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### RESEARCH ARTICLE

#### THE PROS AND CONS OF CO2 CT ANGIOGRAPHY VERSUS CONVENTIONAL CONTRAST ENHANCED CT ANGIOGRAPHY IN THE TREATMENT OF PERIPHERAL VASCULAR OCCLUSIONS

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#### Abstract

Over the past two decades, the field of vascular surgery has experienced tremendous advances in technique and technology. After the description of vascular anastomosis by Dr. Alexis Carrel almost one hundred years ago, the subsequent years were slowly crowned by the differentiation of general and vascular surgeons (Friedman 2016). Notably, surgeons were able to distinguish themselves by developing and acquiring techniques that are specific to operations in vascular surgery. This type of surgery involves diseases associated with the vascular system, which specifically includes the arteries, veins, and the lymphatic structure. Thus, vascular surgery provides treatment for diseases associated with the veins and arteries and is used in cases where less invasive methods cannot be incorporated (Reis and Roever 2017). Importantly, vascular diseases arise from damaged vessels or the presence of inflammations or blood clots leading to the occurrence of illnesses like peripheral vascular disease or peripheral arterial disease (PAD) that is occlusive in nature. Notably, vascular occlusion can be defined as the blockage of blood vessels due to the growth of an abnormality or the accumulation of fat or calcium in the inner lining of the venous structure. Occlusion is a common characteristic of PAD where the diameter of the blood vessels narrows considerably (Rotzinger, Lu, Kawkabani, Marques-Vidal, Fetz and Qanadli 2020). Another good example of peripheral vascular occlusion arises from atherosclerosis. This is an occlusive disease where the arteries harden due to fat or calcium, leading to the narrowing of the internal diameter of the vessels (Rotzinger et al. 2020). Over time, this diameter narrows greatly resulting in the formation of clots that restrict the supply of blood to the entire area past the blockage, leading to the development of PVD/PAD.

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#### Introduction:-

Importantly, angiography involves the imaging of the interior of the blood vessels using radiography to obtain a computerized tomography (CT). A CT angiography (CTA) is a common technique in the management of peripheral vascular occlusions since it helps in the detection of abnormalities and the imaging of sensitive remote parts of blood vessels for an accurate diagnosis. Importantly, a CT can provide three-dimensional (3D) imaging of the whole vascular system in association with a contrast medium (CM) (Hayakawa, Kodera, Ohki, and Kanda 2019). According to the

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American College of Radiology (ACR) (2020), CMs are important in boosting the contrast and visibility of the anatomical structures within the vascular system. With the addition of innovations such as digital subtraction angiography (DSA), a contrast-enhanced CTA becomes more effective since images obtained have a good-excellent rating (Abdelbary, Mohamed, and Abdel-Hamid 2018). More so, different contrast-enhancement agents provide a varying effect on the quality of the image. Common CMs in the field include iodine and gadolinium, which are used in low to relatively high levels by the administration through injection into the vascular system (ACR 2020). Other than this, CO<sub>2</sub> arose as a viable imaging agent in the venous system (Friedman 2016). Being a natural element, it offers no adverse reactions in patients and thus, poses a strong advantage over the conventional CTA.

In this paper, different case studies in the field of vascular surgery are explored to understand the pros and cons of the above-mentioned techniques in the treatment of indications and varying cases of peripheral vascular occlusions. While case studies on comparative uses of both methods are highly limited, this paper draws evidence-based information from vascular surgery research that touches on either technique with the sole aim of extracting the pros and cons as experienced. A CO<sub>2</sub> CTA offers a safer and more efficient method for the detection of occlusions in the venous and arterial structure because it presents no adverse reactions and offers a higher sensitivity that results in more effective imaging of higher quality.

### **A History of Emerging Techniques in The Field of Vascular Surgery**

Notably, the separation of vascular and general surgery has been facilitated by a difference in techniques and the fact that better patient outcomes are received when an operation on the blood vessels is carried out by an expert. Vascular surgery techniques have had a tremendous progression over the past three decades, rising from the use of simple imaging techniques to CTAs that can provide 3D visualization (Hayakawa et al. 2019). Importantly, the development of the computer age had an immense impact on the specialization of vascular surgeons in one area that focuses on the internal structure and interactions of the veins, arteries, and lymphatic system.

