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**A RETROSPECTIVE STUDY OF CT ANGIOGRAPHY VERSUS DIGITAL
SUBTRACTION ANGIOGRAPHY IN PENETRATING NECK TRAUMA**

by

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DECLARATION

I, Paul Victor John Scholtz, 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.

I empower the university to reproduce for the purpose of research either the whole or any portion of the contents in any manner whatsoever.

This study was approved by the ethics committee of the Health Sciences Faculty, University of Cape Town.

Signed:

Date:

TABLE OF CONTENTS

DECLARATION	2
TABLE OF CONTENTS	3
ACKNOWLEDGEMENTS	4
PART A: PROTOCOL	5
PART B: LITERATURE REVIEW	7
LITERATURE REVIEW REFERENCES	18
PART C: MANUSCRIPT	21
Abstract	22
Introduction	23
Methods	24
Results	25
Discussion	28
Conclusion	34
MANUSCRIPT REFERENCES	35
PART D: APPENDICES	36
Ethics approval	37
Data capture sheets	40
Manuscript guidelines for submission	42

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And finally, to my wife and son for their love and support.

PART A

PROTOCOL

This study aims to retrospectively compare the imaging findings of multidetector CT angiography (CTA) and digital subtraction angiography (DSA) in patients with penetrating neck trauma at Groote Schuur Hospital.

Given the limited experience of CTA in evaluating penetrating neck trauma at Groote Schuur Hospital, the role of CTA in clinical management of patients is currently unclear. DSA is an invasive procedure which has potential complications such as puncture-site haematoma, vascular injury and embolic complications, including stroke. DSA is also more resource-intensive than other modalities, despite permitting therapeutic endovascular options in some patients. The purpose of this study is therefore to assess the role of CTA in the management of these patients in an effort to reduce the number of DSA's performed at our institution.

The imaging of stable patients with penetrating neck trauma remains controversial¹, although DSA is felt by many to be the standard for identifying and treating vascular injury in both high- and low-velocity penetrating trauma. CTA does however provide an attractive alternative. A few prospective studies have assessed the accuracy of CTA versus DSA in penetrating neck trauma, and claim that CTA has a high sensitivity in detection of vascular injury and can be used as an initial screening tool.^{2,3,4,5} The point is also made that CT has the ability to detect associated visceral, bony or aerodigestive tract injury.

Patients with penetrating neck trauma who have had both DSA and CTA in the acute period will be selected for the study. CTA studies are performed on a 16-slice Siemens

Emotion multidetector CT scanner. Patients will be selected from February 2009 onwards which is the date of scanner installation.

The CTA and DSA studies will then be retrospectively reviewed separately by experienced radiologists, with consensus opinions reached. Reviewers of the CTA will be blinded to DSA findings, and vice versa. The DSA findings will be used as the reference standard for vascular injury. The CTA studies will also be assessed for what are judged to be other clinically significant findings. The overall study findings will then be compared and statistically evaluated.

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PART B

LITERATURE REVIEW

South African violent crime and trauma rates are high.¹ Penetrating neck trauma is commonly encountered in trauma centres, with knives or bullets the major penetrating agents. These injuries have high mortality and morbidity (3-6%) due to the number of vital structures traversing this confined space, with most fatalities resulting from injuries to major neck vessels.²

Given the risk of vascular, aerodigestive tract and neurological injury in penetrating neck trauma, prompt clinical decisions have to be made regarding further investigation or intervention. The imaging and further management of penetrating neck trauma has long been controversial, although paradoxically less so in unstable patients who may require airway control, fluid resuscitation and emergency surgical haemostasis due to life-threatening injury. Classically, stable patients with injuries penetrating the platysma muscle required mandatory exploratory surgery.³ Since the 1990's however, selective non-operative management (SNOM) has gained favour and has become the rule.^{3,4} This is in part because mandatory neck explorations have high negative rates with resultant cost and complications.⁵ Obligatory imaging investigations such as angiography, oesophagography, oesophagoscopy or bronchoscopy are likewise cost- and time-consuming with associated complications.

Penetrating neck trauma can usefully be classified by the anatomical site of wound entry as this has some predictive value of likelihood of injury and specific type of injury. The neck is divided into anterior and posterior triangles with the anterior margin of the sternocleidomastoid muscle serving as the divider. The anterior triangle is divided into three zones:

Zone 1 extends from the sternal notch, thoracic inlet and superior border of the clavicle to a transverse line through the inferior aspect of the cricoid cartilage. The contents of this zone include the brachiocephalic artery and veins, segments of the subclavian arteries and veins, carotid and vertebral arteries, oesophagus, trachea and thyroid. It is important to note that this zone also includes the lung apices and thoracic duct. This shared thoraco-cervical location of zone 1 makes clinical evaluation and operative approaches especially challenging.

Zone 2 arises inferiorly from the inferior level of the cricoid cartilage to a transverse line at the angle of the mandible. The contents include the carotid arteries (common, internal, external), jugular veins, oesophagus, pharynx and trachea. This is the most surgically accessible zone.

Zone 3 extends from the angle of the mandible up to the base of skull. Important structures include the internal and external carotid arteries, vertebral arteries, jugular veins and pharynx. As with Zone 1, Zone 3 is surgically challenging due to its proximity to the skull base and overlying facial structures.

Fewer vital structures cross the posterior triangle, which is delineated by the posterior margin of sternocleidomastoid muscle, the anterior margin of the trapezius muscle, and inferiorly by the thoracic inlet. The contents include the third part of the subclavian artery and the terminal inferior segment of the external jugular vein. Neural structures include branches of the cervical, brachial and phrenic nerves, along with the spinal accessory nerve (cranial nerve XI).

In taking a more balanced approach to investigation, certain clinical signs that are suggestive of vascular injury can be useful in guiding further investigation. 'Hard signs' that are the most reliable in detecting vascular injury include bruit or thrill, expanding or pulsating haematoma, pulsating haemorrhage (including a reliable history of such), pulselessness in a downstream artery, and major neurologic deficit (such as stroke).

On the other hand, 'soft signs' (which are less reliable) include systemic hypotension, identifiable injury in proximity to vessels and a moderate to large stable haematoma. Injuries crossing the midline or those requiring Foley-catheter balloon tamponade have also had influence on the decision to perform angiography. Foley-catheter balloon tamponade is a well recognised method of temporally arresting bleeding using the inflated catheter within the wound tract.

Traumatic vascular injury occurs due to disruption of one or more layers of a vessel. In penetrating injuries, this is caused by either direct contact by the object (such as in stab or gunshot wounds) or by shockwave energy imparted to the vessel by a projectile (as in gunshot wound).

Further classification of penetrating injuries can be as high- or low-velocity injury. Low-velocity injuries include those due to handgun bullets and sharp objects such as knives or broken glass. High-velocity injuries are a result of high-speed projectiles (exceeding 610 metres per second) such as rifle bullets; these having the propensity for more widespread injury.

