



An Analysis of Intracranial Aneurysm Detection and its Developments



Rebecca Nieves¹, Kevin B. Sneed² and Yashwant Pathak^{2*}

¹Judy Genshaft Honors College, University of South Florida, Tampa, Florida

²Taneja College of Pharmacy, University of South Florida, Tampa, Florida

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***Corresponding author:** Yashwant Pathak, Taneja College of Pharmacy, University of South Florida, Tampa, Florida

Abstract

Detection of intracranial aneurysms presents a significant challenge in modern medicine, largely owed to the asymptomatic progression of these aneurysms during their development. Aneurysms historically grow at bifurcations of main arteries and the more significant their growth, the higher the likelihood for rupture. The contributor to the largest risk associated with Cerebral Aneurysms is the potential for consequences such as hemorrhagic stroke. In order to decrease the associated morbidity and mortality associated with these aneurysms, detection must occur early in the disease. Detection modalities for cerebral aneurysms fall into two sections: invasive and non-invasive imaging techniques. Invasive techniques include diagnostics such as Digital Subtraction Angiography (DSA), which is a method where a medical device is inserted in order to access body function. Imaging such as Magnetic Resonance Angiography (MRA) and Computed Tomography Angiography (CTA) are non-invasive, not requiring internal insertion but relying entirely on electromagnetic waves to scan the inner body. DSA is currently the most efficient aneurysm detection method, allowing vessels and aneurysms to be seen at the highest definition. However, CTAs are actually the most commonly used imaging technique due to reduced risk and cost. Researchers and healthcare providers continue to improve these diagnostic and screening methods to offer safer and more effective detection mechanisms. There are a multitude of detection methods in place, but the issue stems from the general population not taking advantage of these modalities. Advancements surrounding these methods offer the potential to enhance screening rates for aneurysms and improve overall detection.

Keywords: Intracranial Aneurysms (IAs); Aneurysm Detection; Non-Invasive Imaging; Invasive Imaging, Computed Tomography Angiography (CTA); Magnetic Resonance Angiography (MRA); Digital Subtraction Angiography (DSA)

Abbreviations: IAs: Intracranial Aneurysms; CTA: Computed Tomography Angiography; MRA: Magnetic Resonance Angiography; DSA: Digital Subtraction Angiography

Introduction

In modern medicine, conditions that exhibit high rates of mortality and morbidity tend to be addressed swiftly, especially from the perspective of discovering methods of detection. Intracranial aneurysms (IAs) present a notable exception, largely due to difficulty in detection for the majority of patients. An aneurysm is characterized as an abnormal dilation or bulging in a section of an arterial wall that has been weakened. They are commonly found on artery bifurcation points especially within the brain and along the aorta. The risk of these aneurysms can depend on their size, prevalence, and location. However, the largest threat is rooted in the possibility of rupture of the arterial wall. Rupturing of an aneurysm causes blood to seep out of the artery into surrounding tissues. This condition is referred to as a hemorrhage and is particularly perilous when it occurs in the

cranial cavity. This issue is more prominent than one would think, since it presents in around 3% of the general adult population [1].

The clinical presentation can vary from seemingly nonexistent to quite pronounced. Aneurysms that are symptomatic are usually larger cerebral aneurysms that are capable of causing headaches, vision loss, and even partial paralysis of the face [2]. These side effects are grave and life-altering even without considering the potential threat of rupture. Research found that there is around a 4 to 5 percent probability of a cerebral aneurysm rupture within the first-year post detection [3]. Unfortunately, the mortality rate for patients with intracranial ruptures is quite high, and survivors will likely face long-term debilitating consequences. The brain's sensitivity to these incidents potentially cause symptoms such as loss of extremity or delayed mental faculties. Overall quality of life

is significantly diminished in individuals with aneurysms, pre and post rupture.

Genetic predispositions increase susceptibility to aneurysms, but external factors also play a critical role. Two controllable factors are smoking and hypertension. Both have been found to independently increase the risk of aneurysm formation particularly in cerebral regions [4]. Both of these factors impact blood vessels through enlargement of vessels either through plaque accumulation or overall increased internal pressure. Given the prevalence of these factors in the general population, the ability to detect aneurysms is vital for overall global health and impact on healthcare dollars.

Detection of IAs can be lifesaving if done early enough in the process. Despite this fact, it can be quite challenging to encounter aneurysms in the initial stages. This is contributed to the minuscule size and asymptomatic nature that many unruptured aneurysms take on. This is a significant complication because there is a tendency for aneurysms to have continual growth, and the larger they become the higher the probability of rupture. Studies demonstrate that the size ratio of aneurysms with the vessel can be a decently accurate prediction of whether a rupture will occur [5]. For that reason, it gets increasingly more difficult to prevent rupture once an aneurysm reaches a certain size. Consequently, it is critical for detection to occur early on in development so as to prevent catastrophic outcomes. This review of literature will examine both historic and current means of intracranial aneurysm detection. The focus will be on imaging techniques as they are the primary means of internal observation of the body. There are both invasive and noninvasive methods when putting these techniques into the perspective of aneurysm detection. Based on an analysis of these imaging techniques, there will be a demonstration of the quality of current aneurysm detection and an explanation of future possible developments.

