CT ANGIOGRAM FINDINGS IN PATIENTS PRESENTING WITH MECHANICAL STRANGULATION AND NEAR HANGING INJURIES

BY

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Declaration

I, Dr Zorina September-Jaffer, hereby declare that the work on which this dissertation/thesis is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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Dedication

I dedicate my research to my mother, Sakeena September who made significant sacrifices throughout my life and career, who encouraged me and who has supported me immensely through it all.

To my husband, Abdul Kader Jaffer, without whose support, love and encouragement, none of this would have been possible.

To my family, for providing me with support.

To the Groote Schuur Radiology Department, for being my family, teachers, counsellors and friends during my training.

Publications and presentations

This work has never been published.

It has never been presented at a congress.

Abstract

Background:

Blunt cerebrovascular injury (BCVI) is relatively uncommon in near-hanging and strangulation injuries but may have devastating neurological outcome. In developed countries, CT angiography (CTA) of the head and neck is performed as a screening tool in the acute clinical setting. This study was undertaken to assess the prevalence of vascular injury in patients presenting acutely to GSH trauma unit with these injuries and to recommend guidelines to ensure rational use of CTA in our resource-restricted environment.

Aim:

1. To assess the prevalence and nature of vascular injury in patients referred for CTA imaging following strangulation or hanging injury at our institution.

2. To determine if international criteria (modified Denver Criteria) for CTA referral for suspected BCVI due to strangulation or hanging injuries are followed at our institution.

3. To determine if international criteria for CTA imaging following suspected BCVI are appropriate following strangulation or hanging in a resource-restricted environment, and to identify aspects of existing protocols that may require future discussion.

Method:

This is a retrospective, quantitative, cross-sectional review of patients who had CTA studies after presenting with either strangulation or hanging to an urban Level 3 Trauma Unit. Radiological reports for the 45-month period ranging from January 2013 until September 2016 were reviewed and the frequency of positive findings was recorded.

Results:

45 patients met the inclusion criteria after presenting with a history of strangulation (n=8) or hanging (n=37). The average age was 31 years, 73% were male, 18% presented with strangulation injuries and 82% presented after hanging. 82% received a non-enhanced CT head scan and all patients had CTA scans of the neck and head. Six (13%) vascular injuries were reported on CTA (2 arterial and 4 venous). Both arterial injuries were reported in the strangulation group and none after hanging ($p < 0.05$). Two venous injuries were reported in each group). No base of skull, cervical spine or Le Fort facial fractures were demonstrated and there was no correlation between nadir of GCS and the presence of vascular injury on CTA.

Conclusions:

In this study comparing BCVI in strangulation and hanging, arterial injury was reported only in patients presenting after strangulation. Although such injury may be partially attributable to other co-existing mechanisms of trauma we support the continued use of CTA screening in the setting of strangulation injury in a resource-restricted environment.

The absence of arterial injury in the setting of near-hanging, however, argues against routine screening CTA screening even in patients with depressed level of consciousness.

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1. Literature Review

1.1. Introduction

Blunt cerebrovascular injury (BCVI) is a term used to describe injury to the carotid and vertebral arteries as a result of blunt trauma to the neck (1),(2). These injuries are usually seen in trauma populations where patients are at risk due to high-energy injury mechanisms to the head, neck and chest (2).

The majority of these cases (up to 80%) are therefore caused by motor vehicle accidents (3).

BCVI is of major concern as it may have devastating consequences such as focal neurology, stroke, or even death if left untreated (4).

The extracranial common carotid, internal carotid arteries and internal jugular veins are at high risk of injury during compression secondary to neck trauma(5). Carotid artery dissection secondary to a traumatic event is considered rare, however, this may be underestimated due to potential delayed manifestation of symptoms and a lack of clinical evidence of neurologic findings at the initial presentation (5). Complications have been reported between 10 and 72 hours after the traumatic event (6). This quiescent phase may result in delayed diagnosis and appropriate management of BCVI (6). This raises the question as to whether diagnostic screening investigations should initially be performed on these individuals in order for appropriate management to be implemented sooner rather than later (7). The diagnostic radiologist plays a crucial role, not only in detecting these injuries, but also in helping to guide clinical management thereof (2). Increased awareness of these types of injuries has led to a need for establishing adequate and cost-effective screening criteria (7).

Knowledge of the appropriate screening criteria, most appropriate screening modalities and grading systems are essential for rapid diagnosis of this entity and implementation of the most appropriate treatment (2).

1.2. Incidence

Early studies by Davis and colleagues in 1990, showed an incidence as low as 0.08 % for BCVI, however, these studies were done in the absence of screening (1),(8), (9). Later studies showing the use of increased screening, particularly the use of computed tomography angiography (CTA), have shown an increase in these incidence rates, now estimated to be between 1.2 % and 2.99 % (1). Technological advancements in imaging and more aggressive screening protocols probably explain this increased incidence (2), (9).

Stroke is a serious consequence of these injuries with early studies from 1980 describing mortality rates of 24% and morbidity rates of 58% (9), (10), (11). A later study by Langner et al in 2008 demonstrated higher mortality rates of up to 33 % (9), (12).

The current literature reports an overall incidence of 10 % - 13 % for stroke in BCVI with nearly 50 % of these patients presenting to hospital already symptomatic (1). In the asymptomatic group the incidence of stroke has been shown to decrease to < 1 % when aggressive screening and prompt appropriate treatment are performed (1).

The rates of infarction are higher for carotid artery versus vertebral artery injuries. In addition, high-grade arterial injuries (grades III to V) also carry a higher rate of infarction than low-grade arterial injuries (grades I to II) (2).

Recent published data have shown that the morbidity and mortality rates for untreated carotid artery injuries are 32%-67% and 17%-38 %, respectively (2). The morbidity and mortality rates for untreated vertebral artery injuries are lower at 14%-24% and 8-18%, respectively (2).

Apart from arterial injuries suffered during blunt neck trauma, jugular venous injuries also occur and these are often identified during surgical exploration of an arterial injury. Due to the fact that venous injuries either tamponade or occlude, significant haematoma or haemorrhage is less likely with injury to this low pressure system (6).

1.3. Mechanism of Injury

The most common cause of BCVI is trauma (2). As previously mentioned, this is usually due to high-energy mechanisms such as motor vehicle accidents, but other mechanisms of high-energy injury are due to pedestrian-vehicle accidents, sporting activities, assault with strangulation, attempted suicide in the form of hanging, falls from heights greater than standing and other direct trauma to the head, neck or face (2). In one case series, the majority (70%) of blunt carotid injuries were due to motor vehicle accidents, 12 % to sporting activities, 10% as a result of assault and 7 % to a fall (13).

It is important to note that low-energy mechanisms may on the odd occasion also result in cervical arterial injuries, which is usually not associated with other significant trauma-related findings (2). An example of this type of low-energy trauma mechanism is chiropractic manipulation of the neck (2).

Blunt injury to the cerebrovascular vessels are caused by three basic mechanisms including (1), (2), (7) : severe hyperextension and contralateral rotation resulting in longitudinal stretching, twisting, or compressive forces on the arteries; direct impact to the vessel; vessel injury/laceration secondary to a closely related fracture fragment; and direct trauma to the oral cavity.

These types of injuries could occur anywhere along the vessel and patients with cervical spine fractures are at highest risk of vascular injury (2). Carotid artery injuries tend to occur in the region of the skull base, whilst vertebral artery injuries tend to occur along the transverse foramina (1). The extracranial vessels are more susceptible to injury because they are superficial, mobile and are in close relation to skeletal elements (1).

Contralateral rotation and hyperextension of the neck causes the vessel to stretch over the lateral masses/transverse processes of C1-C3 at the skull base which commonly causes injury to the distal extracranial carotid artery (1), (7). A high incidence of BCVI (up to 8 %) has been reported with C1-C3 spinal fractures/dislocations (2). Lower rates (2 %) occur in patients with C4-C7 fracture/dislocations (2). Base of skull fractures extending through the carotid canal often cause injury to the intracranial segment of the internal carotid artery (7).