In the technique of angiography, blood vessels in the body are imaged through radiography to find the presence of occlusions in the vascular system (Koch and Robbs 2016). Importantly, carbon dioxide (CO<sub>2</sub>) computerized tomography (CT) angiography is a fairly modern approach in the management and treatment of vascular procedures (Koch and Robbs 2016). Notably, CO<sub>2</sub> CTA traces its origins back to the 1970s where an accidental intra-arterial introduction of room air was performed in the place of an iodine CM (Koch and Robbs 2016). This facilitated the imaging of the vessels, even though the quality of the picture was low at the time due to the lack of CT. It also did not subject the patient to any negative effects (Koch and Robbs 2016). This resulted in the rise of research about the use of CO<sub>2</sub> as an imaging agent and how the quality of the image could be improved (Friedman 2016; Koch and Robbs 2016). However, before the use of CO<sub>2</sub> as a radiographic contrast agent, a liquid was first used in 1924 (Gocer 2020). With the gradual improvement in technology, CO<sub>2</sub> continued to take its place as a sustainable CM with minimal risks to patients. By the 1980s, CO<sub>2</sub> had grown into a reliable imaging agent for the vascular system, facilitated further by the development of DSA (Gore 2020; Abdelbary et al. 2018). Thus, CO<sub>2</sub> could be used alone or with the conventional contrast-enhanced angiography that uses iodine. Note that, the properties of CO<sub>2</sub> enabled its capacity to produce a high-quality image with the use of CTAs. Unlike the conventional CTA with a CM, CO<sub>2</sub> presented increased accuracy and a wider criterion for patient selection because it provided no adverse reactions within the body.

Further, the conventional contrast-enhanced CT angiography uses 'contrast agents' to distinguish between different types of organs and also to detect lesions and their features (Horehledova, Muhl, Milanese, Brans, Eijsvogel, Hendriks, Wildberger, and Das 2018). For instance, iodine is a common contrast media that has been used in conventional CT angiography since the 1970s (ACR 2020). With the evolution of technologies in angiography and the introduction of the computer and the application realm in the 1990s and the 2000s, the application of contrast-enhanced and CO<sub>2</sub> CTAs began to find popularity as the image size improved (Gocer 2020). According to Abdelbary et al. (2018), the emerging technique of DSA arose with the need to improve the conventional contrast-enhanced CTA. It involves the observation of specific areas in blood vessels by eliminating (subtracting) surrounding structures of anatomy to boost the contrast of features under study (Abdelbary et al. 2018). This technique is suitable for the visualization of the peripheral arterial system and is popular in the emerging diagnostic approaches for vascular treatment. Note that, the conventional contrast-enhanced CTA also uses a similar underlying principle of 'hiding' other anatomical structures by increasing the contrast and 'shining a light' on the needed parts under study. Importantly, the DSA contributed to the establishment of CO<sub>2</sub> as a reliable contrast agent in angiography, in comparison to the conventional approach that uses iodine-contrasted CT. Thus, patients who were often hypersensitive to iodine could safely use a CO<sub>2</sub> CTA.

## Criteria for Patient Selection

### CO<sub>2</sub> CT Angiography

Note that, the use of CO<sub>2</sub> in angiography takes advantage of all properties of the gas. Thus, the criteria for patient selection must be considerate of this, and the patient's relationship with CO<sub>2</sub>. For starters, when CO<sub>2</sub> is injected into the arteries, it displaces the blood resulting in a difference in the present densities (Sharafuddin and Marjan 2017). It is thus imperative to ensure patients' selected for the CO<sub>2</sub> CTA can handle the presence of this gas within their bloodstream with no negative reactions. According to Sharafuddin and Marjan (2017), the inclusion criteria covers members of all sexes, those with diabetes, hypertension, hypercholesterolemia, chronic obstructive pulmonary disease (COPD), smokers, and those with a transit ischemic attack. Despite this, the severity of these conditions must be evaluated to avoid any unprecedented intolerances in the patient.

Note that, the patient history must include any interactions with risk factors that increase susceptibility for the development of vascular occlusions. This includes the creatinine content of the blood and even the pressure. With CO<sub>2</sub>, there is no increased risk for allergic reactions, meaning that individuals with underlying vascular diseases can be imaged comfortably with reduced risks (Abdelbary et al. 2018; Sharafuddin and Marjan 2017). In a CTA study by Abdelbary et al. (2018), the criteria for patient selection included individuals with uncertain renal functions where the levels of creatinine were between 1.5 mg and 2 mg/dl. However, Abdelbary et al. (2018) note that a CO<sub>2</sub> CTA is not recommended for patients who are pregnant or those who have had prior occurrences of a kidney or heart failure, or with severe COPD. Furthermore, CO<sub>2</sub> can increase pressure in the local venous area where it is in contact (Sharafuddin and Marjan 2017; Corazza, Taglieri, Pirazzini, Rossi, Lombi, Scalise, Caridi, and Zannoli 2018). Therefore, it is imperative to measure the vascular pressure at the local area to determine the patient's risk for vascular hypertension. Additionally, patients must have given their informed consent before the beginning of the procedure for ethical reasons.