History of Aneurysm Detection

Historically all identification of brain ailments were preceded by a patient exhibiting some symptom or side effect of an aneurysm. In 1555, the first reported aneurysm was documented, using the criteria: “‘in the chest, or about the spleen and mesentery where a violent throbbing is frequently observable” [6]. Up to this point in history only one type of aneurysm had been discovered, being found within the aorta. Diagnostic criteria at this time included only one possible symptom of a single type of aneurysm. A problem with this criterion was that it was only specific to aortic aneurysms, so it decreased the chances that a cerebral aneurysm would be discovered. Another significant issue with this definition is that the amount of time taken for a symptom to become evident may be detrimental to the affected patient.

The detection of cerebral conditions has seen improvement over the past decade. The main reason is due to technological advancements within the medical field that have allowed new imaging and testing methods to be discovered. X-rays were first

discovered in 1895 by Wilhelm Conrad Roentgen and this was a breakthrough that finally allowed for the ability to view the inside of the human body [7]. This paved the way for bio-medical engineers and other scientists to create more sensitive imaging machines that give a clearer view of the body.

Modern techniques that are commonly used for screening of intracranial conditions are invasive imaging, noninvasive imaging, and cerebrospinal fluid testing [2]. There have been significant improvements in these methods; however, intracranial aneurysms continue to be difficult to diagnose. Even considering the sophisticated levels that medical machinery has reached, most aneurysms continue to be discovered either post-rupture or incidentally. This condition may gradually progress in a manner that makes it challenging to detect its presence or growth. Studies have shown that asymptomatic intracranial aneurysm detection percentages using CTAs (computed tomography angiographies) and MRAs (magnetic resonance angiography) have grown in recent years, from a 2.5% detection rate to 3.4% in 2019 [8]. This leaves a significant section of the population without proper diagnosis.

Pathophysiology Concerning Aneurysm Detection (Rupture Risk Factors)

The pathophysiology of intracranial aneurysms impacts the quality of detection possible. Disease pathophysiology can be split into four sections: etiology, pathogenesis, manifestation of symptoms, and clinical significance [9]. Etiology focuses on all the probable causes of a disease. Aneurysms are typically caused by multiple factors that work in conjunction to weaken arterial walls and cause them to balloon. Aneurysms may not present congenitally but can still exhibit genetic factors of causation such as abnormal blood flow or arterial characteristics. This is proven through the fact that IAs have been found to have an overall higher occurrence in patients with direct relatives who also present with one or more aneurysms [10]. Consequently, there is an aspect of aneurysm formation that is entirely beyond the patient's control.

There are also quite a few external risk factors for aneurysm growth that can be monitored and maintained. For the aforementioned common causes, smoking and hypertension, the ratio for an aneurysm to form when there is exposure is equal to around 8.3 when both exist in an individual, but when separated it is 3 for smoking and 2.9 for hypertension [4]. The fact that these are two of the leading antecedents for IA formation causes quite a bit of difficulty. This is a result of aneurysms not commonly being the focus when someone is dealing with these ailments. For a patient who is a smoker, there will most likely be an emphasis on preventing respiratory conditions and not on screening for aortic or cerebral aneurysms. A similar problem ensues with those who deal with hypertension due to the prominent symptoms being centered around the heart specifically and not all of the arteries. As a result of this focus, aneurysms continue to have a low detection rate.

The second part of the pathophysiology of intracranial aneurysms is their pathogenesis. Pathogenesis is defined as the overall development of a disease or condition state. As stated, growth is multifactorial, and the primary causes of aneurysms are unique to each patient. Despite this uniqueness, the development of an aneurysm and its rupture are similar among most patients. Intracranial aneurysms begin with a deformity within the endothelium due to an abnormal pressure or flow within the artery [11]. The immune system will detect any deformity within the artery and trigger a response. This inflammatory response will occur which is the major cause as to why aneurysms increase in size and eventually rupture [12].

The possibility of rupture increases over time due to aneurysm growth. While aneurysms are still of a small-scale, the possible consequences of treatment are usually considered to be more of a risk than leaving a patient untreated. However, this comparison modifies as an aneurysm grows. A study determined that as time went on within the first year of detected aneurysmal growth there was a concurrent growth in the probability of rupture and in all there was around a 1 in 25 chance of rupture during that year [3]. The fact that the probability of rupture increases over time causes treatment to become a viable option. Overall, this supports the idea that early detection is important to minimize the likelihood of a rupture.

