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HEAD AND NECK

Penetrating neck trauma: radiological predictors of vascular injury

Daniele Borsetto[1] · Jonathan Fussey[1] · Jacqueline Mavuti[2] · Steve Colley[2] · Paul Pracy[1]

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Abstract

Purpose Vascular injury in penetrating neck trauma predicts a poorer outcome and usually requires surgical neck exploration. Multi-detector computed tomography (MDCT) angiography is a readily available non-invasive diagnostic tool that can identify direct and indirect signs of vascular injury in stable patients. This study aims to investigate the diagnostic accuracy of radiological signs of vascular injury on MDCT, and their implications on patient management in the setting of penetrating neck trauma.

Methods A retrospective cohort study of penetrating neck injuries (PNI) between 2012 and 2018 in a UK major trauma centre was performed. Clinical data and operative findings were compared with radiological findings on MDCT performed at the time of admission.

Results 157 patients were identified with PNI in the study period, with 67 meeting inclusion criteria. The predictive value of indirect radiological signs of vascular injury alone was low, with only 12.1% of these patients having significant vascular injury found at neck exploration. However, the combined use of direct radiological signs with clinical signs resulted in a specificity of 97.7% for vascular injury.

Conclusions The use of direct and indirect radiological signs of vascular injury can increase the accuracy of diagnosis when used in conjunction with clinical signs. Combining clinical assessment and radiological investigation, specifically contrast-enhanced MDCT, improves the specificity in pre-operative assessment of potential vascular injury in PNI. MDCT is recommended in stable patients with clinical signs of vascular injury to reduce the rate of negative neck exploration.

Keywords Trauma · Computed tomography (CT) · Penetrating wound · Neck surgery · Vascular injury

Background

Penetrating neck injuries (PNI) are defined by a full-thickness breach of the platysma muscle [1] and are estimated to account for 5–10% of all trauma cases [2]. These injuries are associated with a high risk of potentially catastrophic damage to the vital vascular, neurological and aerodigestive structures located within a relatively small and vulnerable anatomic area. Mortality from penetrating neck injuries ranges from 2 to 10% [3].

PNI have been categorised into three anatomical zones of the neck by the site of the entry wound (Fig. 1), as described by Monson et al. [4] and Roon et al. [5]. However, several authors have shown that the site of the entry wound does not accurately predict the site of internal injury and, therefore, the vascular structures are at risk [6]. As a result, some authors have advocated a 'no zone' approach to PNI, focusing on clinical assessment of hard and soft signs (Table 1), and modern multi-detector computed tomography (MDCT) imaging [7].

Multi-detector computed tomography (MDCT) angiography is a quick, non-invasive initial diagnostic tool that provides global information about the status of vessels, the upper aerodigestive tract and skeletal structures, and has been shown to reduce the rate of negative neck explorations

Daniele Borsetto and Jonathan Fussey contributed equally to this work.

Steve Colley and Paul Pracy equal senior contributors.

✉ Daniele Borsetto
daniele.borsetto@gmail.com

1 Department of ENT Head and Neck Surgery, Queen Elizabeth University Hospital, Mindelsohn Way, BirminghamBirmingham B15 2TH, UK