### Conventional Contrast-Enhanced CT Angiography

Importantly, patients selected for the conventional contrast-enhanced CTA should have no interactions with the contrast-medium chosen for use (ACR 2020). According to the ACR guidelines, the history of the occurrence of an allergic-like reaction with a CM is the biggest risk factor for the development of a negative condition in the future. For instance, patients who have portrayed a reaction to CM have about a five-fold risk of having another reaction in the future if exposed to the same medium (ACR 2020). In a study by Rotzinger et al. (2020), the selection criteria for patients included those who were suffering from PAD, above the age of eighteen, were not sensitive to iodine as a CM, did not have a creatinine presence of fewer than thirty ml/ min regarding kidney failure, and those without risk factors like diabetes, hypertension, and heart failure. Note that, the presence of a history of kidney failure points to the patient's risk for the development of an allergic reaction with a CM like iodine (Rotzinger et al. 2020; Hayakawa et al. 2019). According to Rotzinger et al. (2020), iodine can enhance progression on the damage present in the kidney, by further breaking down the functions. Thus, for a patient to become eligible for a CTA using a CM like iodine, there should be no history of recent kidney failure or disease. Further, a CTA with a CM is not recommended in pregnant women due to an increased supply of radiation as well as the introduction of a foreign object (CM) into the bloodstream (ACR 2020). According to the ACR guidelines, it is imperative to ensure that the administration of a contrast-enhanced CTA is suitable for the patient and their condition. This helps to control the probability that a negative reaction will occur with the CM during the procedure. It also allows the doctor to use an effective approach in the diagnosis of the indications of the patient (ACR 2020). Thus, enough medical history of the patient is required to understand their interaction with different substances.

Additionally, asthmatic patients have an increased probability of an allergic reaction with a CM and can easily lead to the development of bronchospasms (ACR 2020). It is also imperative to remember that for patients who have had a history of severe cardiac illness, a negative event can also occur if an allergic reaction happens. Furthermore, evidence suggests that in patients with anxiety, more allergic reactions with CMs occur (ACR 2020). It is important to note that children and older individuals have a lower reaction to CMs as compared to medium-aged adults (ACR 2020). Also, for patients taking beta-blocker medications, discontinuation is not necessary during the CTA. Beta-blockers have been found to reduce the threshold for reactions with CMs (ACR 2020). Notably, patients with an acute thyroid storm can be affected by an iodine CM leading to the development of thyrotoxicosis (ACR 2020). Furthermore, in individuals under an iodine therapy, the use of iodine as a CM can result in interference with the uptake of the treatment. Thus, the criteria for patient selection focuses on individuals with a normal thyroid function, especially in the use of an iodine CM. It is further imperative to consider other medications the patients may be using at the time of the CTA. For instance, simultaneous use of CTA with intra-arterial medications like "papaverine" can lead to the formation of clots in the blood vessels (ACR 2020: 7). Thus, before the injection of a CM into the blood vessels, up-to-date medication history is necessary for the consideration of the patient's viability.

### **Results of Both Methods Based On Recent Studies CO2 CT Angiography**

According to a study by Abdelbary et al. (2018) to find the results of a DSA using a CO2 CTA in patients with occlusive lesions of the femoropopliteal, it was found that no allergic reactions occurred with the gas and also that it provided images with superior quality. The study focused on 18 participants of Egyptian descent with a femoropopliteal occlusive condition. These patients were injected with an average volume of 76.1 ml of CO2 and 24ml of an iodine-contrasted medium. 6 patients had TASC B lesions, 7 TASC C, and 5 TASC D (Abdelbary et al. 2018). Note that all participants had critical limb ischemia and presented a high operative risk. According to the results by Abdelbary et al. (2018), an 88% success rate was recorded with CO2 imaging, with an exception of two individuals who had TASC D lesions. Notably, no allergic reactions were noted, however, 5 patients became intolerant to the administration of CO2 leading to the use of very little amounts in subsequent injections. The quality of the image produced by the CO2 DSA was very high in comparison to that of iodine. Besides, unlike iodine, CO2 does not cause nephrotoxicity and can be tolerated very well in patients with arterial occlusions. According to these results, the use of CO2 has been proved to be instrumental in the imaging of the vascular system, especially alongside the use of DSA.