Digital subtraction angiography (DSA) is the gold standard for detecting vascular injury.⁶ DSA is however an invasive procedure with potential complications such as haematoma or vascular injury at the puncture site, and dissection, thrombosis, distal embolization and ischaemia in the arch and brachiocephalic arteries. Of these, the neurological complications can be the most devastating. Overall, transient and permanent neurologic complication rates of 1.3% and 0.5% respectively have been reported for angiography.⁷ DSA is also more resource-intensive, requiring specialist teams, time and equipment. Still, DSA remains an appropriate procedure in the correct setting and offers the benefit of direct conversion to endovascular intervention through embolisation or stent placement.

Colour Doppler ultrasound as a non-invasive modality able to assess vasculature at the patient's bedside. Unfortunately, multiple limitations include operator dependence, surgical emphysema, soft-tissue swelling, soft-tissue distortion and bandaging. Most of these limitations reduce sound transmission and visibility. It is also unable to adequately assess injuries to zones 1 and 3, or evaluate the pharynx and upper airway, oesophagus and spine. Sensitivities of over 90% have nonetheless been reported in penetrating neck trauma from some centres.⁸

Despite recent advances in Magnetic Resonance Imaging (MRI) and Magnetic Resonance Angiography (MRA), its application in acute penetrating neck trauma is very restricted, in part due to availability, length of scanning time, need for MR-compatible support equipment and non-compatible metallic foreign bodies (especially in gunshot wounds).

Because Computed Tomography (CT) has already rapidly become an integral part of emergency units worldwide, CT Angiography (CTA) provides an attractive alternative to DSA. The study is less invasive, requires no arterial puncture, and no vessel catheterisation is required. Diagnostic images are rapidly acquired using standard protocols and acquisitions, therefore reducing operator dependence. Axial images are usually sufficient to make the majority of correct diagnoses, but image manipulation, multiplanar reformations and three-dimensional reconstructions are complementary in some cases and assist in endovascular and surgical planning. Image manipulation and interpretation are however time-consuming and can be complicated by errors of both over- and under-interpretation.

Approximately 15-25% of penetrating injuries to the neck result in arterial injury, with this accounting for most adverse outcomes (e.g. stroke).⁹ Vessel injury may result in either partial wall damage or complete wall disruption and transection. Types of arterial injuries include: intimal flaps, occlusions (complete or partial), pseudoaneurysms, dissections and arteriovenous fistulae (AVF's).

Partial or complete vessel occlusion is determined by reduction in luminal contrast on CTA and DSA. It is the most common carotid artery injury in both penetrating and blunt trauma.¹⁰ Difficulty in interpretation exists when surrounding haematoma results in vessel compression and apparent reduction in luminal contrast. Smooth vessel contours and/or a short segment of involvement may point to local mass effect. Arterial vasospasm may also mimick occlusion.

Pseudoaneurysms arise when partial wall disruption leads to luminal contrast outpouching contained by vessel wall adventitia. In this case, CTA demonstrates abnormal contrast protrusion in continuity and eccentric to the injured vessel lumen. This ‘contained’ blood may be difficult to differentiate from contrast extravasation on CT, while this may be easier to delineate on DSA due to the dynamic nature of the study. Smaller pseudoaneurysms may go undetected on DSA if varied imaging projections are not used.

Intimal flaps are detected as linear focal filling defects within the vessel lumen; if small they may be difficult to detect on CT. The clinical significance of these injuries is controversial as they may be self-limiting

Dissections are seen on CTA as elongated, often undulating linear filling defects of the dissection flap, and a narrowed ‘twisted-ribbon like’ lumen.

AVF’s result when contiguous arterial and venous disruption has occurred, allowing direct arterial to venous communication. The imaging hallmark of an AVF on DSA is early venous filling, although enhanced normal venous opacification may mask or simulate early venous filling on CTA. If an AVF is strongly suspected, DSA may be required despite an apparently negative CTA.

Single detector helical CT was first used prospectively in 1997 by LeBlang et al to evaluate 35 patients with penetrating neck trauma; sensitivity for injury detection in comparison with DSA, surgical exploration and duplex ultrasound was 80%.¹¹ In 2000, Munera et al prospectively evaluated 60 patients with penetrating neck trauma using CTA. Sensitivity of 90% and specificity of 100% were achieved using single-detector CT, measured against the gold standard of DSA.¹² Munera et al then followed in 2002 by prospectively comparing CTA of 175 patients against DSA, surgical findings and clinical follow-up as the combined reference standard. Sensitivity and specificity measured 100% and 98.6% respectively.¹³

Thereafter, four-row multi-detector CT (MDCT) was used in 2006 by Inaba et al to evaluate 91 patients with penetrating neck trauma. MDCT accuracy was tested against an aggregate gold standard encompassing all imaging, surgical procedure findings and clinical follow-up. MDCT achieved 100% sensitivity and 93.5% specificity.⁵ This is the only study to evaluate penetrating neck trauma using MDCT in the reviewed English literature.

The capability of CT to evaluate structures other than the arterial vasculature adds further benefits. Assessment of veins, projectile trajectory, bony structures (especially the spine), viscera (lungs, thyroid) and aerodigestive tract aid in clinical management.

Determination of the wound trajectory aids in evaluation, as structures lying in the track have a higher likelihood of injury. This may however be difficult in the case of multiple injuries, fragmentation (metallic or bony) and deviation of the penetrating agent due to bony or other deflection. Surgical emphysema, haematoma, fractures and intra-thoracic injuries can help identify the tract. Clinical and radiographic findings must also be taken into account. Multiplanar reconstructions are essential in defining tracts as they are seldom confined to conventional axial, sagittal or coronal planes and are not always linear.

The assessment of bullet and bone fragments not only aid in determining the wound track but may also be helpful in assessing the direction of a bullet. Careful evaluation of the bone should show beveling toward the direction of travel, which is important in forensic analysis.¹⁴

Missed upper aerodigestive tract injuries are potentially devastating, as delay in diagnosis may lead to major morbidity and mortality, mainly as a result of sepsis, especially mediastinal. Patients presenting with odynophagia, dysphagia, blood in the mouth and injuries crossing the midline have a significantly higher incidence of injury than those without these signs or symptoms.⁴ Further investigation with a contrast swallow or endoscopy is mandatory if clinical suspicion exists, or if CT findings suggest injury. It is important to note that oesophagography may be difficult, if not impossible, to perform on acutely injured patients and/or those with reduced level of consciousness. Traditionally, the oesophagram in penetrating neck trauma is performed promptly using water-soluble contrast media. If this is normal, the study is repeated using a barium sulfate suspension to reveal less visible injuries. Recently however it has been suggested that using water-soluble contrast media alone is safe (avoiding the risk of barium aspiration), reliable (identifying all injuries) and cost-efficient in this setting.¹⁵

Airway compromise is life-threatening in trauma. Tracheal injuries must be suspected if the wound tract is in the vicinity of the airway and/or there is extensive surgical emphysema clinically. Direct injury and disruption of the tracheal wall can be identified on CT when using the appropriate window settings. Indirect signs of tracheal injury include excessive surgical emphysema, pneumomediastinum and/or pneumothorax. The degree of airway displacement and compression due to surrounding haematoma must be noted, as these patients may require their airways to be secured.

Bony injury is well demonstrated on MDCT. Thoraco-cervical spine injuries are the most concerning, due to the risk of spinal cord injury. Signs suggesting spinal injury include bone fragments, foreign bodies and/or gas in the spinal canal. Blood and air within the pleural and mediastinal spaces, along with parenchymal lung injuries are also easily recognized.