2 Department of Radiology, Queen Elizabeth Hospital, Birmingham, UK

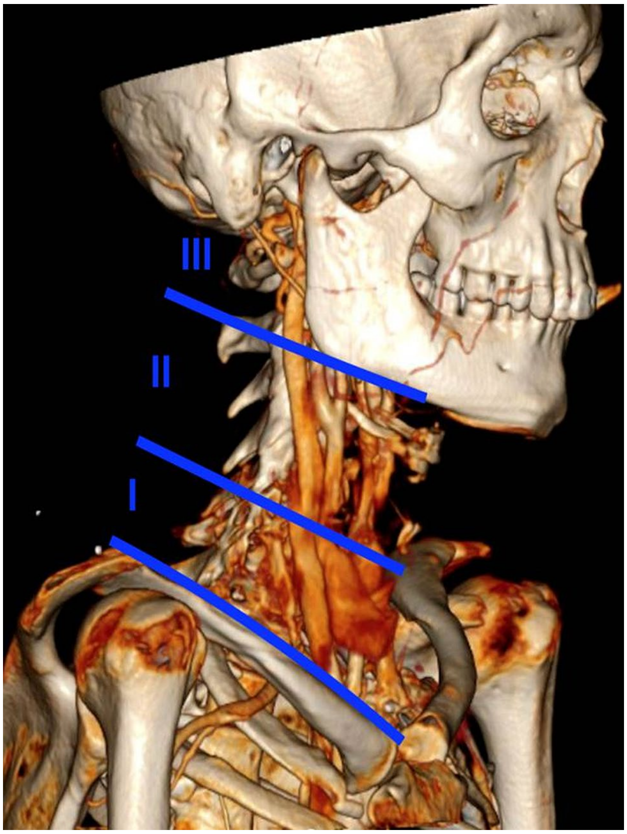

Fig. 1 Three-dimensional volume-rendered CT image illustrating the zones used in traditional classification of PNI

Table 1 Hard and soft clinical signs in penetrating neck injury

Hard signs	Soft signs
Expanding/pulsatile haematoma	Non-expanding haematoma
Shock	Venous oozing
Active haemorrhage	Minor haematemesis
Airway compromise	Chest tube air leak
Air bubbling wound	Subcutaneous emphysema
Haematemesis	Dysphagia
Neurological deficit/cerebral ischaemia	Dyspnoea
Paralysis	Paresthesia
Compromised radial pulse	

[8]. Evaluation of the wound tract also helps in the determination of potential injury.

Vascular injury is reported in approximately 15–25% of all penetrating neck injuries [3, 9] and contributes substantially to poor clinical outcomes [10, 11]. Radiological signs of vascular injury at MDCT may be grouped into direct and indirect as shown in Table 2 [3, 9].

The aim of this study was to evaluate the diagnostic accuracy of direct and indirect signs of vascular injury on MDCT and its clinical implications, as well as the value of MDCT in a 'no zone' approach to PNI, specifically focusing on vascular injury.

Methods

All patients attending the emergency department at the Queen Elizabeth Hospital Birmingham with penetrating neck injuries between 2012 and 2018 were identified using the emergency department coding system and OPCS codes. Those patients who following clinical assessment were found to have injuries not penetrating platysma were excluded. Patients who were too unstable for pre-operative imaging were taken immediately to the operating theatre without imaging, and were also excluded, as were those patients who underwent MDCT imaging but did not have subsequent formal exploration in theatre. Demographic characteristics, mechanism of injury, clinical presentation, presence of hard and soft signs of vascular injury (as shown in Table 2), clinical investigations, presence of direct or indirect signs of vascular injury on MDCT, intraoperative findings and post-operative outcomes were analysed.

Demographic data along with clinical and operative findings were collected from medical records. Two head and neck radiologists (JM and SC), blinded to operative findings and outcomes, then reviewed all the MDCT images and reported on direct and indirect signs of vascular injury as shown in Table 2. These findings were then compared with operative findings. Data were collected using Excel (Microsoft, Redmond, WA, US) and analysed using the Stata statistics software package (StataCorp LLC, College Station, TX, US). Categorical variables are reported as numbers and percentages. Fisher's exact test was used to assess for statistical significance, with a p value of less than 0.05 being taken as significant.

The research protocol was conducted in compliance with the Helsinki Declaration (2008). Informed consent for surgery was obtained from patients according to UK law. This study was observational and did not affect patient care in any way.