Vertebral artery injuries are most commonly seen in the transverse foramina (V2-between C2 and C6) or at the atlas loop, usually due to laceration as a result of a fracture fragment (7). Stretching of the vertebral arteries may occur due to spinal subluxation, dislocation or ligamentous injury (1), (2). This extreme stretching of the artery results in disruption of the arterial mural integrity, which may be complete or partial (14).

Compression of the vessels against the dural margins may occur with cranio-cervical injury (14).

A direct blow to the artery may either cause direct injury to the vessel or injury may be secondary to compression of the vessel against an adjacent bony structure (2).

In addition, extreme hyperflexion of the head or a posteriorly displaced mandible fracture may cause arterial injury by crushing the internal carotid artery between the mandible and spine (14). The vertebral artery may similarly be crushed against C1 in the case of a dislocated occipital condyle (14).

It is important to note that direct injury to the vessels in cases of blunt trauma may also be caused by a seat-belt injury (7).

Locally, platelet aggregates form at the site of vessel injury. These platelet aggregates may thromboembolize into the cerebral circulation and result in neurologic injury. Low flow infarcts may result from a different mechanism relating to luminal narrowing or occlusion secondary to these platelet aggregates as well as intramural haematoma (1).

1.4. Injuries specifically related to strangulation

Strangulation occurs when external pressure applied to the structures of the neck results in asphyxia due to obstruction of the airway or blood flow (5). The sequence of clinical events experienced by a patient after strangulation is severe pain, then loss of consciousness and eventually, brain death (5). The loss of consciousness may result from injury to the carotid arteries and/or jugular veins or by airway obstruction (5).

Mortality related to strangulation is usually related to one or more of the following four clinical situations, which are not in any particular order: cerebral ischaemia (i.e. stroke); cerebral hypoxaemia caused by venous congestion (i.e. obstruction to venous blood flow); asphyxia related to obstruction of the larynx or cardiac dysrhythmia leading to cardiac arrest (5).

All that is needed to obstruct the jugular veins is a mild, but prolonged pressure and the resultant venous congestion in the brain is the most common cause of mortality in cases of strangulation (5). Death secondary to cardiac dysrhythmia is very uncommon (5).

In general, the diagnosis of carotid dissection is rare and is even less frequently seen in cases of blunt trauma and it is for this reason that much of the literature is based on case reports or case series (13).

The emergency room clinician often requests an objective radiological study to assess the carotid and vertebral arteries in patients presenting with a history of strangulation (13). In a review by Vilke and Chan 2011, patients diagnosed with carotid dissection after strangulation usually present with neurological fall out (13). Furthermore, none of the strangulation victims who presented without focal neurology, neck pain, bruising or tenderness demonstrated carotid dissection, emphasising the rarity of carotid dissection. The clinician should therefore consider the mechanism of injury and a carotid injury or dissection should only be suspected in the appropriate clinical setting (13), which will be discussed later.

In addition to vascular injury, fracture of the hyoid bone is a common injury in fatal strangulations. Fractures of the thyroid and cricoid cartilages may also occur (5).

1.5. Clinical Presentation

Vascular distribution dictates the territory of the brain affected and therefore the clinical manifestations of stroke in BCVI are variable (2).

Victims of hanging and strangulation may present early, usually without neurological symptoms, or late (hours to days or even after several weeks) with new focal or lateralizing neurological fallout such as Horner's syndrome or stroke (2), (13).

In a review of 155 cases of blunt neck injury to the ICA prior to 1996, 56 % of patients presented symptomatically within the first 24 hours (15). Delayed onset with cerebral infarction was seen in up to 82 % of all cases of carotid artery dissection from all mechanisms (16), (13).

In a more recent article, Rutman et al reported a mean delay (latent period) of 72 hours before patients manifest the clinical symptoms of infarction. Further, neurologic symptoms at presentation, out of keeping with non-angiographic non-enhanced CT are concerning for either an evolving or overlooked BCVI. The authors therefore argue that angiographic imaging is most useful during this latent period as clinical management may be timeously commenced in cases of asymptomatic BCVI (2).

Arterial transection and AVF should be suspected clinically in the setting of arterial haemorrhage or an expanding soft tissue haematoma (2). Orbital symptoms and rapid progression of vision loss may occur as a result of venous congestion secondary to a high-flow AVF (2). Venous congestion and back-pressure may also lead to retrograde cortical venous drainage, in-turn leading to subarachnoid or even parenchymal haemorrhage (2).

Other signs highly suspicious for BCVI are incorporated in the international criteria which are discussed in section 1.8 (Screening Criteria).

1.6. Rationale for Screening

Studies have shown that patients demonstrate a significant improvement in outcome and possibly prevention of adverse outcomes when treatment is administered early during the asymptomatic latent period (1). If BCVI is not detected early enough, patients may suffer irreversible neurologic deficits (1). It is for this reason that early screening is advocated for accurate diagnosis and appropriate management (1), (3).

Screening in the setting of blunt vascular injury requires appropriate clinical and radiological assessment and standardised protocols should be employed to reduce mortality and morbidity (3). Several screening criteria have therefore been suggested to identify patients at increased risk of BCVI.

In a prospective analysis by Cothren et al (1996-2004), stroke was prevented in 32 of 187 asymptomatic patients with BCVI demonstrated at CTA, placed on antithrombotic therapy (17), (7). This analysis was based on stroke risk stratification determined by the degree of carotid injury at angiography (7). The authors concluded that screening played an important role in early detection of patients at risk of stroke as well as subsequent prevention using antithrombotic treatment and in the reduction of stroke-related long-term morbidity (7). One may, however argue that this is a hypothetical assessment of stroke risk and one cannot guarantee that these patients would have suffered a stroke in the absence of therapy.

Digital subtraction angiography (DSA) remains the gold standard, however this invasive procedure has its own stroke complication rate of 0.1 – 1 % (6).

Computed tomography angiogram (CTA), is however, now the imaging modality of choice and has the advantage of a 12-fold reduction in the time interval from presentation to diagnosis compared with DSA (18), (6).

1.7. Indications for Imaging

Patients may present completely asymptomatic, however, radiologically they may have severe injuries. These types of injuries include base of skull fractures, cervical spine fractures involving C1-C3 and the vertebral transverse foramina. In addition, they may have severe hyperextension or hyperflexion injuries (3).

Indications for screening of BCVIs considers the mechanism of injury as well as the patient's signs and symptoms at presentation. These signs and symptoms include acute arterial haemorrhage from the neck, mouth, nose, and ears; expanding neck haematomas; a cervical bruit; new focal neurological fallout; disparity between the neurological exam and radiological findings; as well as evidence of ischaemic stroke on follow up non-enhanced CT head (2), (6). Urgent CTA of the carotid and vertebral arteries should be performed if at least one of these findings are present (6).

A study by Subramanian et al suggested that the presence of dysphagia, dysphonia, stridor and subcutaneous emphysema in a patient with normal neurological examination is concerning and similarly warrants imaging (19).

Other independent risk factors, which form the Modified Denver Risk Criteria, include a high energy mechanism of injury, diffuse axonal injury with a GCS of < 6/15, Le Fort II or III fractures, base of skull fracture with extension into the carotid canal, and near hanging with axonal brain injury (6), (20). These criteria are currently in clinical use as a guide for screening CTA, in order to ensure prompt diagnosis and initiation of treatment of BCVIs (6).

1.8. Screening Criteria

Over the past 20 years, many screening criteria and guidelines have been proposed by various professional organizations and research groups to establish patients at highest risk for BCVI. (1),(2),(21).

Based on symptoms and signs previously described, the Denver Criteria (20), (22), (1) and the Memphis Criteria (23), (24), (1) were developed at the Denver Health Medical and the University of Tennessee Health Science Center, respectively (Table 1.1).