Although there are numerous advantages to using MDCT in penetrating neck trauma, pitfalls do exist. Multiple types of artefacts have to be taken into account, including those induced by patient size, motion, incoming dense venous contrast and post-traumatic fragments (bullet shrapnel, knife or bone fragments). Contrast inflow artefact is usually due to use of upper limb venous injections resulting in streak artefact at the thoracic inlet. This may interfere with the visualisation of the proximal arteries exiting the thorax, especially the ipsilateral subclavian artery. Injection of contrast into the contralateral side of injury or using femoral venous access is helpful in reducing this artefact. The use of a saline chaser also reduces the amount of streak artefact.¹⁶

Knowledge of anatomical variants is important during the evaluation of CTA's; as they need to be recognised and not be misinterpreted as injuries. A high-riding "cervical arch" may be injured in the neck. Although the normal carotid bifurcation lies near the level of C4, it may be situated anywhere in a range from T2 to C1. It is important to note that the internal carotid artery may be congenitally hypoplastic or absent, and to also be aware of persistent embryonic anastomoses between the carotid and vertebrobasilar systems (such as the persistent hypoglossal and trigeminal arteries). Variants of the cervical segments of the vertebral arteries include unilateral and bilateral hypoplasia. The vertebral arteries may enter the foramen transversarium at variable levels (apart from the usual level of C6) and be of varied diameter within the canal.

If, for whatever reason, the CTA proves to be equivocal or non-diagnostic, DSA should be considered on clinical grounds.

Contrast-induced nephropathy may be of concern if a patient undergoes both CTA and DSA. Each modality usually requires approximately 100ml of iodinated contrast media. Although the majority of trauma patients are young adults with normal renal function, underlying medical conditions predisposing to nephropathy such as diabetes and chronic kidney disease have to be considered. Reducing contrast volume in high-risk patients would be beneficial and could be achieved by limiting DSA injections. Measuring baseline and post-procedural serum creatinine levels are advised. Adequate hydration supplemented by other measures such as renal protective pharmacotherapy including N-acetylcysteine and sodium bicarbonate are advised.¹⁷

The lower spatial resolution of CTA compared to DSA may limit the role of CT in the detection of subtle abnormalities such as mild vessel wall irregularity and small pseudoaneurysms. Although the significance of these “minor” lesions may be controversial, studies do show that many of these lesions either resolve or remain asymptomatic.¹⁸

Overall CTA is a good, non-invasive alternative to DSA in the initial evaluation of penetrating neck trauma. High sensitivities and specificities have been demonstrated in the detection of arterial injuries, while also allowing assessment of wound trajectory, and the integrity of the aerodigestive tract, viscera and bones. With the advent of increasing number of detectors in MDCT and improved software, further diagnostic improvements are possible. The radiologist is nonetheless required to use a considered and systematic approach in their evaluation, along with multiplanar, volume-rendered and bone-subtracted reformations as required.

Previous South African data in 1999 on the use of Colour Doppler in penetrating neck trauma showed high sensitivity and specificity.¹⁹ Little South African data exist in the use of CTA versus DSA in penetrating neck trauma. No data exist on the use of 16-slice MDCT in the English literature review (search terms “neck, penetrating trauma, MDCT, 16 slice”). The relatively short length of coverage required in neck imaging allows peak opacification of the arteries using 16-slice MDCT. In resource-limited settings, CTA seems ideal as the initial imaging investigation in penetrating neck trauma.

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PART C
MANUSCRIPT

For submission to the South African Journal of Radiology as an original article:

Title: A RETROSPECTIVE STUDY OF CT ANGIOGRAPHY VERSUS DIGITAL SUBTRACTION ANGIOGRAPHY IN PENETRATING NECK TRAUMA

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ABSTRACT

BACKGROUND. Penetrating neck trauma is commonly encountered in South African trauma units, and is associated with high mortality and morbidity rates. The imaging protocol for stable patients with penetrating neck trauma remains controversial. There is only sparse data validating the use of Computed Tomography Angiography (CTA) in the evaluation of penetrating neck trauma.

OBJECTIVES. To assess the sensitivity and specificity of CTA versus Digital Subtraction Angiography (DSA) in detecting arterial injury and secondarily evaluate the ability of CT to assess non-arterial injury.

METHODS. Using hospital and radiology databases, 23 patients were identified who had undergone both CTA and DSA for penetrating neck trauma. The data was retrospectively anonymized and randomized. A radiologist experienced in the interpretation of both trauma CTA and DSA re-reported all the imaging and the findings were compared and analyzed.

RESULTS. Twenty four arterial injuries were detected. The sensitivity of CTA for detecting arterial injury was 78% and the specificity 83%. The ability of CTA to delineate wound track and detect non-arterial visceral injury was also confirmed.

CONCLUSION. CTA is an attractive initial diagnostic investigation that, along with clinical evaluation, effectively guides further investigation and intervention. It is important for the radiologist to understand the limitations of CTA and have a low threshold for DSA in equivocal cases.

INTRODUCTION

South African violent crime and trauma rates are high.¹ Penetrating neck trauma is common in South African trauma centres. These injuries have high mortality and morbidity rates of between 3 and 6 %, with most fatalities due to major neck vessel injuries.²

The role and type of imaging of stable patients with penetrating neck trauma is controversial. Given the probability of vascular, aerodigestive tract and/or neurological injury, important clinical decisions have to be made regarding further investigation or intervention. Although Digital Subtraction Angiography (DSA) is the gold-standard for detecting arterial vascular injury, it is an invasive procedure with potential complications such as puncture-site haematoma, iatrogenic vascular damage and embolic complications, including stroke.³ DSA is also resource-intensive, although it does permit therapeutic endovascular options during the same procedure in some cases.

Because Computed Tomography (CT) has become an integral part of emergency units worldwide, CT Angiography (CTA) provides an attractive alternative to DSA. CT also has the ability to determine the direction and course of any wound tracks that can suggest particular damage, along with direct evidence of visceral, bony or aerodigestive tract injury.

Although frequently used, the role of CTA remains unclear. Sparse data exist in South Africa regarding the use of CTA in evaluating penetrating neck trauma. No data exists concerning the use of 16-slice multidetector CT in the reviewed English literature using search terms- 'neck, penetrating trauma, MDCT, and 16-slice'.

This study aims to retrospectively compare and analyze the findings of CTA and DSA in patients with penetrating neck trauma at Groote Schuur Hospital which is a tertiary referral university hospital in Cape Town, South Africa serving a drainage population of approximately 2 million. The hospital has a busy trauma unit, with a high incidence of penetrating trauma due to gunshot and stab wounds. From July 2004 to June 2005 (12 months), 203 patients with penetrating neck injuries were admitted into the trauma unit, of whom 21% sustained gunshot and 78% stab wounds.⁴

METHODS

Formal ethics approval was obtained from the Research Ethics Committee, Health Sciences Faculty, University of Cape Town.

Using the hospital and radiological databases, all patients with penetrating neck trauma who underwent both DSA and CTA (in either order) during the period from March 2009 to March 2012 were identified for the study. In these patients, CTA and DSA were performed for various reasons, including clinical suspicion, imaging features of injury on the other modality, or for surgical planning and/or endovascular treatment.