The manifestation of symptoms section of pathophysiology explains the observable effects of an ailment. Unruptured intracranial aneurysms are commonly asymptomatic; nevertheless, there are instances when the condition has observable effects on the body. Manifestations include but are not limited to migraines, deteriorating vision, paralysis of the face, and weakness [2]. These symptoms are caused by the enlarged segment of artery pushing against specific parts of the brain and causing abnormalities in the cranium. With IAs rupture, the severity of the condition grows exponentially. Ruptures commonly cause an event called a “Thunderclap Headache” where intense head pain appears abruptly in a patient [13]. This headache can precede common consequences of rupture such as subarachnoid hemorrhages, seizures, partial body paralysis, and loss of consciousness [2].

Each of these symptoms exhibit unique consequences which then form the significance of the aneurysm in the clinical setting. Clinical settings are concerned with the treatment and management of intracranial aneurysms. Unruptured aneurysms, depending on size and risk of rupture, require different means of evaluation and management. Possible treatments for unruptured aneurysms include endovascular and microsurgical approaches. Microsurgical clipping was the standard procedure for much of the history of aneurysm treatment. Clipping requires cutting a section of the skull in order to access the brain and then placing a metal clip at the base of an aneurysm, cutting it off from the rest of the vessel [14]. This would prevent blood from reaching the aneurysm and causing future bleeds or ruptures. Endovascular coiling has the same goal of microsurgical clipping but has a

smaller chance for serious complications. Coiling is the process of a platinum coil being placed into an aneurysm through a catheter as a means to prevent growth and rupture due to blood flow [14]. If both of these treatments aren't deemed fit by the healthcare provider, then an IA can be monitored over time and a patient can be put on medication or guided through lifestyle changes that reduce the risk of aneurysm progression.

Ruptured cerebral aneurysms cause subarachnoid hemorrhages which must be treated immediately. This event is life-threatening and affects many bodily processes that often must be addressed before the actual rupture. These include respiratory and cardiac events that must be prioritized over all to ensure the patient's life. Once those primary sequelae are dealt with, then the rupture can be addressed with similar methods of an unruptured IA. Microsurgical and endovascular treatments are also utilized when handling aneurysms that have already ruptured. The conditions that aneurysms cause have high rates of mortality and morbidity, and the feasible treatments themselves also have large risks of complications. The detection of aneurysms in a timely manner can allow a patient to avoid major morbidity and mortality.

Invasive Imaging

Invasive Imaging Techniques are a major section of Intracranial Aneurysm detection. In most instances, invasive signifies that a medical device will enter the body either by insertion or through an artificially made opening. Commonly, these will require some sort of procedure where an incision may be made or a needle used to place the device into a patient's artery. Invasive Imaging for IAs specifically allows for a catheter to be introduced to the body and contrast to be flushed through to the brain. This contrast allows for X-rays to capture aneurysms or other abnormalities present in the vessels. The most effective means of aneurysm imaging is Digital Subtraction Angiography (DSA). DSA uses a catheter that is inserted through an artery, usually the femoral, to reach blood vessels in the brain [15]. The catheter is pushed through the arteries and vessels until it reaches the impacted area with contrast then being flushed through the catheter. The area can then be viewed using x-ray imaging. The inner view of the brain and vascular system that DSA provides allows for a deeper and more detailed view of cerebral aneurysms.

Even though DSA is known to be the most effective means of detection, multiple risks are associated with it. Much like most other invasive procedures, there is a risk of injury to internal organs, infection of the open site, and hemorrhaging. When speaking exclusively about the DSA, there is a possibility for neurological complications such as thromboembolisms, ischemic stroke, and other conditions caused by examination [16]. These are feasible risks due to the catheter having to travel throughout the body into cerebral brain vessels. While these conditions seem severe, the potential for diagnosis may be seen by healthcare providers to outweigh the risk of complications.

Non-Invasive Imaging

The term non-invasive represents any procedure or examination that does not require access to the inner body. Imaging techniques that are non-invasive typically use electromagnetic energy to view organs within the body. In the circumstance of screening the cranium, non-invasive imaging has been found to be more common along the masses, yet seemingly less accurate. They are known to not be as dependable as invasive processes in the ability to detect aneurysms or other small abnormalities.

One example of non-invasive imaging is a Computed Tomography Angiography (CTA). Computed tomography scans take images of cross-sections of the body, and angiography highlights blood vessels and certain tissues [17]. CTAs are efficient in exhibiting the space that different sections of the body take. This would support CTA usage in finding over-sized and bulging aneurysms at the bifurcation points of arteries.