Results

Demographic data

Between 2012 and 2018, there were 157 patients admitted with PNI. Of these, 56 did not undergo MDCT imaging, either because they were too unstable, or because it was not felt to be indicated by the treating clinician. Thirty-one patients underwent imaging but no surgical wound exploration and were, therefore, excluded. A further three

Table 2 Clinical and radiological (MDCT) signs of vascular injury

Radiological signs on MDCT		Clinical signs	
Direct signs	Indirect signs	Hard	Soft
Vessel transection	Perivascular haematoma	Expanding or pulsatile haematoma	Non-expanding haematoma
Partial or complete occlusion	Perivascular fat stranding		
Active bleeding	Perivascular gas, foreign body or bone fragments within 5 mm of the vessel	Shock	Venous oozing
Pseudoaneurysm or pseudodiverticulum		Active haemorrhage	
Intimal injuries			
Dissection			
Arteriovenous fistula			
Luminal calibre changes in arteries			

patients were excluded because their CT images were not available, or the neck was incompletely imaged. This left 67 patients who met the inclusion criteria of the study of whom 58 were male and 9 were female (male:female ratio, 6.4:1). There were no children in the cohort with patients ranging in age from 16 to 69 years. The mean age of the patients was 36.17 ± 15.47 years. Table 3 summarises the mechanism of injury, modality, clinical presentation, clinical investigations and zone of injury. The most common cause of penetrating neck injury was stabbing with a knife, which was seen in 31 patients (46.3%). In 39 cases (58.2%), the penetrating neck injury resulted from assault, in 20 (29.9%) it was self-inflicted and in 6 (9%) the injury was accidental.

Clinical presentation

All patients attended via the emergency department and were clinically assessed by an otolaryngology registrar and/or consultant following initial assessment by the trauma team. The most common symptom at the time of initial assessment was bleeding (52%). Soft signs were present in 46% of patients (42% haematoma, 33% venous oozing), and 22% presented with hard signs (100% active bleeding, 20% expanding haematoma and 13% shock).

Radiological investigations

All patients underwent MDCT (Siemens Definition AS Scanner, 128 Slice, Siemens Germany) of the neck and chest following 100 ml IV contrast. Forty percent of patients underwent a specific carotid angiography protocol with IV contrast bolus tracked to the aortic arch, with the remaining CT studies performed using a combined arterial/venous phase CT (50 s post-IV contrast). All MDCT scans revealed subcutaneous air. In 39 patients (58.2%), there were direct signs of vascular injury (Figs. 2, 3), in 19 patients (28.3%) there were both direct and indirect signs of vascular injury (Fig. 4), and in one patient there was indirect evidence of vascular injury only (Fig. 5). In 11.9% of scans, there was no radiological evidence of vascular injury.

Table 3 Patient characteristics ($n=67$)

Median age (range)	36 (16 -69)
Gender	
Male	58 (86.6)
Female	9 (13.4)
Mechanism of injury	
Knife	48 (71.6)
Gun	1 (1.5)
Road traffic accident	1 (1.5)
Glass	8 (11.9)
Other sharp object	9 (13.4)
Modality	
Self-inflicted	20 (29.9)
Accident	6 (9.0)
Assault	39 (58.2)
Unknown	2 (3.0)
Soft signs	33 (49.3)
Hard signs	15 (22.4)
Imaging	
CT	39 (58.2)
CT angiography	27 (40.3)
CT + US	1 (1.5)
Zone of injury	
I	5 (7.5)
II	35 (52.2)
III	5 (7.5)
I and II	11 (16.4)
II and III	8 (11.9)
I, II and III	3 (4.5)