CTA was performed using a 16-slice Siemens Emotion multidetector CT scanner in the radiology department. Intravenous access was obtained using a cubital or forearm cannula of at least 18-gauge placed in an upper limb vein, if possible contra-lateral to the side of injury. A volume of 100ml of non-ionic contrast medium (Iohexol 350) was administered using an injector pump at a rate of 6ml/s. Caudocranial helical acquisition was planned using the lateral scout view of the neck from at least the aortic arch to the Circle of Willis. The scan was initiated using a bolus tracker system placed over the aortic arch triggering at 100 Hounsfield units. Saline chaser was not utilized. Typical reconstruction parameters were 1mm slice thickness, a pitch of 1.5, 110 kVp and 100 mAs.

DSA was performed using a single C-arm ceiling-suspended DSA system (Toshiba Infinix VC-i). For initial diagnostic purposes, aortic arch and relevant selective brachiocephalic and branch vessel arteriograms were performed. Approximately 100ml of non-ionic contrast (Iopromide 300) was used on average.

The CTA and DSA images were retrospectively anonymized and randomized. A radiologist experienced in the interpretation of both trauma CTA and DSA and who was blinded to the clinical data and prior opinions, reported on all the imaging. Various window settings, multiplanar reconstructions (MPR) and maximum intensity projections (MIP) were permitted. Bone subtraction was used when considered warranted in CTA. Both CTA and DSA were evaluated for both vascular and non-vascular pathology. Unsubtracted DSA images were not always available due to image archiving technicalities.

All vessels within the field of view were assessed. Any identified vascular injuries on CTA and DSA were localized and described. Injury types were categorized as occlusion, contrast extravasation, pseudoaneurysm, arteriovenous fistula (AVF), intimal flap or a combination of these. Non-vascular evaluation in both modalities included the soft tissues, aerodigestive tract, bones, lungs and mediastinum. Contrast swallows were also included. Where possible, the wound tract was identified on CTA.

Clinical data that was retrospectively analyzed included patient demographics, penetrating agent, zone of injury, indications for investigation, associated injuries and management.

CTA and DSA findings were compared and analyzed. DSA findings were considered the standard of reference for arterial pathology, while CTA was considered the reference for soft-tissue damage. True positives required the correct definition and appropriate clinical correlation of injury type and location. Sensitivity, specificity and positive and negative predictive values were specifically calculated for arterial vascular injuries.

RESULTS

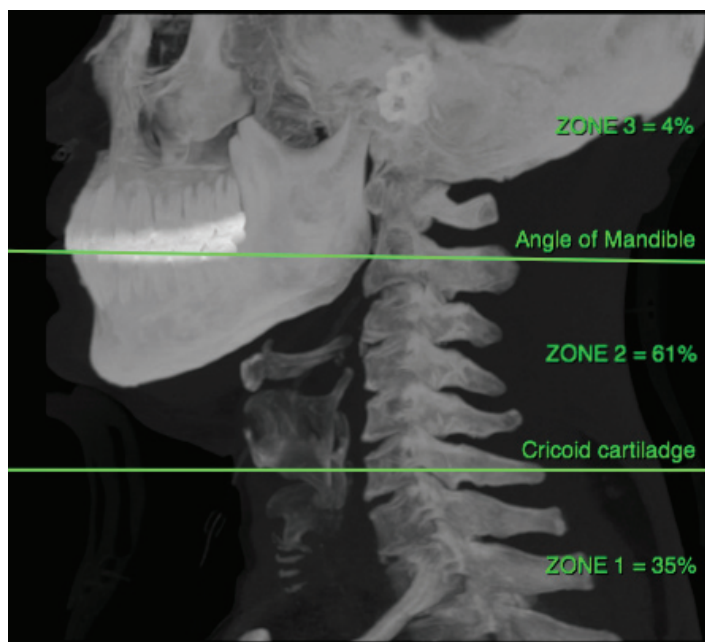
Over the three-year period, 23 patients (18 male and 5 female) were included in the study. All imaging was considered to be of diagnostic quality, and complete clinical data were available on folder and radiological review.

The delays between CTA and DSA ranged from an immediate follow-on procedure, to up to 72 hours. All but one patient underwent CTA prior to DSA; the single follow-on CTA was performed due to concern of an injury at the origin of the left common carotid artery on DSA.

The mean age was 30 years with a range of 19 to 51 years. Stab wounds accounted for 20 (87%) and gunshot three (13%) of the injuries.

The location of the entry sites of penetrating neck injury was allocated into the three standard anterior triangle anatomical zones (Fig. 1). There were no injuries involving the posterior triangle.

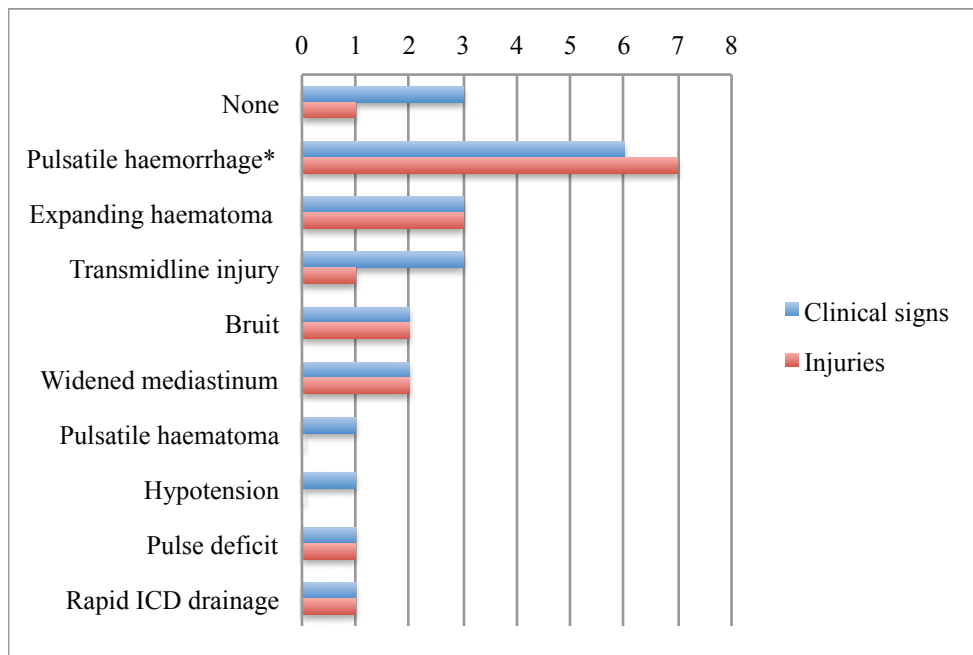
Figure 1: Anatomical zones and percentage injuries



Injury locations amounted to eight (35%) in zone 1, 14 (61%) in zone 2 and one (4%) in zone 3. Sixteen (70%) of the patients suffered injuries to the left neck, six (26%) to the right and one (4%) had bilateral injuries.

Various clinical signs for vascular injury were recorded in the clinical notes (Fig. 2). Three patients had no detectable significant clinical signs of injury at the time of scanning.