Another common example of a non-invasive technique is Magnetic Resonance Angiography (MRA). This type of imaging utilizes magnetic fields as a means to observe bodily tissues and vessels that have been highlighted. The strength of MRAs comes from their ability to differentiate between tissue types in a way that allows professionals to identify specific issues. They are utilized in a way to screen for IAs because blood vessels and arteries would be apparent in the image; however, MRAs are preferred as imaging for follow-up appointments after Endovascular Coiling is done [14]. This is due to the fact that MRAs are able to identify where the coil was placed and then be able to tell if any changes have occurred within the artery.

Conclusion

Aneurysm detection has significantly improved over the last few decades but still lacks much of what it needs to reduce the percentages of those that go undetected. The pathophysiology of Intracranial Aneurysms explains the majorly asymptomatic presence and growth that they partake in. In many patients, rupture of the IA is the first point where symptoms present. The tendency to be asymptomatic until rupture causes there to be great uncertainty in both patients and doctors about the presence and risk of rupture in IAs. This causes not only detection to be difficult but also treatment and further management of the condition.

Non-invasive imaging tends to be the more common set of techniques used in hospitals and other medical settings when compared with invasive imaging. A part of this tendency may come from the fact that non-invasive techniques require less money, resources, and time than other types. Studies found that in some circumstances a Digital Subtraction Angiography can cost 3-4 percent more than a CTA [18]. When added to the risks of going through an invasive procedure, this cost difference causes many patients to not see the worth of what is actually the more accurate method.

Unfortunately, aneurysm screenings are not common within

the general population and most diagnoses come incidentally. Aneurysms are usually found in an instance that a patient is being screened due to some other condition or symptom. As seen, the technologies needed to increase the detection percentages are there, it requires more of the population to take advantage of them. However, this is not likely due to imaging techniques not being cost-effective for many patients and there being a severe lack of knowledge concerning cerebral conditions such as aneurysms. Another aspect of why someone may not undergo screening is the fact that researchers found that the accuracy of any imaging technique highly depends on the experience and knowledge of the clinician carrying it out [19]. Patients will not likely pay a large sum of money to get screened if they aren't exhibiting symptoms, especially when there is a chance that a doctor wouldn't be able to accurately diagnose based on this diagnostic testing.

Future Trends

Medical technology advancements continue to grow through the years, and this allows for novel detection or improvement of current means to be developed. When aneurysms were first diagnosed, clinicians would have never thought of having the ability to see the aneurysm or any other part of the inner body. Currently, there are multiple techniques possible that allow for different levels of definition and perspective of the internal organs. When discussing screening techniques there are dozens to select from. The three most common are DSA, CTA, and MRAs, where each go through a vascular system assessment using a contrast dye, and are able to give unique perspectives to clinicians and patients.

Digital Subtraction Angiography has been thoroughly studied to determine a means of automatic detection for Intracranial Aneurysms. Experimentation with new computer-aided diagnosis methods would be more efficient with time and resources while accurately identifying IAs [20]. If these methods continue to be researched and be proven as accurate, this could potentially provide some relief to clinicians who usually need to be able to interpret the images and identify any abnormalities. This potentially could increase the public trust in DSA and detection in general, which could then cause more of the population to get screened. If the accuracy and efficiency of an examination improves, then it is likely that more people will undergo these lifesaving screenings for themselves.

Researchers are testing developments concerning Computed Tomography that could potentially allow CTAs to become more effective. Approaches such as Subtraction CTAs, bone removals, and dual-energy CTAs could cause CTAs to be able to detect a higher percentage of aneurysms on average, especially those in close proximity to bones [21]. CTAs in the past were most efficient at imaging the beginnings and ends of structures in the body but struggled with differentiating between internal structures. If these new methods are found to be of good quality, then the faults of

CTAs could be resolved, and more patients would be encouraged to be examined. Based on this information patients could then feel more confident that when they go through screening they are being examined thoroughly.

Magnetic Resonance Angiography has also had current developments that improve Intracranial Aneurysm screening. High-resolution MRAs are constantly being produced which have allowed for clearer images. An interesting development concerning IA detection is that using MRA they have connected wall enhancement in the aneurysm to its rupture [22]. As a result of this, through an MRA, a healthcare provider can assess the potential of rupture of an aneurysm based on the intensity of the vessel wall under contrast. This would represent a great achievement in the detection and management of cerebral aneurysms. Overall, both invasive and non-invasive imaging techniques have consistently been developed, especially in the context of aneurysm screenings. As technological advancements continue there is an increased opportunity for patients to undergo screening for IAs or any other cerebral conditions. The goal is that as improved detection methods are developed, an increase in individual screenings for intracranial aneurysms will occur. IAs can be deadly or life-altering upon rupture; therefore, the larger the base of detection modalities available to the general population the larger the potential benefit on the morbidity and mortality would be and thus the overall health of the population.

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