According to another study by Corazza et al. (2018) to explore the use of CO2 in angiography of the coronary artery, it was found that a careful injection of the gas does not lead to reflux or overflow into the aorta. While human tests on CO2 angiography on the coronary artery are very limited, the study by Corazza et al. (2018) incorporates a mechanical model of the coronary system to find the effect of using CO2 in this vessel. Notably, older patients with a history of renal dysfunction can be adversely affected by iodine CMs. Because CO2 presents no chances of toxicity, it is suitable for imaging with minimal adverse effects (Corazza et al. 2018; Abdelbary et al. 2018). Thus, Corazza et al. (2018) avoided reflux of the gas into the aorta by carefully injecting and controlling the process. At first, when the model was created, CO2 was injected inside the coronary ostium with the help of two catheters. To extract the results, a video recording of the process was made. It showed that controlling the pressure of the injection at a diastolic value that is minimum prevents the reflux of CO2 to the adjacent aorta (Corazza et al. 2018). Despite these results, more research is needed to evaluate whether this supposition still holds in a more practical setting involving animal studies. This is because there exists a sea of information that offers contradictory evidence in human trials that suggests that the introduction of CO2 in the aorta can lead to reflux (Sharafuddin and Marjan 2017). Thus, it is imperative to replicate these results of this case study in a larger setting using an animal model.

Moreover, Mascoli, Faggioli, Gallitto, Vento, Indelicato, Pini, Vacirca, Stella, and Gargiulo (2018) note that CO2 is superior to other techniques like the traditional contrast-enhanced CTA with iodine. In their study, Mascoli et al. (2018) introduce iodine into the suprarenal aorta using a catheter, as well as CO2. The capacity to identify type II endoleaks is tested in regards to the contrast-enhanced CTA, and the CO2 CTA, in comparison with contrast-enhanced ultrasound (CEUS). In this case study, there were 21 participants (patients) who met the inclusion criteria of the research. Results indicated that a contrast-enhanced CTA was able to detect only 5% (1 patient) of the type II endoleak cases, while a CO2 CTA identified 33% (7 patients), and the CEUS discovered the problem in 19% (4 patients) of the sample population (Mascoli et al. 2018). The study further found that in 3 of the incidences that were identified by the use of CO2, they were not detected by CEUS. The single case that was identified by the contrast-enhanced CTA was also seen in the use of CO2 and CEUS. Additionally, all cases that were identified by using CEUS were also seen in CO2 (Mascoli et al. 2018). Based on these results, it is clear that CO2 is a more superior technique in the diagnosis of intravascular conditions and abnormalities given its high sensitivity as an imaging agent. Thus, for this research, the results on the comparison of CO2 and the contrast-enhanced CTA that used iodine can help provide evidence-based comparisons of the advantages and disadvantages of both methods in the larger sphere of vascular surgery.

### **Contrast-Enhanced CTA**

In layman's terms, a contrast-enhanced CTA is a technique that incorporates a CM to provide additional visibility to the internal structure of veins and arteries for imaging in vascular surgery. As earlier noted, iodine is one of the most commonly used CMs for contrast-enhancement during imaging. In a study by Hayakawa et al. (2019), a CT fusion was performed on a seventy-three-year-old male with an occlusive iliac artery. The authors used a three-dimensional road map for the CT. In this case, the CT effectively showed that the patient had a total occlusion in their iliac artery with good image quality (Hayakawa et al. 2019). In a different study by Horehledova et al. (2018), results indicated that the incorporation of an ultra-low CM in CTA was effective for the diagnosis of PAD. The CM entailed a fifteen-milliliter test bolus and a thirty milliliter main that was injected in 50 patients who had PAD with aggravated occlusions. The patients were imaged from the abdomen to the foot. Results indicated that the quality of the subjective image was excellent from the aorta to the segment of the popliteal. However, from this point downwards, they noted that the image was simply good, basing this on a standard rating system. The authors concluded that the incorporation of an ultra-low volume of contrast media is effective in the assessment of PAD, leading to the presence of an image of good to excellent quality (Horehledova et al. 2018). However,

this study had certain limitations such as the fact that there was no evaluation for the renal function and creatinine levels before the CTA (Horehledova et al. 2018). Also, the sample size was insufficient and thus, did not represent a sufficient part of the population under study.