Since then, there have been several modifications to the Denver Criteria (1999 to 2004) due to missed injuries with the initial criteria. The so-called Modified Denver Criteria (Table 1.1) were expanded in 2012 due to missed injuries to include mandible fractures, complex skull fractures, traumatic brain injury with associated thoracic injuries, thoracic vascular injuries and scalp degloving injuries (25), (1). This expanded Denver Criteria (2016, Table 1.1) have been shown to detect previously missed injuries and it is recommended that this is used for screening. In 2016, the Denver group (26) also found that there was an overall rise in the incidence of BCVI from 2.36 % to 2.99 % when the expanded screening criteria was used, as it identified more cases (1). They also demonstrated that the incidence of stroke, related to BCVI decreased from 12 % to 9.3 % (26), (1).

It is important to note that some risk factors such as cervical spine or base of skull fractures, carry heavier weighting for BCVI than others (27). Absence of a cervical spine injury does not, however exclude a vascular injury (27).

Another set of criteria, the Boston Criteria (Table 1.2), based on a study at the Boston Medical Center, has also recently been proposed for the identification of BCVI, however, the Modified Denver Criteria is more widely used (28), (1).

The most recent guidelines by the Western Trauma Association (29) and the Eastern Association for Surgery of Trauma (EAST) (30) were published in 2009 and 2010, respectively, and have endorsed the Modified Denver Criteria (1).

Even with a more aggressive approach to screening of BCVI, approximately 20 % of patients will not fit the screening criteria and these injuries may be identified incidentally with other studies, such as CTA of the thoracic aorta, which may identify proximal carotid artery (6), (27). Similarly, Bruns et al showed that up to 30 % of BCVIs demonstrated at CTA had no radiographic or clinical risk factors for BCVI (31), (2). Further expansion of the Modified Denver Criteria may therefore still be required (1).

1.9. Pathophysiology and Types of Vascular Injury

BCVI is usually initiated at the level of the intima or media as an intimal tear or intramural haematoma (1). The mechanisms of injury include minimal intimal injury/disruption, adventitio-medial/adventitial injuries (intramural haematoma), intimal dissection, pseudo-aneurysm formation, arteriovenous fistula formation (haemodynamically significant or non- significant), partial intramural thrombosis, complete occlusion and complete transection (2), (7), (27).

It is important to note that more than one injury can manifest in a single vessel and that injuries to multiple vessels occur in 18 – 38 % of cases (27).

This intimal injury or tear usually occurs secondary to vessel stretching or twisting and may similarly be initiated by shearing forces, which may lead to vessel wall dissection, cranial extension, luminal stenosis or even complete vessel occlusion. The associated platelet aggregation, , may lead to vessel occlusion due to embolization (2). Minimal intimal injury is best seen on multiplanar reformatted and 3D CT imaging, where areas of non-stenotic luminal irregularity may be visualised (3).

Adventitiomedial and adventitial injuries are specific types of arterial vessel wall injuries in which there is no break of the intimal lining. Instead, disruption of the vasa vasorum leads to formation of an intramural haematoma as a result of blood dissecting through the media and/or adventitia. Similarly, these types of vessel wall injuries may also result in luminal stenosis and/or occlusion (2). Intramural haematoma secondary to arterial dissection is manifested as either circumferential or eccentric mural thickening (3).

In dissection an intimal flap, a linear filling defect within an artery, may be seen extending from the arterial wall into the lumen and multiplanar reformatted imaging assists with assessment (3).

A traumatic pseudoaneurysm is formed when blood from an arterial transection is contained by the incomplete mural layers and surrounding soft tissues resulting in a focal outpouching (saccular or fusiform) from the arterial wall at the site of injury. These occur due to breach of the vessel wall and may compress the main vessel lumen resulting vessel stenosis and/or occlusion (2), (3). The associated abnormal flow dynamics in combination with exposed subendothelium within the aneurysm sac may promote coagulation, thrombosis and possible downstream embolization (2). Rupture of a traumatic pseudo-aneurysm is always of concern, although devastating rupture is thought very rare (2).

An arteriovenous fistula (AVF) is formed when blood from an arterial transection decompresses into an adjacent vein forming a fistulous communication (1). These types of communications are high-flow in nature and are fortunately seen infrequently. Many of these patients do not reach the hospital alive, nor survive long enough for imaging to be initiated (2). An arteriovenous fistula should be suspected on imaging when early venous contrast opacification and prominence of draining veins are seen at CTA (3).

Carotico-cavernous fistulas (CCFs) are a type of AVF, often in the setting of a base of skull fracture where a ruptured cavernous segment of the internal carotid artery (ICA) results in a direct communication between the cavernous ICA and the cavernous sinus (2).

Complete arterial transection is the most severe outcome of a BCVI, but is uncommon in clinical practice (1).

Arterial transection results in haemorrhage into the neck and face and can also result in massive stroke. Haemorrhage from arterial transection can result in rapid exsanguination if urgent management is not commenced timeously (2). This is demonstrated as active contrast extravasation into the extravascular space on CTA (3).

Occlusion is the most commonly seen type of common carotid injury in blunt trauma (33%) and is manifested by a complete lack of intraluminal contrast opacification

(3). ICA occlusion usually has a more tapered appearance and demonstrates gradual narrowing of the lumen, whereas vertebral artery occlusions tend to be more abrupt (3).

Venous mural injuries are also seen in patients with BCVI, more commonly in cases of penetrating trauma. Types of venous injuries include venous pseudoaneurysm formation, venous transection and injury to the dural venous sinuses in cases of base of skull fractures. Injury to the dural venous sinuses may predispose to dural venous sinus thrombosis and/or occlusion (2).

Cerebral ischaemia is due to haemodynamic instability secondary to dissection and intimal disruption, which induces platelet aggregation due to exposure of subendothelial collagen fibres. This causes thrombosis and eventually thromboembolism (7).

1.10. Grading of Vascular Injury

Due to the wide array of potential vascular injuries in BCVI, Biffl et al from the Denver Health Medical Center proposed an angiographic-based classification for blunt carotid artery injury in 1999 (Table 1.3) in order to grade the types of injuries and their severity (27). The probability of stroke and worse clinical outcome corresponds to an increasing grade of severity.

The initial grading system was based on carotid artery injuries demonstrated at DSA, but has since then also been used for CTA and MRA and for both carotid and vertebral artery injuries (1).

This Denver grading system correlates CTA findings with their corresponding prognostic value for the future risk of a stroke and is currently the standard for reporting BCVI (1), (21).

1.11. Imaging Modalities

Several imaging modalities may be used to evaluate for BCVI including CTA, MRI/MRA and DSA (1).

This section explores the various imaging modalities which may be used to assess BCVI.

1.11.1. Digital Subtraction Angiography (DSA)

DSA is still regarded as the gold standard for screening of BCVI as it has a high sensitivity and specificity when compared to other non-invasive modalities such as single or 4-slice CTA and MRA. Another advantage of DSA, is that it provides flow analysis.

It is important to mention that DSA is an invasive procedure, with a complication rate of 1 %-3 % (1). Complications from DSA include puncture site complications, vascular dissection and thromboembolism, which in itself may result in stroke and haemorrhage (1), (2), (7).

DSA is expensive, requires highly specialised and expensive equipment including an angiography suite, is technically demanding and requires adequately trained personnel to perform the procedure (6), (7). In addition, it is not ideal to perform a DSA on a critically ill patient (1). Due to these factors DSA is only available in certain centres and lack of immediate availability or accessibility may result in prolonged time to diagnosis (6). Lastly DSA cannot provide vital information required by surgeons, regarding the vessel wall itself (specifically, non-stenotic intramural haematoma) or the status of the surrounding structures as it relies on intraluminal opacification (2), (6).

The indications for DSA include equivocal or non-diagnostic CTA in a high risk patient, a normal CTA study in a patient with persistent clinical signs of vascular injury and when lesions on CTA are amenable to endovascular treatment (i.e. intervention planning) (1), (3).

1.11.2. Multidetector Computed Tomographic Angiography (MDCTA)

Early studies on single and 4-slice MDCT scanners demonstrated a low sensitivity for BCVI ranging from 45-70% compared with DSA. However, more recent studies have also demonstrated the specificity of CTA on 16- to 64- channel MDCT scanners equivalent to DSA in BCVI, though the sensitivity is still lower on CT (was 66 % - 98 % and 92 % - 100 %, respectively) (2). Missed injuries in these instances were low-grade (1), (2).