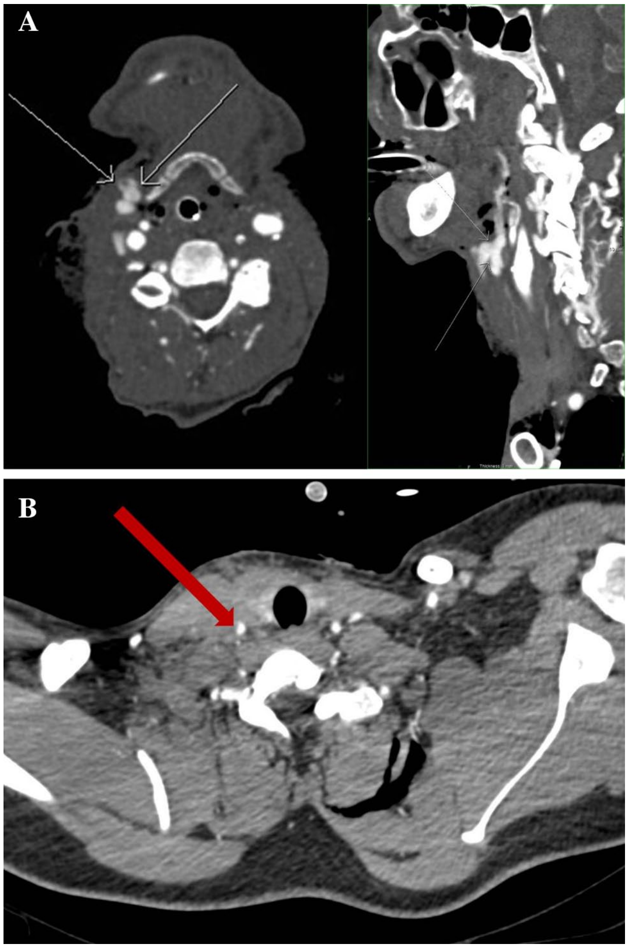

Fig. 2 **a** Post-contrast CT showing acute extravasation of contrast (arrows) from anterior wall of the lower facial vein, at the level of the hyoid bone; **b** direct sign of arterial injury on contrast-enhanced MDCT. The red arrow indicates an irregular eccentric filling defect with distortion of the margins of the right common carotid artery, suggestive of intimal injury

Intraoperative findings

Major vessel involvement (CCA, ICA, ECA, IJV) was seen in 7 patients (10.4%), 13 patients (19.4%) suffered an arterial injury and the overall rate of direct vessel ligation/repair was 36%. Neck exploration revealed no named vessel injury in 64% of cases. In this subgroup, diffuse oozing, managed with bipolar diathermy, was found. All patients received a post-operative drain, which was removed within 48–72 h. Broad-spectrum antibiotics were used for at least 48 h following neck exploration.

Of the 23 patients who, at operation, were found to have a vascular injury requiring intervention, 19 had either direct or indirect evidence of vascular injury on blinded review of CT imaging, giving a sensitivity of 82.6%. Of the 33 patients with indirect radiological signs of vascular injury only, 4 (12.1%) were found at operation to have clinically significant vessel injury. When only direct radiological evidence of vessel injury was considered, 9 of 19 patients (47.1%) had clinically significant vessel injury. The accuracy of direct signs on MDCT in predicting vessel injury was 71.6%, with a negative predictive value of 76.6% ($p=0.006$). This was slightly superior to using hard signs on clinical assessment alone, which was accurate in 73.1% of cases and gave a negative predictive value of 75% ($p=0.005$).

The addition of hard clinical findings and direct evidence of vascular injury was 97.7% specific and 26.1% sensitive for vascular injury requiring intervention, with a negative predictive value of 71.7%, positive predictive value of 85.7% and overall accuracy of 73.1% ($p=0.005$). The negative predictive value of clinical assessment for vascular injury alone was 72.5%, but the specificity (84.1%) was lower than that of combined clinical and radiological assessment (98.8%) suggesting a reduced false-positive rate with the utilisation of direct signs on CT. Finally, the rate of negative neck exploration in patients with soft clinical signs only fell from 85.7% in patients without direct radiological signs of vascular injury to 44.4% in patients with direct signs of vascular injury. These figures are for positive findings of vascular injury only, and, therefore, do not represent the true overall negative exploration rates including aerodigestive tract injuries. Table 4 summarises the value of radiological and clinical assessments in diagnosing clinically relevant vascular injury.