Further, in a different study by Rotzinger et al. (2020) that goes into further detail on the various techniques of image acquisition in CTA using an iodine CM, 60 patients were included and randomly placed into 3 groups. According to Rotzinger et al. (2020), the method of acquisition in the performance of a CTA directly affects the quality of the image as well as the risk of occurrence of adverse reactions with the CM. For this research, the outcome under study was the detection of the presence of occlusive disease. Notably, the researchers evaluated the quality of the image received using intraluminal attenuation. According to Rotzinger et al. (2020), the retrograde acquisition (RA) technique presented scored lower than the anterograde acquisition (AA) and the standard anterograde acquisition (SA). Moreover, the study noted that the use of AA has proven to be stronger, allowing the 'harmonization' of the circulation system of the participant with the acquired angiograph (Rotzinger et al. 2020). The final results of this study indicated that AA was the leading technique with great attenuation values and speed of improvement in the vascular system. Hence, this article recommends that AA is the acquisition technique of preference in CTA. Additionally, the researchers note that the RA approach can also be beneficial in patients with peripheral vascular occlusive diseases, especially those that affect vessels in the lower limbs (Rotzinger et al. 2020). Thus, this article is important in the identification of the pros and cons of CTA, in specific, with the use of iodine as a CM.

In yet another study by Kayan, Demirtas, Türker, Kayan, Çetinkaya, Kara, Çelik, Umul, Yılmaz, and Aktas (2016), results indicate that a low volume of CM presented an image of good quality and high attenuation values. In this study, the authors aimed to assess the quality of an image of a carotid CTA that incorporated a very low volume of iodine as the CM. One hundred and one participants were randomized into two groups, A (50 patients) and B (51 patients). Patients in the first group were given the CM at an amount of 1 ml/kg at 100 kilovolts (kV), while those in the second were administered with 0.5ml/kg of the same substance at 80 kV. According to the results, the CTA was able to observe the absence of venous contamination in both cohorts. Obtained attenuation values in both groups were also above three hundred, with the average in B, being higher than in A (Kayan et al. 2016). This means that the combination of an ultra-low CM volume and voltage, as well, can be used in the performance of CTAs effectively with minimal risks for adverse reactions. Based on these results, one can speculate that the effectiveness of the conventional CTA with a contrast-enhancement medium can be enhanced by the incorporation of suitable amounts of the CM.

## **Discussion and Recommendations:-**

### **The Pros of a CO<sub>2</sub> CT Angiography**

Notably, the properties of CO<sub>2</sub> make this gas a reliable agent for imaging in CTAs (Sharafuddin and Marjan 2017). As a naturally occurring element, CO<sub>2</sub> offers a high rate of sensitivity when injected into the vascular system. For instance, CO<sub>2</sub> is rapidly soluble, allowing for its incorporation in intravascular procedures (Sharafuddin and Marjan 2017; Koch and Robbs 2016). Note that, CO<sub>2</sub> is more soluble even up to "30 times" the rate of solubility in oxygen (Abdelbary et al. 2018: 79). Also, with CO<sub>2</sub>, allergic reactions are eliminated since it is a natural element with no contraindications when used for CTA in the vascular system, except for cerebral cases (Abdelbary et al. 2018; Sharafuddin and Marjan 2017). Furthermore, operators can use high levels of CO<sub>2</sub> during vascular procedures safely because it is dispensed easily in the process of respiration. Thus, this means that accidental intravascular administration of high volumes of CO<sub>2</sub> is less harmful than in the use of a contrast media like iodine since the gas will be effortlessly released during exhalation. Notably, CO<sub>2</sub> travels to lungs for exhalation through different approaches like direct dissolution, by being attached to the hemoglobin, and by being carried as a bicarbonate ion. Therefore, in angiography, the properties of CO<sub>2</sub> allow it to facilitate a more effective imaging process given that it is a gas with reduced viscosity.