CTA is also quick, readily available, non-invasive, cost efficient and has a high spatial resolution (1), (7). An added advantage of CTA is that the vessel wall and surrounding structures can also be evaluated, which is not possible with DSA (6), (7). In cases of polytrauma, MDCT is commonly used to identify injuries to the head, neck, chest, abdomen, pelvis and spine. MDCT can be therefore be performed at the same time for suspected BCVIs in high risk patients (7).

The rapid image acquisition time allows for decreased motion artefact and post processing allows for multiplanar reformatting which allows for better visualisation of the vessel lumen and wall (6).

It is for these reasons that the Western Trauma Association now considers CTA to be the screening modality of choice for BCVI (6).

Despite all these advantages, CT is not devoid of limitations such as streak artefact or sequelae such as radiation exposure and contrast-related nephropathy (6).

Iterative reconstruction is a newer technique, which reduces radiation dose to the patient while maintaining image quality (6).

1.11.2.1. Pitfalls of CT

Artefacts may obscure the region of interest (e.g. spinal hardware or dental amalgam) (3).

1.11.3. Dual Energy CT

Dual energy is an advanced CT technique which allows for better visualisation of vessels by pure automated bone removal, especially of the petrous portions of the carotids and vertebral arteries traversing the transverse foramina (6). Newer dual energy bone subtraction algorithms are improving imaging of the carotid vessels. However, even using these advanced scanners, the bone removal near the vertebral arteries is less effective than near the carotids (6).

1.11.4. Magnetic Resonance Imaging and Angiography (MRI and MRA)

MRI and MRA are non-invasive, offer comprehensive vessel imaging and can therefore assess and delineate carotid or vertebral artery dissections, which are best demonstrated with proton-density-weighted or fat-saturated T1-weighted sequences (1), (2), (6). MR also allows assessment of intramural haematoma, atherosclerotic plaques and intraluminal thrombus in cases of dissection (1).

In addition, MRI provides excellent imaging of the brain and spine allowing for the evaluation of ligamentous/spinal injuries and it far surpasses DSA and CTA in its ability to evaluate for acute cerebral infarction using DWI and/or perfusion (1).

The advantage of MRA over MDCT is the lack of ionising radiation, lack of base of skull streak artefacts and that contrast administration is usually not required (1), (2), (7). Gadolinium-based contrast agents are associated with fewer reactions than iodinated contrast (1), (2). Where contrast is required, a non-nephrotoxic MRI contrast agent may be utilised.

The sensitivities and specificities of MRA in BCVI are, however lower than CTA when compared with DSA at 50 %- 75 % and 67 %, respectively (2).

Several factors render MR imaging impractical in the multi trauma patient: longer image acquisition times, more artefact related to motion, the need for MRI-compatible line and tubes in the acute trauma patient, poorer spatial resolution compared with CT, low sensitivity for acute intramural haematoma (isointense), lack of accessibility and the need for specially trained personnel to perform the imaging (1), (2), (7).

The EAST guidelines do not recommend MR imaging as a single technique for diagnosis, but suggest that it rather to be used as a complementary imaging modality (1). In particular, high-resolution vessel wall MR imaging may play a valuable complementary role to luminal imaging (CTA and MRA) in future (2).

1.11.5. Sonography

The advantages of Doppler ultrasound include a lack of ionising radiation, non-invasiveness, low cost, availability, and easy mobility which make duplex sonography a reasonable screening modality in the assessment of trauma patients (6).

Findings at ultrasound which would suggest vasculature injury include luminal narrowing, hypoechoic intramural haematoma, dissection, significant stenosis and occlusions (6).

Its role in monitoring and diagnosing non-traumatic cerebrovascular pathology is well known, however, due to operator dependency, there may be limitations in its ability to establish subtle injuries or dissections. Visualisation of the base of skull vasculature, especially vessels passing through bony foramina pose particular challenges (7). Duplex ultrasound has a disappointingly low sensitivity (38 %) and specificity (86 %) compared to DSA in accurately diagnosing BCVI (6), (7).

The EAST guidelines suggest that duplex sonography is not used for screening as 90 % of the lesions are difficult to access sonographically, it is operator-dependent and has a lower sensitivity in comparison with CTA, MRI/MRA and DSA (38.6 % for both the carotid and vertebral injuries and 86 % for the carotid artery injuries alone) (1).

1.12. Management

The appropriate management of BCVIs depends on the type of injury and anatomic site (7). Management may be pharmacological or interventional, depending on the individual clinical scenario (9).

Symptomatic and asymptomatic patients with BCVI should be closely observed for neurological compromise (7).

The need for early detection and treatment has been emphasised in order to prevent morbidity and mortality (7). Early commencement of antithrombotic therapy is crucial for reducing the risk of BCVI-related stroke and/or mortality (2). The majority of these vascular injuries are in the region of the skull base and are not amenable to open surgical intervention (7). In addition, many of these injuries result in acute thrombosis, thrombus propagation and distal embolization, which require medical rather than surgical intervention (7). There is however still controversy regarding optimal treatment for dissection, thrombosis and pseudoaneurysms (7). Although older studies showed a preference for surgical management of dissection and thrombosis, the newer approach advocates for medical management(7).

1.12.1. Antithrombotic (Medical) Therapy

Antithrombotic therapy encompasses both antiplatelet and anticoagulation therapies (2). Bleeding is a concern in trauma patients, however, antithrombotic therapy used to treat BCVI has shown to be safe in these patients and lowers the risk of stroke to < 1 % (1), (2).

Grade I-IV type vascular injuries are currently being treated with antithrombotic therapy, unless contraindicated (e.g. known acute intracranial or local cervical haemorrhage) (2).

Duration of medical therapy depends on the grade of injury and response to therapy. Grade I injuries are treated with aspirin for approximately 3-6 months as these are not flow-limiting lesions and because this this is the approximate time for the lesion to heal (1), (2).

Grade II-III injuries are treated with antiplatelet therapy indefinitely for lesions which demonstrate stability over time. If these injuries resolve on antithrombotic therapy alone, then treatment can be stopped (2). If they progress at follow up, usually at 7-10 days, then then either surgical or endovascular treatment will be required (2).

Grade IV injuries are treated with lifelong antiplatelet therapy, using aspirin as the first-line agent. Clopidogrel can be added to the regimen or treatment can be changed to anticoagulation therapy if the neurologic symptoms persist or if the lesion increases in severity (2).

Grade V injuries are treated with surgical or endovascular (interventional) management initially. Long-term antithrombotic therapy is decided on an individual basis by evaluating the risks and benefits to the patient as no specific data exist to guide therapy as yet (2).

1.12.1.1 Anticoagulation

Anticoagulation is considered the treatment of choice for patients with BCVIs, in particular those with inaccessible vascular lesions (7). Its role in preventing embolization and permanent occlusions to injured vessels is well established (7).

In the initial stage, heparin is used for hospitalized patients who may undergo surgical intervention, as it has a short half-life, is easily reversible and is safe provided that no contraindications exist and that the benefit outweighs the risk of haemorrhage in high risk patients (2), (7).

Systemic heparin (weight-based unfractionated heparin - > 10 U/kg/h) is one of the current treatment recommendations for carotid dissection and is given as stroke is usually due to emboli from occlusion of the proximal carotid artery rather than haemodynamic alterations (13). A low activated partial thromboplastin time of 40-50 seconds is the goal with heparin therapy (1).

Heparin is then followed by warfarin (coumarin), an oral anticoagulant, for approximately 3-6 months after the initial injury with a targeted international normalized ratio (INR) of 2-3 (2), (7). Recent studies, have however, recommended the use of antiplatelet agents instead of anticoagulation agents for prolonged use due to its greater safety profile, lower cost and similar efficacy (1).

Studies have shown neurological improvement in symptomatic patients who were commenced on heparin at initial diagnosis in comparison with those who did not receive heparin (13).