Figure 2: Clinical signs and corresponding injuries detected on DSA



***Dual injury in a patient with pulsatile haemorrhage**

Foley-catheter tamponade using the inflated balloon to temporarily arrest bleeding within the wound tract was employed in six (26%) patients.

Contrast swallows were performed on 14 (61%) of the patients on the basis of clinical symptoms and signs, with a single oesophageal injury detected. A further oesophageal injury was detected intra-operatively (this patient had not undergone a contrast swallow as the patient was intubated and had other existing indications for surgical exploration).

DSA demonstrated eighteen arterial injuries in 17 patients, with one patient having both a vertebral and an inferior thyroid artery injury (Fig. 3).

In comparison to DSA, the sensitivity of CTA for detecting arterial injury was 78%, the specificity was 83%, the positive predictive value (PPV) was 93% and the negative predictive value (NPV) 56%.

Conservative management was undertaken in three (17%) patients. Endovascular management was used to manage eight (44%) injuries, of whom five were treated with covered stents, two were embolised with cyanoacrylate glue and one was embolised using a detachable balloon. Surgical vascular repair was performed in seven (39%) cases.

During the in-hospital course, one patient suffered a middle cerebral artery infarction seven days after primary surgical repair of a common carotid injury, and another died of hypoxic brain injury two days after surgical repair of a common carotid injury.

Figure 3: Table showing CTA and DSA findings and subsequent treatment.

	CTA FINDINGS	DSA FINDINGS	TREATMENT
1	None	None	None
2	Thyro-cervical PA	Thyro-cervical PA	Endovascular (glue)
*	None	Vertebral PA	Conservative
3 *	Ascending cervical AVF	None	None
4 *	Internal jugular vein PA	Thyro-cervical AVF	Endovascular (glue)
5	Thyro-cervical AVF	Thyro-cervical AVF	Surgical repair
6	None	None	None
7	None	None	None
8	Subclavian PA	Subclavian PA	Endovascular (stent)
9	Subclavian PA	Subclavian PA	Endovascular (stent)
10	Common carotid PA	Common carotid PA	Endovascular (stent)
11 *	Transverse cervical PA	Subclavian PA	Endovascular (stent)
12 *	External carotid PA	External carotid Occlusion	Endovascular (balloon)
13	Common carotid PA	Common carotid PA	Surgical repair
14	Common carotid PA	Common carotid PA	Surgical repair
15	Subclavian PA&AVF	Subclavian PA&AVF	Endovascular (stent)
16	Common carotid PA	Common carotid PA	Surgical repair
17	None	None	None
18	Vertebral Occlusion	Vertebral Occlusion	Conservative
19	None	None	None
20	Common carotid PA	Common carotid PA	Surgical repair
21	Common carotid PA	Common carotid PA	Surgical repair
22	Superior thyroid CE	Superior thyroid CE	Conservative
23	Internal thoracic PA&AVF	Internal thoracic PA&AVF	Surgical repair

PA = pseudoaneurysm, AVF = arterio-venous fistula, CE = contrast extravasation

* Discrepancies

DISCUSSION

Classically, stable patients with injuries penetrating the platysma muscle mandated exploratory surgery.⁵ Since the 1990's however, selective non-operative management (SNOM) has gained favour and has become the rule.^{4,5} However, the optimal management and imaging strategy for stable patients with penetrating neck trauma remains controversial.

Vascular injury is suspected clinically when certain 'hard' signs are present. The most reliable pointers to vascular injury include a bruit or thrill, expanding or pulsating haematoma, pulsating haemorrhage (including a history thereof), pulse deficit and/or major neurologic deficit.

'Soft' signs are less reliable and include systemic hypotension, identifiable injury in proximity to vessels and a moderate to large stable haematoma. Injuries crossing the midline or those that requiring use of Foley-catheter balloon tamponade also may influence on the decision to perform angiography. Other clinical signs included in our study included rapid drainage of blood from an intercostal drain and a widened or abnormal mediastinal contour on chest radiography.

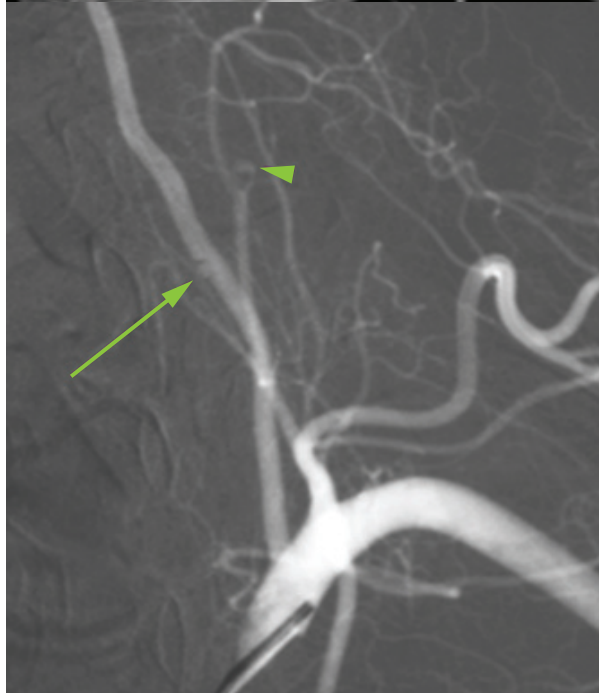
The most reliable clinical sign to predict arterial injury was pulsatile haemorrhage. Three patients had no vascular signs on presentation. One of these patients had a significant injury (subclavian artery pseudoaneurysm with an AVF) requiring endovascular stenting, but the other two were normal on imaging. All patients with Foley-catheter balloon tamponade suffered arterial injuries.

Several groups have compared CTA with DSA for detection of arterial injury in penetrating neck trauma. Reported sensitivities ranging between 80 and 100%, with specificities above 90%.^{6,7,8,9} Our study demonstrated a CTA sensitivity of 78% and specificity of 83%. Four false-negative findings and one false-positive finding occurred with CTA.

Of the false-negative findings, a small (3mm) pseudoaneurysm in case 2 seen on DSA of the vertebral artery was not detected on CTA (Fig. 4). The lesion could also not be detected on retrospective review of the CTA using MPR and MIP imaging. Subtle lesions may not be well demonstrated on CT as compared to DSA due to the inferior spatial resolution of CT, lack of bone subtraction and pulsation artefact. Although the clinical significance of these 'minor' lesions may be controversial, studies do show that many of these lesions either resolve or remain asymptomatic.¹⁰ The small vertebral artery aneurysm was managed conservatively and therefore no significant management difference occurred.