According to Abdelbary et al. (2018), CO<sub>2</sub> has a low viscosity in comparison to a contrast-enhanced CT using liquids such as iodine. This makes it to easily diffuse and travel slowly through a flow system, thus, increasing its sensitivity and effectiveness as an imaging agent. Therefore, with increased sensitivity, it can easily detect a slow hemorrhage, an endoleak, and even an arteriovenous fistula (Koch and Robb 2016). This property of sensitivity gives CO<sub>2</sub> its efficacy as a reliable imaging agent. In the study by Mascoli et al. (2018), this property is proved when endoleak cases that cannot be detected by either a contrast-enhanced CTA using an iodine CM or even a CEUS are identified by incorporating CO<sub>2</sub>. While every case under CEUS and the CM had been detected by CO<sub>2</sub>, more hidden occlusions within the vascular system could only be detected by the use of the gas alone without iodine (Mascoli et al. 2018). This implies that CO<sub>2</sub> moves more swiftly in the blood, diffusing into the arterial and venous structure to detect even the tiniest presence of peripheral vascular occlusions. More so, CO<sub>2</sub> is lighter in weight in comparison to other CMs, implying that it can be easily transported and excreted out of

the body with minimal effort. Further, according to Sharafuddin and Marjan (2017), the use of new “computerized CO<sub>2</sub> injectors” can help to boost the appearance of venous and arterial segments under study. Importantly, this can be attributed to the optimization of the flow parameters, as well as the heightened solubility of the gas.

In the study by Corazza et al. (2018), evidence suggests that CO<sub>2</sub> can be introduced into the coronary artery with no reflux and negative reactions in case research that involved a simulated model. By slowly injecting the gas into the vein, Corazza et al. (2018) find that the likelihood of reflux is eliminated when extreme caution is taken. This advantage of CO<sub>2</sub> must, however, be further appraised because there is an insufficient number of animal studies that can be used to reference different aspects and rising issues in this CTA. Note that, with a limited number of studies, the population sample represented is also limited, given the fact that peripheral vascular occlusions affect a large number of persons with PAD. However, more research into this supposition is needed because no human case studies have been reported, given that the later uses a simulator.

### **The Cons of a CO<sub>2</sub> CT Angiography**

While CO<sub>2</sub> is highly soluble, its use in the cerebral vessels and the thoracic aorta is harmful and should not be introduced due to the risk of cerebral reflux (Corazza et al. 2018). Also, due to the inclination of reflux in CO<sub>2</sub>, it should still not be used above the diaphragm (Koch and Robbs 2016; Sharafuddin and Marjan 2017). With the use of gas for imaging, patients become exposed to possible events of embolization. Due to the presence of vascular pressure, CO<sub>2</sub> can boost the ‘storage’ of gas in the vascular space, leading to peripheral emboli (Sharafuddin and Marjan 2017). When incorporated on top of the diaphragm, it can cause embolism or trapping of air, increasing the risk for stroke (Koch and Robbs 2016; Sharafuddin and Marjan 2017). It is imperative to note that CO<sub>2</sub> bares contradictions with elements like nitrous oxide, which is general anesthesia, and thus, should not be used alongside the later gas. When CO<sub>2</sub> mixes with nitrous oxide, the property of solubility in the blood are reduced, leading to difficulties in the removal of the gas from the body.

Furthermore, in patients with COPD, it is imperative to insert breaks between the CO<sub>2</sub> injections. Normally, in other cases, a break of around thirty to sixty seconds is often observed between every CO<sub>2</sub> injection. However, for COPD patients, the recommended amount of time is about two to three minutes (Young and Mohan 2019). This helps to facilitate the absolute dissolving of the CO<sub>2</sub> into the vessel and to ensure it displaces other structures effectively for high-quality imaging despite the presence of occlusions.

Besides, the use of a CO<sub>2</sub> CTA with the DSA technique increases the risk of prolonged exposure to radiation, in both the patient and the individual performing the procedure (Abdelbary et al. 2018). Thus, the recommended amount of frame rate is six per second or more to obtain images with CO<sub>2</sub> and minimize radiation exposure. Also, for medical professionals, the transition from a fluid-based agent to gas (CO<sub>2</sub>) can be challenging. To use CO<sub>2</sub> effectively with minor adverse effects, operators must understand the properties of CO<sub>2</sub> as odorless and invisible, and thus, unlike iodine, cannot be seen. Besides, CO<sub>2</sub> is not as dense as other CMs like iodine (Sharafuddin and Marjan 2017). This means that any movement by the patient during the angiography can adversely affect the resulting quality of the image. Thus, it is recommended that the patient holds still during the performance of a CO<sub>2</sub> to ensure that the image quality obtained is not blurry or without focus.

