Chandrananth Meera (Orcid ID: 0000-0002-3217-967X)
Read David (Orcid ID: 0000-0002-6555-7358)

TITLE PAGE

Title: The "No Zone" Approach to the Management of Stable Penetrating Neck Injuries – A Systematic Review

Authors: Meera L Chandrananth[1] MD, BBiomed; Andrew Zhang[1] MD, BBiomed (hons); Catherine R Voutier[2] BSocSci, MInfoMgmt; Anita Skandarajah[1,3] MBBS, FRACS; Benjamin NJ Thomson[1,3,4] MBBS, FRACS; Rezvaneh Shakerian[1] MBBS, FRACS; David Read[1] MBBS, FRACS

[1] Department of General Surgical Specialties, The Royal Melbourne Hospital, Parkville, Victoria, Australia
Trauma Service, The Royal Melbourne Hospital, Parkville, Victoria, Australia

[2] Health Sciences Library, The Royal Melbourne Hospital, Parkville, Victoria, Australia

[3] Department of Surgical Oncology, Victorian Comprehensive Cancer Centre, Parkville, Victoria, Australia

[4] The University of Melbourne Department of Surgery, The Royal Melbourne Hospital, Parkville, Victoria, Australia

Corresponding author's contact details:
Name: Meera L Chandrananth
Address: 300 Grattan St, Parkville VIC 3052
Email: meera.chandrananth@gmail.com

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ABSTRACT

Objective: To review outcomes of the "no zone" approach to penetrating neck injuries (PNIs) with the advent of high-fidelity CT-Angiography (CT-A) in order to determine the most appropriate management for stable PNIs.
Design: Systematic review
Population: Retrospective and prospective cohort studies of patients who sustained penetrating neck trauma, as defined by an injury which penetrates the platysma, and whose initial management involved CT-A evaluation.
Method: An extensive literature search was performed in July 2019 using the following databases: Pubmed Central, EMBASE, Medline and Cochrane CENTRAL. Only studies published in English from the last 15 years were included.
Results: Nine cohort studies met inclusion criteria. There has been an increase in CT-A focussed evaluation of PNIs in recent years. CT-A is a highly sensitive and specific imaging choice and reduces negative neck exploration rates. A new management algorithm for stable patients involving initial radiological assessment using CT-A first, and subsequent selective surgical exploration, is safe and effective.
Conclusion: The results of this review provide level 2A evidence that the "no zone" approach to PNIs, complemented by CT-A and thorough clinical assessment, is a safe management strategy which reduces negative neck exploration rates.

Keywords: penetrating neck injury, computed tomography angiography, no zone

INTRODUCTION

Penetrating neck injuries (PNIs) comprise 5 to 10 percent of adult traumatic injuries, with mortality rates of up to 10 percent.[1] PNIs are defined as those which penetrate the platysma, and are most commonly caused by gunshot and stab wounds.[2] Traditionally, the description and management of PNIs has been zone-based, whereby Zone 1 extends from the clavicles to cricoid cartilage; Zone 2 between the cricoid cartilage and angle of mandible; and Zone 3 between the angle of mandible and base of skull.[3, 4] Patients with PNIs can have "hard" or "soft" (Table 1) signs of injury, based on the severity of their clinical presentation. The management of PNIs with hard signs has predominantly been surgical but PNIs with no or soft signs were traditionally managed based upon the zones of wound entry. An entry wound deep to platysma in Zone 2 was an accepted indication for surgical exploration, regardless of symptoms, whereas zone 1 and 3 injuries have had more selective surgical management due to difficult surgical access in these regions.[5, 6] Since the widespread availability of computed tomography angiography (CT-A), there has been a shift from mandatory neck exploration based on zone of injury to selective management through careful physical examination due to high negative exploration rates. Furthermore, numerous studies have demonstrated a lack of correlation between the zone of entry wound and underlying injured structures.[5, 7-13] CT-A evaluation of haemodynamically stable PNI patients has high sensitivity and specificity with low rates of missed injuries.[5, 14-16] This systematic review aims to examine patient outcomes and CT-A use based on clinical signs in the "no zone" approach to managing stable PNI patients.

METHODS

The search strategy was developed in Ovid Medline and translated to Ovid Embase (including Medline and conference abstracts) and Cochrane CENTRAL by an information specialist on 31st July 2019. PubMed Central (PMC) was also searched to retrieve articles from journals not indexed in Medline. Databases were searched from inception to the date searched (Medline 1946 to 29.07.19, Embase 1974 to 29.07.19, CENTRAL 1996 to 31.07.19 and PMC 2000 to 31.07.19). No database filters were applied. The following keywords were used: penetrating neck injury, computed tomography angiography and no zone. The complete search strategy is listed in the supplementary materials (Document S1). Duplicates were removed and 1071 citations were obtained. Of these, 1019 articles were excluded after screening titles and abstracts, resulting in 52 eligible papers. After applying the inclusion and exclusion criteria, 9 key articles were selected for use in the review as shown in the PRISMA flowchart (Figure 1).