It has been suggested that follow up be arranged for patients treated with anticoagulation initially for BCVI, in order to identify pseudoaneurysm development (7).

1.12.1.2 Antiplatelet Therapy

Aspirin has been used as an alternative to heparin in the management of BCVI. Currently, there are no randomized control trials comparing the use and efficacy of antiplatelet and anticoagulation therapies for the treatment of BCVI, however, some studies have shown that aspirin has a similar efficacy compared with heparin for prophylactic therapy of stroke with a better safety profile, especially in reducing the bleeding risk in the setting of trauma (2), (7).

1.12.2. Open Surgical Repair

Grade V injury is a major vascular injury, in which there is active bleeding or haemodynamic instability requiring either surgical or endovascular management, depending on the clinical scenario (2).

Proximal and distal control is important and therefore open surgical repair is reserved for discrete lesions at the carotid bifurcation or for lesions below the skull base (7). The neck is divided into three anatomical zones. Zone II, which extends from cricoid cartilage to the angle of the mandible is surgically accessible. Zone I (extending from the sternal notch/clavicles to the cricoid cartilage) and zone III (extending from the angle of the mandible to the skull base) are not (2). If injuries occur in this region then urgent referral for endovascular treatment should be considered (2).

Another indication for either surgical or endovascular treatment is failed medical therapy (2). Surgical repair is recommended for pseudoaneurysms, unless small or inaccessible, in which case, anticoagulation with/without proximal ligation is suggested or, rarely, extracranial-intracranial bypass (7).

Types of surgical repair include primary repair, interposition graft placement, carotid artery ligation, extracranial-intracranial bypass and thrombectomy (13).

1.12.3. Interventional/Endovascular Therapy

Endovascular therapy such as angioplasty and endoluminal stenting with bare or covered stents is an alternative to open surgery. (7).

It is indicated when medical therapy is contraindicated or fails, for surgically inaccessible injuries and for grade III pseudoaneurysms (2), (7). Intervention should be considered if a pseudoaneurysm becomes symptomatic despite medical treatment or if it increases in size to between 1.0-1.5 cm in diameter. Balloon occlusion is the preferred management of carotid-cavernous sinus fistulae. (2)

Resection with patch interposition graft placement or coil embolization is less commonly used as definitive treatment of pseudoaneurysms in the neck region (2).

Antiplatelet therapy is advised after endoluminal stenting to prevent thrombosis or embolic events (7).

1.13. Follow Up and Follow Up Imaging

Current guidelines (Denver group, WTA and EAST) recommend that medically managed injuries (grades I-III) have follow-up CTA at 7-10 days to assess response to antithrombotic therapy and to further guide management of these patients (1), (2). Therapy is stopped if repeat imaging demonstrates resolution of the injury. Antithrombotic therapy is continued for another 3-6 months if the findings persist on repeat imaging with further imaging follow up arranged thereafter. Endovascular treatment is commenced for worsening symptoms or progression of the imaging findings at 7-10 days (1).

Symptom-based follow up is used for patients who received initial surgical or endovascular management (1).

2. Materials and Methods

2.1. Study Objectives

Aim:

1. To assess the prevalence and nature of vascular injury in patients referred for CTA imaging following strangulation or hanging injury at our institution.

2. To determine if international criteria (modified Denver Criteria) for CTA referral for suspected BCVI due to strangulation or hanging injuries are followed at our institution.

3. To determine if international criteria for CTA imaging following suspected BCVI are appropriate following strangulation or hanging in a resource-restricted environment, and to identify aspects of existing protocols that may require future discussion.

2.2. Research Paradigm

This is a retrospective, quantitative, cross-sectional, single-centre study based on referrals for imaging from an urban Level 3 Trauma Unit. The study was conducted in the Groote Schuur Hospital Radiology Department.

This study was reviewed and approved by our local Institutional Ethics Committee.

We reviewed electronic clinical CT requests and radiological reports.

Patients folders were not accessed for the purpose of this study.

Our study was not randomized.

2.3. Sample

All patients who presented to the GSH Trauma Unit with either "Strangulation or Hanging" injuries and in whom a CTA neck study was performed in the GSH radiology department were included. Data was collected for the forty-five-month period spanning from 01 January 2013 until 30 September 2016.

2.3.1. Inclusion criteria

All patients who presented to the GSH trauma unit with a history of manual strangulation or near hanging injury during the above time period, and in whom a CTA of the neck vessels was performed were selected.

2.3.2. Exclusion criteria

Cases of penetrating trauma were not included

2.4. Data collection

We searched the GSH hospital electronic PACS imaging database (iSite Enterprise, Philips, Philips Healthcare) using a plugin called inSight for our data collection. We identified all the CTA neck vessels and CTA neck/cerebral vessels studies, which were requested from our trauma unit and performed during the above-mentioned time period. Once we identified these cases, we then searched all these clinical requests for the keywords, “Hanging” and “Strangulation”.

Specific data and patient variables were extracted from the clinical reports as determined by the study investigators.

Patient variables collected included age, gender, level of consciousness, the clinical presence of soft tissue injury, whether the patient was intubated and Glasgow coma scale level.

The radiology reports were read by a radiology registrar and reviewed by a specialist radiologist.

On review of the radiological imaging and reports we collected further data including whether a non-enhanced CT head was performed or not, whether the CT head then demonstrated pathology or not, whether a vascular injury was demonstrated and if present, we defined the type of vascular injury.

The presence of a vascular injury could either represent an arterial or venous injury. A positive arterial injury on CTA was defined as one that demonstrated either carotid or vertebral artery injury. Each arterial injury was graded using the Biffl/Denver grading scale (Table 1.3).

The imaging of patients was performed on one of two machines. A Siemens Somotom Emotion 16-detector array multi-slice CT scanner (Erlangen, Germany) or a Toshiba Aquilon PRIME 160 slice multiple detector array (Tochigi, Japan).

A plain helical cranial CT would, in most cases, be performed first to exclude an infarct. A CTA study of the cranio-cervical vessels is acquired from the level of the carina to the vertex.

2.5. Statistical analysis

The collected data were entered into a computerised spreadsheet for review. Statistical analysis was performed using frequencies and percentages comparing the previously mentioned variables for each group.

We established the frequency and percentage of arterial injury in our population groups and the frequency and percentage of these patients who met international criteria for initial CTA screening.

We then determined the relevant *P* values by applying the Fisher Exact Test (due to our small sample size) and the 95% confidence intervals. Statistical significance was determined by P value < 0.05.

3. Results

3.1. Combined Results For Both Strangulation And Hanging

A total of 45 patients were identified as having a CTA neck study for hanging or strangulation injuries during the period 01 January 2013 until 30 September 2016.

None of these patients met the exclusion criteria.

In total, 82 CT studies were performed.

The study group included 33 male (73%) and 12 female (27%) patients. The mean age was 31 years of age (14-69 years).

Table 2.1 summarises the demographics for the study group.

3.1.1. Loss of Consciousness (Combined)

Thirty-one (69 %) of the 45 patients experienced a loss of consciousness after the event.

3.1.2. Glasgow Coma Scale (Combined)

Glasgow coma scale (GCS) readings *on scene* varied between 3-9 out of 15, with the readings of 35 patients (78%) not provided in the clinical request.

The GCS of patients at *presentation to GSH* ranged from 2T-15 out of 15, with 24 readings (53%) not provided in the clinical request.

3.1.3. Clinical Evidence of Soft Tissue Neck Injury (Combined)

Thirty-two (71 %) of the 45 patients demonstrated clinical evidence of soft tissue neck injury.

3.1.4. Intubation (Combined)

Eighteen (40 %) of the 45 patients were intubated at the time of imaging.

3.1.5. CT Head Findings (Combined)

Of the 45 patients, 37 (82 %) patients received a non-enhanced CT head study.

Five (13 %) patients demonstrated evidence of acute intracranial abnormality. Of these, two patients from the strangulation group demonstrated intracranial haemorrhage, due to associated assault. Two demonstrated suspected ischaemic changes and four were reported as having cerebral oedema.