Since CO<sub>2</sub> is very soluble and has a high rate of viscosity, it can easily become contaminated by room air after some time (Koch and Robbs 2016; Abdelbary et al. 2018). Note that, with a gas that has a large amount of buoyancy like CO<sub>2</sub>, there exists an increased risk for ischemia and vessel occlusion that is embolic (Abdelbary et al. 2018). That is, CO<sub>2</sub> can be transferred into different bodies in the spinal cord, leading to the occurrence of ischemia that has been caused by the embolization. Similar to the use of a conventional contrast-enhanced CTA, CO<sub>2</sub> also increases the pressure within the blood vessels and has the potential of aggravating or triggering hypertension in the vascular system (Sharafuddin and Marjan 2017; Corazza et al. 2018). Given this fact, it implies that the patient selection must be performed with the consideration of the individual’s blood pressure, a heart condition, as well as the presence of hypertensive tendencies. Further, it is imperative to ensure that the gas is introduced carefully into the vascular system to prevent embolization and also enhance its sensitivity through an accurate dispensation.

Besides, when a great volume of CO<sub>2</sub> is enclosed in the pulmonary artery, it poses the risk of blocking the venous return. Notably, this can lead to very low blood pressure and bradycardia. Notably, low blood pressure presents the risk of a reduced supply of oxygen to different instrumental parts of the body. When embolization happens, it is recommended for the practitioner to facilitate in the release of the trapped gas to ensure adverse reactions like the rupture of a vessel and internal bleeding do not occur. Thus, to prevent bradycardia, it is recommended that the patient is rotated left into a lateral decubitus placement (Sharafuddin and Marjan 2017). This will differentiate the gas into a ‘thin film’ that will float on the

liquid and thus, will not hamper its flow and the structures within. Because CO<sub>2</sub> glides on the blood's surface that is not reliant on gravity, any occlusions in the parts of the vessels that are dependent on it might also not be seen. Despite this, CO<sub>2</sub> CTAs are a superior technique when compared to the use of conventional CMs like iodine (Rotzinger et al. 2020). It is important to remember that the introduction of CO<sub>2</sub> into the vascular system is limited and does not cover the cerebral vessels.

### **The Pros of the Conventional Contrast-Enhanced CT Angiography**

In the use of a CM CTA, there also exists an excellent detection of the anatomical structures of different 'bodies' within the vascular system (Horehledova et al. 2018; Rotzinger et al. 2020; Kayan et al. 2016). Importantly, vascular surgeons who are proficient in this technique have performed studies on different ways in which a CTA with a CM can produce effective results. Outcomes have indicated that a CTA with contrast enhancement is beneficial in individuals without contraindications with the type of CM that is being used, such as iodine (ACR 2020; Rotzinger et al. 2020). Furthermore, a contrast-enhanced CTA ensures that the period of examination is short and not tedious. Importantly, this process is also non-invasive yet it ensures that anatomical structures are visible during imaging (Kayan et al. 2016). Note that, a basic CT offers 3D imaging opportunities that allow for the all-round evaluation of the structures under study. In other cases, a CTA can reduce occlusions and get rid of the requirement for vascular surgery (Rotzinger et al. 2020). More so, in very small vessels, a CTA with a CM provides greater image quality of occlusions and abnormalities. Also, with a CM, no pain is suffered because the material is administered directly into the vein.

When it comes to the application of CTA in vascular procedures, a faster injection rate has been found to enhance the rate of contrast in the material provided (Rotzinger et al. 2020). This is because a concentration of the CM facilitates the increased contrast in the vascular interiors, leading to increased sensitivity. Further, the use of a CM for CTA is more economical in comparison to a CO<sub>2</sub>. Also, note that a CTA with CM can image the whole vascular 'tree' of the body in very little time with the provision of a multidimensional output (Hayakawa et al. 2019). Thus, this technique can be used to detect aneurysms, stents, and even calcifications in the venous structure. Importantly, Rotzinger et al. (2020) explain that the efficacy of a CM in the body is influenced by the process through which the agent has been administered to the vascular system. This is also because liquid CMs are denser than those made of gas, and thus, have a higher viscosity.

Importantly, studies have indicated that the toxicity caused by iodine (nephrotoxicity) can be reduced by the reduction of the volume of the CM (Horehledova et al. 2018; Kayan et al. 2016). As seen in the article by Horehledova et al. (2018), a lower volume of the CM still provides an effective image while reducing the risk for nephrotoxicity. Notably, for patients who cannot use CO<sub>2</sub> imaging, the incorporation of low amounts of iodine and kV can become beneficial in the detection of occlusions. Furthermore, CTAs with CMs are accurate and thus, have been a reliable technique in the treatment of occlusions in the peripheral vascular system. It is therefore imperative to conduct more comparative studies that can provide different techniques for the control of toxicity with iodine in different patient demographics. This will help to provide a guideline for practitioners and researchers in the management and treatment of peripheral vascular occlusions.