Of note, four of five patients with confirmed internal jugular vein injury were identified by direct signs radiologically, and all three patients with carotid injuries were correctly identified as such radiologically. Of the 32 named vessels identified as being injured in the operative records, 15 (46.9%) were identified as the site of direct or indirect signs of injury radiologically.

Discussion

Blood vessels are the most commonly injured structures in the neck, followed by the laryngotracheal region and pharynx in stabbing injuries, and by the spinal cord, aerodigestive tracts and nerves in gunshot injuries [12, 13]. Laryngotracheal injuries are usually readily apparent in the setting of penetrating neck trauma with agitation and dyspnea, hoarseness, aphonia, and hemoptysis. Physical examination may reveal air leakage into the wound, exposed cartilage, or most commonly, subcutaneous emphysema. Pharyngoesophageal injuries present more subtly with symptoms of odynophagia and chest pain, and signs including, subcutaneous emphysema, hematemesis or hemoptysis. Due to the low incidence of aerodigestive tract injuries, it is difficult to determine the optimal diagnostic and management strategies. For unstable patients, taken to the operating room,

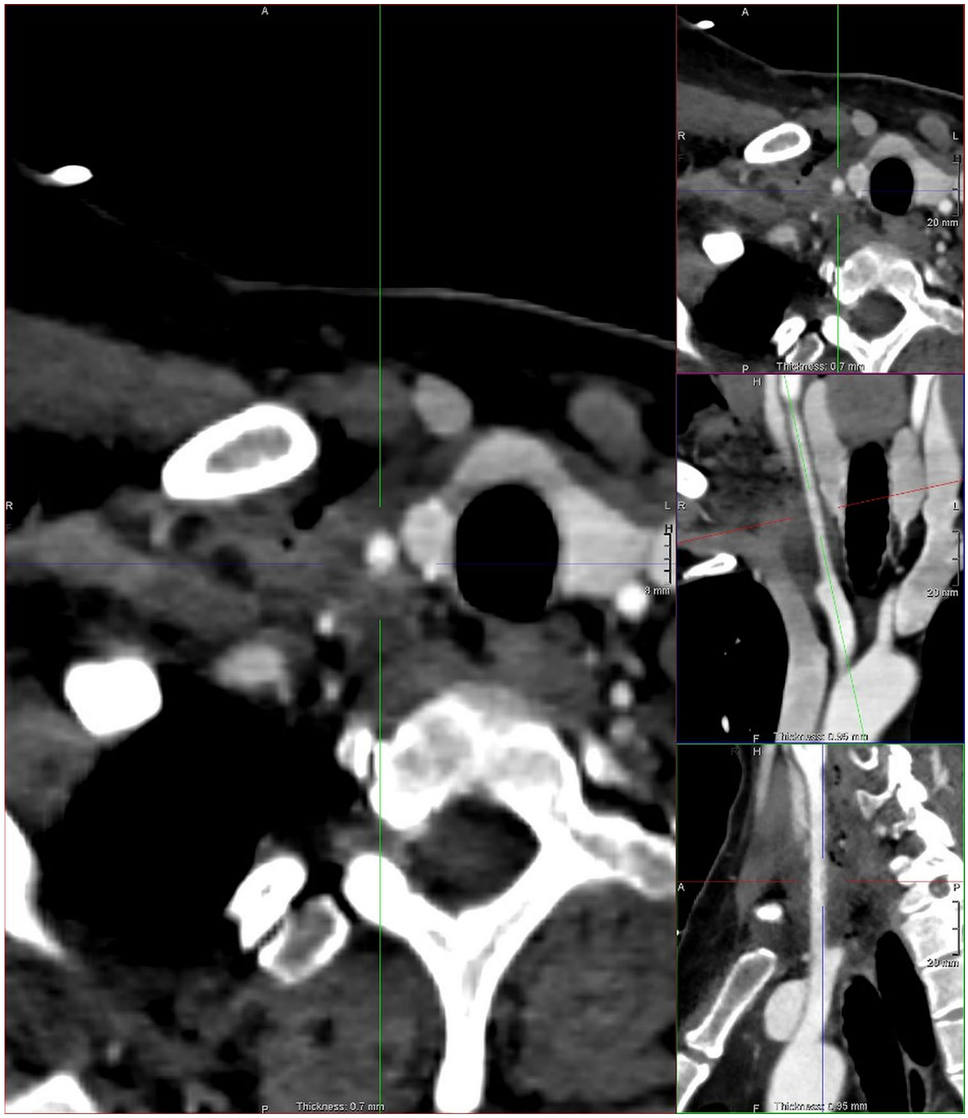

Fig. 3 Post-contrast CT showing haematoma surrounding the common carotid artery, with subtle intimal thickening of the posterior wall, indicating direct vascular injury

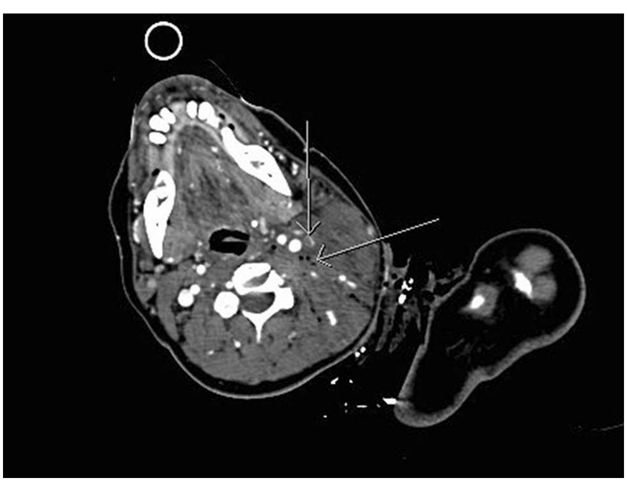

Fig. 4 Post-contrast CT showing gas and haematoma in the left carotid sheath (posterior arrow—indirect sign), and thrombus within a narrowed left internal jugular vein (anterior arrow—direct sign)