3.1.6. CT Angiogram Findings (Combined)

Two (4 %) of the 45 patients demonstrated arterial injuries. None of the 45 imaged patients demonstrated Biffl grade IV or V arterial injuries and none of the hanging victims demonstrated any arterial injury.

Four (9 %) of the 45 patients demonstrated venous injuries.

None of the 45 imaged patients demonstrated base of skull, carotid canal, petrous bone, cervical spine or Le Fort facial fractures.

3.2. Results for Strangulation Only

Of the 45 patients, 8 (18 %) of the patients were victims of strangulation.

3.2.1. Loss of Consciousness (Strangulation Only)

Five (63 %) of the 8 patients experienced a loss of consciousness after the event. Presence and duration of loss of consciousness was not documented in 3 (38 %) of the patients.

3.2.2. Glasgow Coma Scale (Strangulation Only)

Information on GCS was poorly provided in this group with 7 (88 %) out of 8 *on scene* GCS readings being unrecorded. The only recorded GCS *on scene* was 3 out of 15.

The GCS at *presentation to GSH* was documented as 2T (1 patient), 15 (3 patients) and the remaining 4 were unknown.

3.2.3. Clinical Evidence of Soft Tissue Neck Injury (Strangulation Only)

Six (75 %) of the 8 patients demonstrated soft tissue neck injury. Two (25 %) were unknown.

3.2.4. Intubation (Strangulation Only)

One (13 %) of the 8 patients was intubated at the time of imaging.

3.2.5. CT Head (Strangulation Only)

Of these 8 patients, 7 (88 %) patients had a non-enhanced CT head performed.

Of these, 2 (29 %) demonstrated acute intracranial abnormality. Two (29 %) demonstrated intracranial haemorrhage due to assault and 1 (14 %) of these 2 patients, further demonstrated both ischaemic brain changes and cerebral oedema.

3.2.6. CT Angiogram (Strangulation Only)

Two (25 %) of the 8 patients demonstrated arterial injuries.

One (13 %) had a Biffl grade I injury, whilst the other patient had a Biffl grade III injury.

Two (25 %) demonstrated non-occlusive venous thrombosis of the left IJV.

The first patient with an arterial injury demonstrated dissection and pseudoaneurysm formation of the brachiocephalic trunk (Biffl grade III) and extensive intraluminal thrombus within the right common carotid artery (Biffl grade II). His total injury score is therefore a grade III injury. There was no vertebral artery injury. This patient also demonstrated non-occlusive thrombus in the left IJV.

This patient experienced loss of consciousness, had soft tissue injury, was intubated for a GCS of 3 out of 15 on scene and had a GCS of 2T out of 15 on presentation to GSH. The patient had acute trauma-related intracranial injury (CT evidence of diffuse axonal injury), subtle focal loss of grey-white differentiation (possibly ischaemic) and global cerebral oedema demonstrated on non-enhanced CT head.

The second patient with an arterial injury demonstrated dissection of the right vertebral artery with less than 25 % luminal narrowing (Biffl grade I injury). There was no carotid artery injury. This patient was strangled one week prior to presentation in a prison. He had residual clinical evidence of soft tissue neck swelling. Information about his level of consciousness and GCS at the time of injury were not provided. His GCS was 15 out of 15 on presentation to GSH one week after injury and he was therefore not intubated.

3.3. Results for Hanging Only

Of the 45 patients, 37 (82 %) were victims of near hanging.

3.2.1. Loss of Consciousness (Hanging Only)

Twenty-six (70 %) of the 37 patients experienced a loss of consciousness after the event. Loss of consciousness was not documented in the radiological request for 11 (30 %) patients.

3.3.2. Glasgow Coma Scale (Hanging Only)

GCS *on scene* was variable ranging from 3 to 9 out of 15, with 28 (76 %) unknown. The GCS at *presentation to GSH* was variable ranging from 2T to 15 out of 15, with 20 (54 %) unknown.

3.3.3. Clinical Evidence of Soft Tissue Neck Injury (Hanging Only)

Twenty-six (70 %) of the 37 patients demonstrated clinical evidence of soft tissue neck injury. Eleven (30 %) were unknown.

3.3.4. Intubation (Hanging Only)

Seventeen (46 %) of the 37 patients were intubated at the time of imaging.

3.3.5. CT Head (Hanging Only)

Of these 37 patients, 30 (81 %) patients had a CT head performed.

In 3 patients (10 %) cerebral oedema and subtle loss of grey-white differentiation were reported. None demonstrated intracranial haemorrhage.

3.3.6. CT Angiogram (Hanging Only)

None of the 37 patients demonstrated an arterial injury (0%, 95% CI 0 - 9%).

There was a significant difference between the proportions of positive arterial findings between the two groups, i.e. 2 of 8 (strangulation) and 0 of 37 (hanging) (p = 0.03).

The 95% confidence intervals around the sample proportion for both groups were, however, wide (hanging: 0- 9%; strangulation 3.2 - 65%).

Two (5 %) of the 37 patients demonstrated venous injuries, which were in the form of unilateral IJV occlusion, likely secondary to thrombosis.

Both patients with venous injuries had clinical evidence of soft tissue neck injury, both were intubated due to low GCS scores at presentation (7/15 and 8/15) and neither had evidence of abnormality on non-enhanced CT head.

Table 2.1. Patient Demographics (*n*=45)

Demographics	**Number *(n)*/ Percentage (%)**
Age (years)	Mean = 31.16 years (14-69 years)
Age group: 1-14 years 15-55 years >55 years	 1 (2.2%) 42 (93.3%) 2 (4.4%)
Male sex	33 (73%) Strangulation: n = 6 (75%) Hanging: n = 27 (73%)
Female sex	12 (27%) Strangulation: n = 2 (25%) Hanging: n = 10 (27%)
GCS on scene: GCS 13-15 GCS 9-12 GCS 3-8 Unknown	 0 (0%) 1 (2%) 9 (20%) 35 (78%)
GCS on presentation: GCS 13-15 GCS 9-12 GCS 3-8 Unknown	 8 (18%) 2 (4%) 11 (24%) 24 (54 %)

Table 2.2. Comparison of Findings (Strangulation vs. Hanging)

Parameters Assessed	Frequency (out of 8 patients) and Percentage: Strangulation Group	Frequency (out of 37 patients) and Percentage: Hanging group	p value for difference between proportions
Loss of consciousness	5/5 (100%) known (3 unknown)	26/26 (100%) known (11 unknown)	p = 1
Clinical evidence of soft tissue neck injury	6/6 (100%) known (2 unknown)	26/26 (100 %) known (11 unknown)	p = 1
Patients intubated	1 (13%)	17 (46%)	p = 0.12
Non-enhanced CT heads performed	7 (88%)	30 (81%)	p = 1
Acute intracranial abnormality	2/7 (29 %)	3/30 (10%)	p = 0.233
Base of skull fracture	0	0	N/A
Carotid canal injury	0	0	N/A
Petrous bone involvement	0	0	N/A
Cervical spine injury	0	0	N/A
Le Fort II or III fractures	0	0	N/A
Arterial injuries on CTA	2 (25 %)	0	p = 0.028*
Venous injury demonstrated	2 (25%)	2 (5%)	p = 1

Table 2.3. Biffl Criteria Statistics

Biffl Grade of injury	Hanging (n= 37)	Strangulation (n=8)
Biffl Grade I injury	0	1 (13 %)
Biffl Grade II injury	0	1 (13 %)
Biffl Grade III injury	0	1 (13 %)
Biffl Grade IV injury	0	0
Biffl Grade V	0	0

4. Discussion

Blunt cerebrovascular injury may result from different mechanisms of injury to the neck.

Although rare, this condition may have devastating outcomes and for this reason screening with CT angiography is currently recommended for patients demonstrating distinct clinical signs and imaging findings on a non-enhanced CT brain and/or cervical spine.

These recommendations are however derived largely from studies of BCVI secondary to a wide range of cervical trauma (usually in the setting of high-energy motor-vehicle accidents).