### **The Cons of Conventional Contrast-Enhanced CT Angiography**

With prolonged exposure to radiation, patients risk the development of abnormal malignancies in their bodies. Unfortunately, the process of CTA imaging uses radiation, meaning that the patient must go through it as a diagnostic approach. Therefore, if an accurate diagnosis is not performed early, this implies that the patient is at a risk of more CTAs, and thus, frequent exposure to radiation. For this disadvantage, the control measure involves the use of radioactive shielding within the operation room. However, in prolonged use of CTAs, the ACR guidelines indicate that an increased likelihood of radiography contamination in the human body is bound to occur. Importantly, this can lead to the development of cancer within the vascular system, posing a threat to the onset of autoimmune diseases like Leukemia. Note that, patients with a peripheral occlusive disease often undergo CTAs for diagnostic and treatment purposes. Therefore, it is imperative to minimize the exposure to radiography by ensuring that such tests are performed accurately and effectively to prevent the need for frequent repeats.

Furthermore, if a patient has an allergic reaction to a CM, this can present adverse effects in the vascular system, even leading to the formation of blood clots or even thrombosis after a longer period of exacerbation. Note that, an allergic reaction to iodine might not be common, but it is one of the main exclusion criteria during patient selection for contrast-enhanced CTA. Moreover, Rotzinger et al. (2020) note that a previous allergic reaction to a CM implies that another similar response might be observed with the incorporation of a similar substance. Thus, CMs can introduce contraindications in a patient, and even fail to detect vascular occlusion in cases where an allergic reaction has taken place. This means patients with such contraindications have to use an alternative approach to obtain effective imaging results with a CT. For instance,

patients can use the CO<sub>2</sub> CTA that poses no threats in regards to allergic reactions after introduction into the vascular system (Abdelbary et al. 2018; Sharafuddin and Marjan 2017). Also, allergic reactions to a CM have often been managed with the use of steroid days before the CTA. The aim of this is to minimize the likelihood of the occurrence of an allergic reaction.

According to Mascoli et al. (2018), the use of a contrast media like iodine can result in the lack of detection of type II endoleaks. This occurs after the occurrence of an EVAR, and during later checkups (Mascoli et al. 2018). Unfortunately, this means that this technique is not efficient in performing a wide range of intravascular imaging procedures. It can also result in the misdiagnosis of a patient especially in the case where the CTA was not sensitive enough to highlight all the occlusions and anatomical structures in the area under treatment (Mascoli et al. 2018). Therefore, where the conventional CTA cannot be used due to the incorporation of iodine and other CMs, practitioners and patients must become familiarized with more efficient and suitable methods for CT imaging in the vascular system. Based on this review, CO<sub>2</sub> stands out as a more superior technique in CTA.

### **Conclusion:-**

The field of vascular surgery has been graced by a wave of innovation in methods of diagnosis and treatment. Note that, when it comes to the treatment of conditions of peripheral vascular occlusions, it is imperative to use an approach with increased sensitivity to different segments of the veins and arteries. The conventional contrast-enhanced CTA was developed before the CO<sub>2</sub> CTA and it uses a CM such as iodine or gadolinium to provide visibility for imaging. The major contraindication in this technique arises when a patient presents an allergic reaction to the material of different CMs. Note that, this technique is advantageous in that it provides an image with a good-excellent quality, and it can also be used efficiently in small amounts with minimal to no nephrotoxicity. Unfortunately, patients with a history of renal or heart failure can be adversely affected by different CMs. However, steroids or beta-blockers have been found to reduce the likelihood that an allergic reaction will occur when taken days before the procedure. The CO<sub>2</sub> CTA is another method that is used for the visualization of the anatomic structures within the vascular system. It uses CO<sub>2</sub> as an imaging agent. Notably, this technique has become superior to the conventional contrast-enhanced CTA because of the properties of CO<sub>2</sub> that allow it to interact swiftly with the intravascular environment. By being highly soluble, it can easily dissolve into the venous and arterial structure to provide imaging of the vascular system that cannot be achieved with the conventional contrast-enhanced CTA. One key con is that CO<sub>2</sub> can result in refluxes in the aorta, and can also affect the vascular pressure when administered without care or a precise hand. Ultimately, a CO<sub>2</sub> CTA is a safer procedure with more accurate outcomes and can be used effectively in the treatment of peripheral vascular occlusions.

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