Fig. 5 Indirect sign of vascular injury on contrast-enhanced MDCT. The red arrow indicates an air bubble within 5 mm of the left internal jugular vein

Table 4 Predictive value of clinical and radiological signs

Test	Statistic	Value (%)
Direct or indirect signs on CT	Sensitivity	82.60
	Specificity	9.10
	PPV	32.20
	NPV	50
	Accuracy	34.30
Direct signs on CT	Sensitivity	52.20
	Specificity	81.80
	PPV	57.10
	NPV	76.60
	Accuracy	71.60
Hard clinical signs	Sensitivity	43.50
	Specificity	86.60
	PPV	67.70
	NPV	75.00
	Accuracy	73.10
Hard clinical signs and direct signs on CT	Sensitivity	26.10
	Specificity	97.70
	PPV	85.70
	NPV	71.70
	Accuracy	73.10

panendoscopy is usually performed at the time of neck exploration. For the stable asymptomatic patient, however, MDCT has been shown to be a sensitive and specific non-invasive alternative investigation [14].

These findings demonstrate the value of combining clinical assessment with MDCT imaging in stable patients with PNI, when considering the risk of vascular injury. The use of direct and indirect radiological signs of vascular injury can increase the accuracy of diagnosis when used in conjunction with clinical signs. This has the benefit of forewarning the surgeon of the site and nature of vessel injury, as well as reducing the negative exploration rate in patients with soft signs of vascular injury only. Our sample was comparable to other cohorts in terms of the male predominance and mode of injury, knife-stabbing (often self-inflicted) being the most common mechanism [7, 15, 16].