Although CTA is now widely available, it carries with it significant cost implications, with respect to consumables, scanner time and staff experience.

In public hospitals in the developing world, protocols developed in first world settings are often implemented without considerations to cost and without critical analysis of the available data. At present non-enhanced CT head and CTA are requested routinely on all such patients presenting to our trauma unit, despite limited literature on the indications for and the appropriateness of CTA in the setting of strangulation and hanging, specifically.

Given the poor data available to support the use of CTA in these specific settings and being mindful of the increasing cost burden that CTA requests have introduced into our particular radiology service, we should remain cognisant of whether or not a screening CTA is appropriate in the setting of strangulation and hanging.

To our knowledge, this is the first study to examine the subject in a resource restricted environment.

Our study population included 45 patients who had a CTA performed for either strangulation or hanging over a 45-month period, representing an incidence of approximately 12 cases per year.

Thirty-seven of these patients presented after hanging and 8 were reported to have been strangled.

The large majority (73 %) of patients were male.

Thirty-seven (82%) had a non-enhanced CT head performed prior to CTA. Of these 37 patients; two demonstrated intracranial haemorrhage from associated assault, two demonstrated suspected ischaemic changes and four demonstrated cerebral oedema.

Arterial injuries were found in only 2 patients (4 %), both of whom had been strangled.

One, a vertebral artery dissection was reported, interestingly, in the absence of a cervical spine injury raising the possibility of another mechanism of injury.

No arterial injuries were demonstrated in the larger hanging group.

A total of four venous injuries (IJV occlusion) were demonstrated, two from each group, likely consistent with thrombosis.

Assessment of the Appropriate Application of the Denver Screening Criteria:

There are several sets of international criteria available for CTA referral for suspected BCVI. The modified Denver Criteria (Table 1.1) is most widely accepted and against which our study was analysed.

Arterial injury occurred in 2 strangled patients who did not meet the modified Denver Criteria (no base of skull, carotid canal, petrous bone, cervical spine or Le Fort fractures on CT). This emphasises that the criteria have been developed in the setting of high velocity injury and may not be appropriate in the setting of low velocity injury such as hanging and strangulation.

The fact that these patients would not have had screening CTA if the criteria were strictly applied is of concern.

The patient with a Biffl grade III injury (pseudoaneurysm of the brachiocephalic artery and dissection of the ipsilateral common carotid artery) had been assaulted and strangled (Figure.1). He had a very low GCS both on scene and time of scan. He would therefore not have been considered for neurosurgical or vascular intervention at our institution.

The other patient with arterial dissection (of the right vertebral artery) also did not meet the modified Denver Criteria (no fractures or focal neurology and a normal LOC), for a screening CTA and was imaged one week after strangulation for ongoing dysphagia.

We have determined from this study that international criteria for CTA imaging referral for strangulation and hanging injuries are not followed at our institution.

Indications for CTA based on the modified Denver Criteria could not be accurately assessed for the other clinical parameters such as Horner's syndrome since these were not documented in the radiological requests. It is uncertain whether these findings were absent, not assessed or were present but not included in the clinical request.

Loss of consciousness at the time of injury was documented in 62 % and 63 % of the hanging and strangulation groups, respectively.

Glasgow coma scale (GCS) assessments were highly variable for both groups with no correlation between a low GCS and the presence of an arterial injury.

Despite the fact that 46 % of patients from the hanging group were intubated at the time of presentation, no correlation was found between the presence of intubation and arterial injury in this group.

Soft tissue neck injury was equally prevalent in both groups (78 % of those presenting post hanging and 75 % in those with strangulation).

Subramanian et al suggested that in a patient with normal neurological examination, the presence of dysphagia, dysphonia, stridor and subcutaneous emphysema is concerning and warrants imaging (19). The presence of arterial injury without associated cervical, facial or hyoid fracture in our study supports this view.

4.1. Results in Context

From review of the literature, it is apparent that BCVI is rare, however a review by Al-Harthy et al stated that up to 44 % of these injuries may be revealed after screening (7). A significant proportion of these patients may be asymptomatic at presentation and therefore not meet criteria for CTA.

International recommendations therefore advocate early aggressive/liberal screening for blunt neck trauma/blunt cerebrovascular injury.

It is important to mention that the literature focuses on BCVI as a collective term and encompasses all mechanisms of injury, including high energy mechanisms. Our study focuses on isolated hanging and strangulation as the major mechanism of injury. We have demonstrated that arterial injury is significantly higher in our strangulation population than in their hanging counterparts. This supports the continued use of screening CTA at initial presentation. On the other hand, the absence of arterial injuries in our hanging group supports the findings of a recently published large case study of hanging injury reported by Schuberg. In this study of 78 patients presenting to the ER post hanging, no carotid artery dissection was documented on CTA. That study concluded that imaging of these patients did not alter further management but did significantly increase cost (32), (33).

International criteria may therefore not apply to hanging in our resource-limited setting where we need to aim to prevent unnecessary examinations and cut costs.

A GCS of less than or equal to 8 is considered a risk factor for assessing the probability of BCVI (1),(2), however, our results demonstrated that it was a poor prognostic indicator regarding the presence of a vascular injury.

4.2. Limitations of the current study

Our study has several limitations.

This is a single centre study; however, our drainage area is large.

Our small sample size has resulted in very wide confidence intervals

The lack of relevant clinical information i.e. on scene loss of consciousness, GCS level and the presence or absence of focal neurological signs prevents accurate assessment of whether or not international criteria are met for CT angiogram.

We acknowledge that obtaining ethical clearance to access patient folders during the early stages of our study proposal may have alleviated this limitation to a certain degree.

Although we made significant effort to identify all cases of CTA neck studies over the study time period, we acknowledge that some studies may have been missed if strangulation was not suspected at presentation.

4.3. Future applications

The rationale for imaging is often unclear to junior staff, particularly in a busy trauma unit where triage is prioritised over a ‘wait and see’ approach. Our study highlights the inadequacy of the existing criteria for screening CTA, in the setting of hanging and strangulation.

We recommend that the findings of this study be discussed at inter-departmental level at our institution with a view to establishing a more rational and cost-effective approach and policy in respect of the imaging of the patient presenting with hanging.

Further we suggest a larger prospective study with emphasis on the presence of dysphagia, dysphonia, stridor and subcutaneous emphysema in addition to level of consciousness and focal neurology.

5. Conclusion

The medical management of trauma constitutes a large portion of the budget at our institution. This behoves a rational and evidence-based approach to imaging in the trauma setting. CT Angiography is both time and skill intensive and should be requested only where there is good evidence that the result will influence clinical outcome.

This study examined BCVI in patients presenting to the trauma unit at Groote Schuur Hospital post strangulation and hanging.

Our results have determined that international criteria (specifically the modified Denver Criteria) for CTA imaging for strangulation and hanging injuries are not presently followed at our institution.

Arterial injury was found in only 2 patients, both of whom had presented after strangulation. Although the injuries may have been partially attributable to co-existing mechanisms of trauma, we support the continued use of CTA screening in the setting of strangulation injury in a resource-restricted environment.

The absence of arterial injury in the setting of near-hanging, however, supports recent evidence that we may be over-imaging these patients and argues against routine CTA screening even in patients with a depressed level of consciousness.

Appendix A: Ethics Clearance Certificate

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room E52-24 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 404 7682 • **Facsimile** [021] 406 6411
Email: nosi.tsama@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

22 November 2016

HREC REF: 833/2016

Prof S Candy
Radiology Department
GSH

Dear Prof Candy

PROJECT TITLE: DETERMINING THE FREQUENCY AND NATURE OF POSITIVE CTA FINDINGS IN PATIENTS PRESENTING WITH MECHANICAL STRANGULATION AND NEAR HANGING INJURIES (MMED CANDIDATE - DR Z SEPTEMBER-JAFFER)

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30th November 2017. However, data can only be used from 30/09/2016 back. If December 2016 data being used, informed consent will be required.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval before the research may occur.