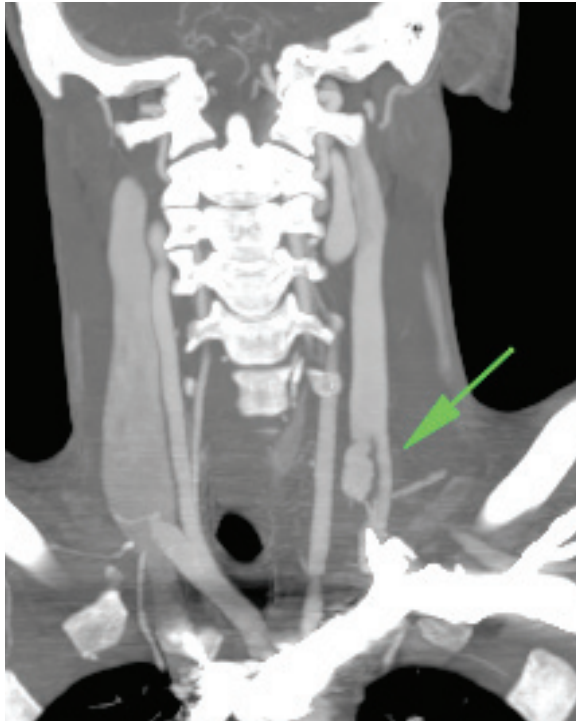
4a



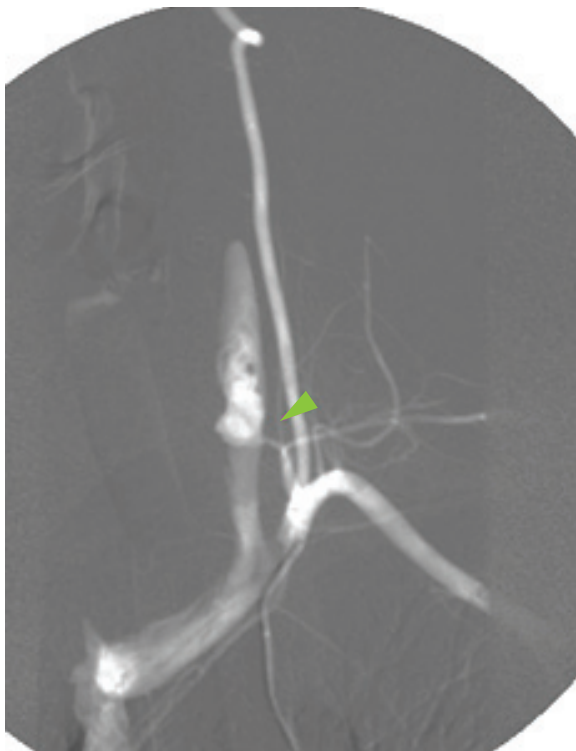
4b

Fig. 4. In 4a, the coronal reformatted MIP CTA image demonstrates no extraforaminal (part one) vertebral artery injury. On the selected DSA of the left subclavian artery (4b), the arrow shows a subtle vertebral artery pseudoaneurysm. The arrowheads on both images depict a pseudoaneurysm arising from the ascending cervical artery.

Another false-negative CTA result in case 4 was due to an AVF arising from the inferior thyroid branch of the left thyro-cervical trunk (Fig. 5). This injury had been misdiagnosed as an internal jugular vein injury on presentation. Clinical concern of an injury persisted due to the presence of a bruit. The patient was therefore referred for DSA, confirming the AVF, for which endovascular embolization was performed. As CTA is not a dynamic study, the single acquisition during the contrast bolus may include physiological venous ‘contamination’ masking early venous filling due to an AVF. DSA is arguably required when an AVF is clinically suspected but not detected on CTA.



5a



5b

Fig. 5. In 5a, coronal reformatted MIP CTA shows an apparent injury to the left internal jugular vein (arrow). On the DSA (5b), an AVF from the inferior thyroid artery to the internal jugular vein was demonstrated (arrowhead).

In case number 12, a transection of the external carotid artery was misinterpreted as a pseudoaneurysm on CTA as the ascending pharyngeal artery was interpreted as spasm of the continuation of the ECA (Fig. 6). When this was referred for DSA and endovascular embolization, it was revealed as an ECA transection. After debate, the vessel was occluded with a detachable balloon.

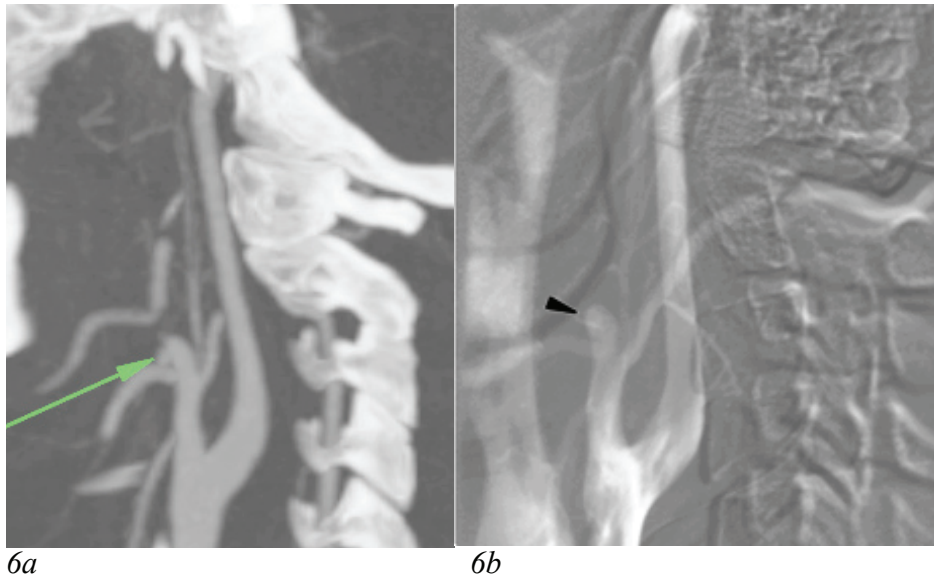


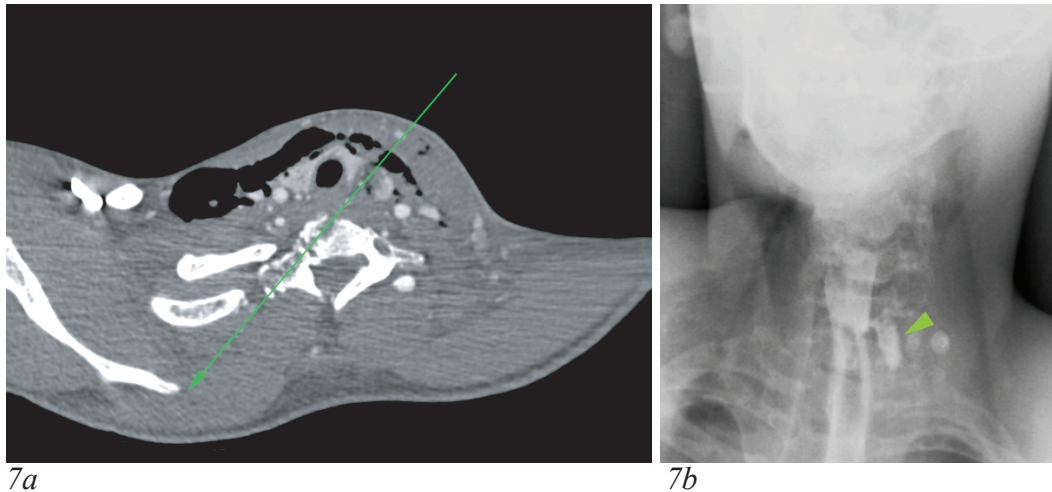
Fig. 6. In 6a, sagittal reformatted MIP CTA was interpreted as an ECA pseudoaneurysm (arrow). DSA revealed an ECA transection (arrowhead) in 6b.