The rate of negative neck exploration in patients presenting with hard signs in this study was 23%, which is comparable to negative exploration rates reported elsewhere, ranging from 10 to 28% [6, 7, 13, 17]. The use of MDCT angiography in selected patients presenting with hard signs reduced the number of these negative explorations (15%), a finding supported by the other authors [7, 18].

Several studies have evaluated the diagnostic accuracy of MDCT angiography against conventional angiography for detection of vascular neck injuries in the context of penetrating neck trauma, with high sensitivities and specificities [10, 11, 17, 19-21]. There are, however, very few studies comparing MDCT signs of vascular injury with surgical findings. A small retrospective study from Brazil found that CT angiography identified less than half of carotid artery injuries found at surgery and just over two-thirds of jugular venous injuries found at surgery [22]. There is no specific data on the significance of indirect signs of vascular injury, and their presence often creates a diagnostic dilemma. Due to the potential of overlooking a vascular injury, some authors recommend further evaluation with conventional angiography or a follow-up CT angiogram when indirect radiological signs of vascular injury are present [3]. In our series, only 4 of the 33 patients with indirect radiological evidence only of vascular injury (12.1%) were found at operation to have clinically significant vascular injury, suggesting that indirect radiological signs alone are not sufficient to justify a neck exploration.

Our findings highlight the importance of combining thorough clinical assessment and radiological investigation, specifically contrast-enhanced MDCT, to improve the specificity in pre-operative assessment of potential vascular injury in PNI. Independently, MDCT did not appear to be superior to clinical assessment in identifying patients requiring neck exploration for vascular injury. However, the decision to explore the neck is made based on a combination of clinical and radiological findings, and the important question is whether MDCT improves the accuracy of clinical assessment alone to increase the proportion of patients that benefit from a neck exploration. In our study, the specificity of a combined clinical and radiological assessment was up to 97.7% as opposed to 86.6% for clinical assessment alone. In an unstable patient with hard clinical signs of vascular injury, radiological imaging is not indicated and immediate neck exploration is mandatory. In stable patients with clinical signs of vascular injury, our study suggests that MDCT is a valuable tool in predicting the site of injury. Patients with hard clinical signs and direct radiological evidence of vascular injury are unlikely to have negative neck explorations; however, patients with no hard signs of vascular injury and only indirect radiological signs could be observed rather than undergo immediate neck exploration.

Our study has a number of limitations, including the number of patients that fit the inclusion criteria, the retrospective nature, and the evaluation only of vascular injury as a criterion for therapeutic neck exploration. There are also inherent limitations and pitfalls in MDCT imaging of the neck related to imaging technique and artefacts, such as suboptimal scan timing, motion artefact and beam hardening artefact from dental amalgam, spinal hardware or metallic foreign bodies. Although uncommon, these may obscure or simulate vascular injuries. On balance, the comparison of blinded radiological assessment with intraoperative findings provided valuable information on the value of MDCT in addition to clinical assessment when planning surgical neck exploration. Future research should focus on multicentre prospective studies with the aim of improving the pre-operative identification of vascular injury, and reducing the rate of unnecessary neck exploration.

This study demonstrates the value of MDCT assessment using indirect and direct radiological signs of vascular injury in PNI. However, it is evident that imaging is not a replacement for clinical assessment, but rather the two compliment each other as part of a 'no zone' approach to reduce the rate of unnecessary surgical neck exploration. Our findings suggest that MDCT is useful in stable patients with hard or soft signs of vascular injury, and whilst a positive scan alone does not guarantee the presence of a clinically significant vascular injury, direct radiological signs are a more accurate predictor than indirect signs, and in addition to hard clinical signs can accurately predict a significant injury. MDCT is, therefore, recommended in stable patients with clinical signs of vascular injury to localise the site of injury and reduce the rate of negative neck exploration. The usefulness of MDCT is less clear in patients without clinical evidence of vascular injury, and in these circumstances a period of observation is more appropriate.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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