We acknowledge that the student Dr Z September-Jaffer will be involved in the study.

Please quote the HREC REF in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938

HREC 833/2016

This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Convention on Harmonisation Good Clinical Practice (ICH GCP), South African Good Clinical Practice Guidelines (DoH 2006), based on the Association of the British Pharmaceutical Industry Guidelines (ABPI),and Declaration of Helsinki (2013) guidelines.
The Human Research Ethics Committee granting this approval is in compliance with the ICH Harmonised Tripartite Guidelines E6: Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and FDA Code Federal Regulation Part 50, 56 and 312.

HREC 833/2016

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

FACULTY OF HEALTH SCIENCES
Human Research Ethics Committee

FHS016: Annual Progress Report / Renewal

HREC office use only (FWA00001637; IRB00001938) This serves as notification of annual approval, including any documentation described below.			
☒ Approved	Annual progress report	Approved until/next renewal date	28/02/2020
☐ Not approved	See attached comments		
Signature Chairperson of the HREC	[signature]	Date Signed	4/2/2019

Comments to PI from the HREC
Thank you for the deviation doc [signature]

Principal Investigator to complete the following:

1. Protocol information

Date (when submitting this form)	04 FEB 2019		
HREC REF Number	833/2016	Current Ethics Approval was granted until	30/11/2017
Protocol title	DETERMINING THE FREQUENCY AND NATURE OF POSITIVE CTA FINDINGS IN PATIENTS PRESENTING WITH MECHANICAL STRANGULATION AND NEAR HANGING INJURIES		
Protocol number (if applicable)			
Are there any sub-studies linked to this study?	☐ Yes ☒ No		
If yes, could you please provide the HREC Ref's for all sub-studies? **Note:** A separate FHS016 must be submitted for each sub-study.			
Principal Investigator	PROF. SALLY CANDY		
Department / Office Internal Mail Address	RADIOLOGY, DEPARTMENT OF RADIATION MEDICINE		

(Note: Please complete the Closure form (FHS010) if the study is completed within the approval period)

HUMAN RESEARCH ETHICS COMMITTEE
04 FEB 2019
HEALTH SCIENCES FACULTY
UNIVERSITY OF CAPE TOWN

Appendix B: Tables

Table 1.1. Modified Denver Criteria and Memphis Criteria for BCVI

Screening Criteria	Signs/Symptoms of BCVI	Risk Factors of BCVI
Modified Denver Criteria (29)	Arterial haemorrhage (from neck, nose, or mouth) Cervical bruit (< 50 yrs of age) Expanding cervical haematoma Focal neurologic deficit: TIA, hemiparesis, vertebrobasilar symptoms, Horner syndrome Infarction on CT or MRI Neurologic deficit inconsistent with non-enhanced CT head findings	**High-energy transfer mechanism with the following:** LeFort II or III fracture Base of skull fracture extending into the carotid canal Cervical vertebral body or transverse foramen fracture, subluxation, or ligamentous injury at any level; any fracture at C1-C3 Closed head injury consistent with DAI and GCS <6 Near-hanging with anoxia Clothesline-type injury or seat belt abrasion with significant swelling, pain, or altered mental status
Memphis Criteria (23)	Cervical spine fracture Neurologic findings not explained by CT brain imaging Horner syndrome LeFort II or III facial fractures Base of skull fractures involving foramen lacerum Soft tissue neck injury (e.g. seat belt injury or hanging)	

DAI: diffuse axonal injury. GCS: Glasgow Coma Scale

Suggested expansion of the Modified Denver Criteria includes the following (25): occipital condyle fractures, mandibular fractures, traumatic brain injuries with thoracic injuries, scalp degloving, thoracic vascular injuries, and blunt cardiac rupture

Table 1.2. Boston Criteria for BCVI (28)

First Tier	**Second Tier**
Base of skull fractures: petrous and basilar fractures	DAI
Any cervical spine fractures	Complex facial fractures with mid-face instability
Cervical spine injury (cord, vertebral body, or ligaments)	Combined significant head and chest trauma
Soft-tissue injury to anterior neck with swelling/ecchymosis/ haematoma/or bruit	Near hanging
Significant neurologic deficit: lateralizing neurologic deficit, TIA, Horner syndrome	Seatbelt abrasions on neck
Evidence of brain infarct on CT	Other unexplained neurologic deficits: vertigo, tinnitus, or GCS </= 6

Table 1.3. Denver (Biffl) Grading System (20)

Injury Grade	**Denver Grading system** (20)	**CTA Findings**	**Stroke Incidence (%)** (25), (34) **(CAI/VAI)**
I	Vessel wall irregularity Dissection or IMH with < 25% luminal narrowing	Non-stenotic luminal irregularity Intimal flap or wall thickening with < 25% stenosis	3/6
II	Intraluminal thrombus Dissection or IMH with > 25% luminal narrowing.	Luminal hypodensity Intimal flap or wall thickening with > 25% stenosis	14/38
III	Pseudoaneurysm	Eccentric contrast-filled outpouching limited by periarterial tissue	26/27
IV	Vessel occlusion	Lack of any intraluminal enhancement Carotid occlusion: abrupt or tapered Vertebral occlusion: usually abrupt	50/28
V	Vessel transection	Irregular extravascular collection of contrast, not limited by periarterial tissue Increases in density on delayed images, if obtained	100/100

CAI: carotid artery injury. VAI: vertebral artery injury. IMH: Intramural haematoma

Appendix C: Figures

Figure 1: Brachiocephalic Dissection

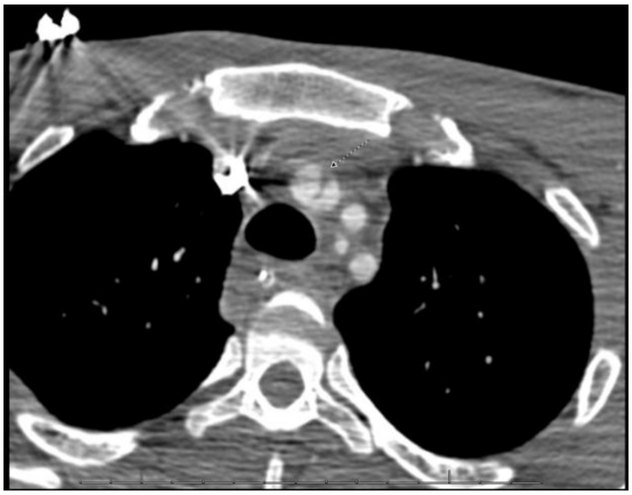

Fig. 1: Axial CTA demonstrates a dissection flap in the origin of the brachiocephalic trunk.

Figure 2: Right Common Carotid Artery Dissection

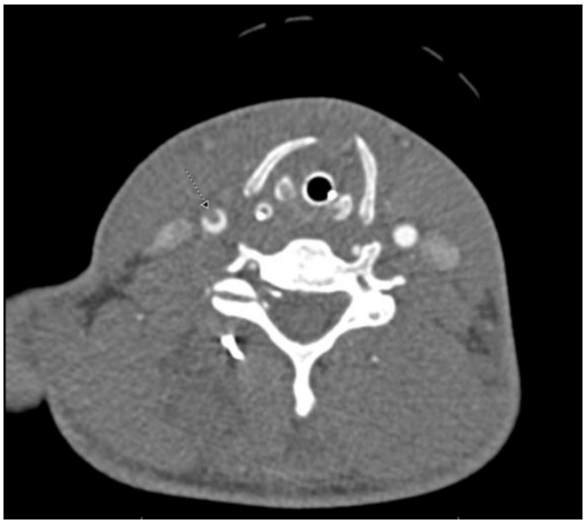

Fig. 2: Axial CTA demonstrating a crescent-shaped filling defect in the right common carotid artery.

Figure 3: Right Common Carotid Artery Dissection

Fig. 3: Coronal MIP CTA demonstrates the extensive filling defect in the right common carotid artery.

Figure 4: Left Internal Jugular Vein Thrombosis

Fig. 6: Axial CT demonstrates a filling defect in the left internal jugular vein.

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