Methods such as redistribution uses full dataset to first train the classifier and then reuse the same dataset to test it, which is easy to implement yet gives a highly optimistic error rate. Other methods, which are more realistic, include partitioning the dataset into two groups for training and testing, which can be done in various ways, such as splitting the dataset once, with the training set being significantly larger than the testing set as done in data partitioning [23].

## Medical classifiers – what is currently being used and for what

## Classification of brain haemorrhage

### What types of classifiers have been built to classify brain haemorrhage for CT scans

### What types of classifiers have been built to classify brain haemorrhage for other scanning techniques such as MRI

## Previously developed systems

the two most common classifiers used in Brain CT scan classification are the K-Nearest Neighbour Classifier and the Artificial Neural Network.

### Accuracy of classification based on techniques

### Possible implementations / improvements on what has already been developed

# Conclusion

## What has been found

## Criticism of current techniques and highlights of possible implementations

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