Incorrect localization of a pseudoaneurysm accounted for the last false-negative result in Case 11. CTA reported the lesion to involve a cervical branch of the subclavian artery whereas on DSA the lesion arose from the subclavian artery itself, near the cervical vessel origin. The pseudoaneurysm was managed with a covered endovascular stent of the subclavian artery. It is questionable whether this led to a significant management difference, as either lesion was amenable to endovascular management.

The only false-positive result was the over-interpretation of what was thought to be a small AVF from the ascending cervical artery to the internal jugular vein on CTA, with DSA revealing no injury. Although an AVF may have occluded spontaneously, this was felt to be unlikely.

CTA was performed after DSA in one patient in whom suspicion of an injury at the origin of the left common carotid artery was suspected on DSA. CTA confirmed the injury as a pseudoaneurysm at the common carotid artery origin.

The ability of CT to evaluate structures other than the arterial vasculature adds further benefits. Assessment of the aerodigestive tract, viscera (lungs, thyroid), veins and bony structures (especially the spine) assist in clinical management. Determining the trajectory of the wound track further aids in the evaluation of patients with penetrating neck trauma, because the organs lying along the path can be considered to have a higher likelihood of injury (Fig. 7).



7a 7b
 Fig. 7. Axial CT image (7a) demonstrates a bullet tract (arrow) passing through the left thyroid lobe, crossing the midline and fracturing the right sided elements of the first thoracic vertebra, with a high index of suspicion for oesophageal injury. The contrast swallow confirms an oesophageal injury with a left sided contrast leak (arrowhead) in 7b.

The assessment of bullet and bone fragments not only aid in identifying the wound track but may also be helpful in assessing the direction of travel of a projectile such as a bullet. Careful evaluation of the bone should show beveling toward the direction of travel, which is important in forensic analysis.¹¹

In penetrating neck trauma, it is also important to deliberately assess the airway on CT. Close attention has to be paid to airway narrowing due to surrounding haematoma or direct injury. Patient 5 with an AVF detected on CTA, acutely deteriorated on the DSA table, requiring intubation and emergency surgery due to airway compromise as a result of a large mediastinal haematoma (Fig. 8). Signs of direct tracheal injury include tracheal wall defects or deformity, excessive surgical emphysema, pneumomediastinum and pneumothorax (Fig. 9). A low threshold for endoscopy is required to accurately assess suspected airway injury.

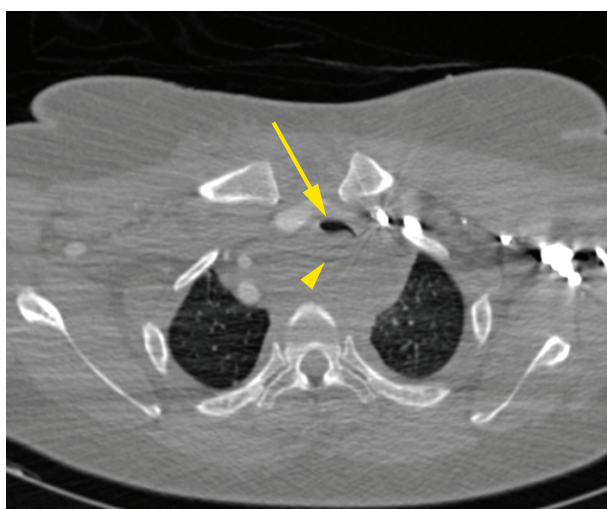
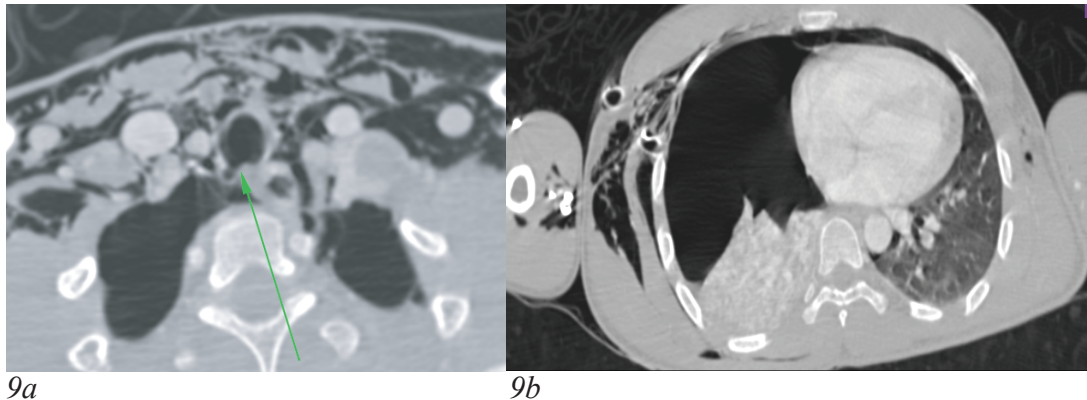


Fig. 8. Axial CT shows severe tracheal narrowing (arrow) due to mediastinal haematoma (arrowhead).



9a 9b
 Fig. 9. Fig 9a demonstrates extensive cervical surgical emphysema with a tracheal defect at the 7 o'clock position (arrow). A right-sided tension pneumothorax is also present with mediastinal shift to the left (9b). Endoscopy confirmed a tracheal injury.

Multiple types of artefacts have to be taken into account during CTA and DSA, including those induced by patient size, motion, incoming dense venous contrast and post-traumatic fragments (bullet shrapnel, knife or bone fragments). Contrast inflow artefact is usually due to use of upper limb venous injections resulting in streak artefact at the thoracic inlet. This may interfere with the visualisation of the proximal arteries exiting the thorax, especially the ipsilateral subclavian artery. Injection of contrast into the contralateral side of injury or using femoral venous access is helpful in reducing this artefact. The use of a saline chaser also reduces the amount of streak artefact.

Multiple limitations were present in the study. Most other studies used two experienced radiologists during the retrospective review, with the consensus reached as the definitive impression. Little short to long-term patient follow-up was present. Unsubtracted images on DSA were not always available due to archiving technicalities; this reduced the ability to evaluate for foreign bodies, bony detail and soft tissues, which are important for thorough assessment.

Although sensitivity and specificity in this study is lower than reported, CTA remains attractive as the initial diagnostic investigation. It is readily available, non-invasive and less resource-intensive, although it may take longer to analyze than DSA.

To our knowledge, this is the first series documenting the use of 16-slice multidetector CT in penetrating neck trauma. Larger, prospective trials are required for further evaluation.

CONCLUSION

Selective non-operative management is the rule in management of stable patients with penetrating neck trauma. CTA is an attractive initial diagnostic investigation that, along with clinical evaluation, effectively guides further investigation and intervention. High sensitivities and specificities for detecting arterial vascular injury have been documented. The added advantages of CTA include the ability to detect wound trajectory and determine visceral, bony and aerodigestive tract injury. It is however important for the radiologist to understand the limitations of CTA and have a low threshold for conventional angiography in equivocal cases, or where there is a strong suspicion of an AVF.

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PART D
APPENDICES

ETHICS APPROVAL

UNIVERSITY OF CAPE TOWN



Health Sciences Faculty
Research Ethics Committee
Room E52-24 Groote Schuur Hospital Old Main Building
Observatory 7925
Telephone [021] 406 6626 • Facsimile [021] 406 6411
e-mail: lamees.emjedi@uct.ac.za

07 September 2010

HREC REF: 407/2010

Dr P Scholtz
Radiation Medicine/Radiology
C16 Room 16
NGSH

Dear Dr Scholtz

PROJECT TITLE: A RETROSPECTIVE STUDY OF CT ANGIOGRAPHY VERSUS DIGITAL SUBTRACTION ANGIOGRAPHY IN PENETRATING NECK TRAUMA.

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

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

Approval is granted for one year until 15 September 2011.

Please send us an annual progress report (website form FHS 016) if your research continues beyond the approval period. Alternatively, please send us a brief summary of your findings so that we can close the research file.

Please obtain permission from Dr Bhavna Patel, Medical Superintendent at GSH, to access medical records for research purposes.

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

Please quote the REC. REF in all your correspondence.

lemjedi

Yours sincerely

Signed by candidate

PP PROFESSOR M BLOCKMAN
CHAIRPERSON, HSF HUMAN ETHICS

Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938

This serves to confirm that the University of Cape Town 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) and Declaration of Helsinki guidelines.

The 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.



Annual Progress Report

Date	9/1/2012
HREC REF Number	4407/2010
Protocol number (if applicable) & Protocol title	A RETROSPECTIVE STUDY OF CT ANGIOGRAPHY VERSUS DIGITAL SUBTRACTION ANGIOGRAPHY IN PENETRATING NECK TRAUMA
Principal Investigator	DR. P. SCHOLZ
Department / Office Internal Mail Address	DIVISION OF RADIOLOGY C16 NGS4

List of documentation



HREC office use only (FWA00001637; IRB00001938)			
<input type="checkbox"/> Approved	This serves as notification of annual approval, including all documentation described above.		
<input type="checkbox"/> Not approved	See attached comments.		
Type of review	<input type="checkbox"/> Expedited <input checked="" type="checkbox"/>	<input type="checkbox"/> Full committee	
Expiry date	30 January 2013		
Signature	Signed by candidate	Date	13-1-12
Chairperson of the HREC			

CTA DATA SHEET

PATIENT NUMBER:

Contrast injection site:

VESSELS (include percentage laceration and injury size):

RCCA LCCA

RICA LICA

RECA LECA

RV LV

Branches

Veins

SOFT TISSUES

BONES

LUNGS

THYROID

AIRWAY

MEDIASTINUM

MPR OR MIP useful?

Defined tract?

COMMENTS:

DSA DATA SHEET

PATIENT NUMBER:

INJURY DESCRIPTION (TYPE, LOCATION, SIZE):

UNSUBTRACTED INFORMATION

SOFT TISSUES

BONES

LUNGS

CONTRAST SWALLOW

COMMENTS:

AUTHORSHIP GUIDELINES FOR THE SOUTH AFRICAN JOURNAL OF RADIOLOGY

Accepted manuscripts that are not in the correct format specified in these guidelines will be returned to the author(s) for correction, and will delay publication.

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Named authors must consent to publication. Authorship should be based on substantial contribution to: (i) conception, design, analysis and interpretation of data; (ii) drafting or critical revision for important intellectual content; and (iii) approval of the version to be published. These conditions must all be met (uniform requirements for manuscripts submitted to biomedical journals; refer to www.icmje.org).

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Provide evidence of Research Ethics Committee approval of the research where relevant.

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ETHNIC CLASSIFICATION

References to ethnic classification must indicate the rationale for this.

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Shorter items are more likely to be accepted for publication, owing to space constraints and reader preferences.

Review articles are written by authors experienced in the specific field or who have researched the topic. They should be no more than 3000 words in length, have up to 20 illustrations and up to 15 references. The article should be useful clinically and may include practice guidelines or a recommended protocol. This is a major didactic component of the journal.

Original articles of 3000 words or less, with up to 10 illustrations, should normally report observations or research of relevance to radiology. References should be limited to 15. Please provide a structured abstract not exceeding 250 words, with the following recommended headings: *Background, Objectives, Methods, Results, and Conclusion*.

Pictorial essays use images to provide learning and review topics, and form a major didactic component of the journal. They should be less than 1500 words, with up to 20 illustrations and 15 references.

Case series highlight new or unusual findings or associations in presentation form. Presentations must not exceed 1500 words, and can contain up to 10 illustrations and 15 references.

Case reports should be about 800 words in length, contain about 2 illustrations and have no more than 6 references. We will only publish exceptional cases. Authors are rather encouraged to convert case reports into pictorial interludes.

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Tips for the radiologist encourages sharing of useful knowledge, experience and skills. The presentation must be sound, referenced, and relate to current practice or local necessity.

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Refer to articles in recent issues for the presentation of headings and subheadings. If in doubt, refer to 'uniform requirements' - www.icmje.org.

Manuscripts must be provided in **UK English**.

Qualification, affiliation and contact details of ALL authors must be provided in the manuscript and in the online submission process.

Abbreviations should be spelt out when first used and thereafter used consistently, e.g. 'intravenous (IV)' or 'Department of Health (DoH)'.

Scientific measurements must be expressed in SI units except: blood pressure (mmHg) and haemoglobin (g/dl). Litres is denoted with a lowercase 'l' e.g. 'ml' for millilitres). Units should be preceded by a space (except for %), e.g. '40 kg' and '20 cm' but '50%'. Greater/smaller than signs (> and <) should be placed immediately preceding the relevant number, i.e. 'women >40 years of age'. The same applies to \pm and $^{\circ}$, i.e. '35 \pm 6' and '19 $^{\circ}$ C'.

Numbers should be written as grouped per thousand-units, i.e. 4 000, 22 160...

Quotes should be placed in single quotation marks: i.e. The respondent stated: '...'

Round **brackets** (parentheses) should be used, as opposed to square brackets, which are reserved for denoting concentrations or insertions in direct quotes.

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The manuscript must be in Microsoft Word or RTF document format. Text must be single-spaced, in 12-point Times New Roman font, and contain no unnecessary formatting (such as text in boxes, with the exception of Tables).

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Tables must be numbered in Arabic numerals (1,2,3...) and referred to in the text (e.g. 'Table 1'). Table footnotes must be indicated with the use of the following symbols (in order): * † ‡ § ¶ || then ** †† ‡‡ etc.

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Authors must verify references from the original sources. *Only complete, correctly formatted reference lists will be accepted.* Reference lists must be generated manually and **not** with the use of reference manager software.

References should be inserted in the text as superscript numbers, e.g. These regulations are endorsed by the World Health Organization,² and others.^{3,4,6}

All references should be listed at the end of the article in numerical order of appearance in the **Vancouver style** (not alphabetical order). Approved abbreviations of journal titles must be used; see the List of Journals in Index Medicus.

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<http://www.who.int/whr/2002> (accessed 16 January 2010).

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5. Illustrations/figures are high resolution/quality (not compressed) and in an acceptable format (preferably TIFF or PNG). These must be submitted as 'supplementary files' (not in the manuscript).
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8. An abstract has been included where applicable.
9. The research was approved by a Research Ethics Committee (if applicable)
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