Inclusion criteria included cohort and case control studies examining penetrating neck trauma (as defined by a penetration of the platysma muscle), the use of CT-A and selective or "no zone" management strategies. Mechanism of injury included gunshots, stab wounds, penetrating objects and motor vehicle accidents. Exclusion criteria included studies published in a language other than English, studies prior to 2004, non-full text studies and case reports. Full text papers were obtained for studies meeting the inclusion criteria, and their eligibility for inclusion independently assessed.

RESULTS

Study Characteristics:

The study characteristics for the 9 key articles are summarised in Table 2. All articles were published between 2006 and 2019 and included 1720 participants. Two out of nine were multicenter, and all were performed at Level 1 trauma centres. Two were prospective whilst the others were retrospective studies. All studies examined the presentation, management and outcomes of PNI patients. CT-A usage, including its relationship with negative neck explorations and its sensitivity and specificity when evaluating PNIs, were also noted. In addition, five studies examined rates of therapeutic neck exploration, and complications or missed injuries were specifically mentioned in all except one.[17]

Impact of CT-A on neck exploration rates in PNIs

Six[3, 14, 17-20] studies examined the use of CT-A in evaluating PNIs and its effect on rates of negative neck explorations. Table 3 compares neck exploration numbers between those who underwent CT-A and those who did not.

Osborn et al.[18] found that with the routine use of CT-A since 2003 at their institution, the rates of negative neck exploration dramatically reduced to nearly zero. The CT-A group had a 0% negative exploration rate compared to 48% in the non-CT-A group ($P < 0.01$). The CT-A group also included 18 zone II injuries, of whom only 5 underwent exploration, thereby avoiding operation in 13 patients who otherwise would have if utilising the traditional zone-based approach.

Borsetto et al.[17] demonstrated that when CT-A was used in addition to clinical examination, specificity of detected injuries increased by 11.1% compared to physical examination alone. Furthermore, in patients with soft signs the rate of negative neck exploration dropped by nearly half in those with direct signs of vascular injury, compared to indirect signs, indicating the sensitivity of CT-A for detecting clinically significant injuries. Importantly, however, this study looked at vascular injuries only so the overall negative exploration rates may have been different.

Schroll et al.[3] performed a four-year retrospective review evaluating CT-A use in patients with zone II injuries and hard signs only. In this study 48% of patients with hard signs underwent CT-A and 46% went immediately to surgery. There was no significant difference in missed injury rates between the two groups ($P = 0.323$) but there was a lower rate of negative explorations in the CT-A group of 0% versus 36% in the operative group. Authors demonstrated a significant reduction in negative neck exploration rates with the addition of CT-A compared with what the rate would have been had all these patients proceeded to immediate exploration due to their hard signs ($P < 0.001$).

Ibraheem et al.[19] utilised a "no zone" algorithm in which patients with soft signs across all zones underwent CT-A and proceeded to surgery only if positive. Although there was a higher negative neck exploration rate in the CT-A group, 68 patients with soft signs and zone II injuries still safely avoided an operation that they otherwise would be subjected to with a zonal approach.

Similarly, Hundersmarck et al.[20] also demonstrated a higher negative neck exploration rate in the CT-A group, but did avoid an operation in 15 stable patients who underwent CT-A, with no complications in those that were managed conservatively.

Prichayudh et al.[14] also produced a low negative surgical exploration rate (7%) with no missed injuries by adopting a symptom-based management algorithm with CT-A.

CT-A sensitivity and specificity

CT-A sensitivity and specificity was examined in five[3, 14-16, 21] studies, as seen in table 4.

A single-centre prospective study found that in patients without hard signs of injury, CT-A had a sensitivity of 100% and specificity of 93.5%[16]. Six years later, the same researchers broadened to a multi-centre prospective trial examining 453 patients with PNIs where asymptomatic patients were simply observed, rather than undergoing CT-A[15]. As a result, CT-A specificity increased to 97.5% whilst still maintaining a 100% sensitivity rate. Both the 2006 and 2012 studies imaged patients with all zones of injury, with zone II injuries comprising 43% and 86%, respectively.

Madsen et al.[21] achieved similar results, quoting a CT-A sensitivity of 94%, specificity of 98% and only a 0.9% false negative rate.

Schroll et al.[3] demonstrated an 83% sensitivity and 100% specificity rate for CT-A in patients with hard signs; and a positive predictive value (PPV) of 100% and negative predictive value (NPV) of 94%. Only one injury was missed in the CT-A group, which was identified through observation, and subsequently repaired.

Likewise, Prichayudh et al.[14] found similar values with 100% sensitivity, 61% specificity, 30% PPV and 100% NPV, thereby reliably excluding injuries requiring surgical management in the soft signs cohort.

Hard Signs and CT-A

Although most studies advocate for immediate exploration of all those exhibiting hard signs, three studies[3, 17, 21] included CT-A evaluation of PNI patients with stable hard signs, rather than proceeding straight to operation.

As stated, the study by Schroll et al.[3] demonstrated a 36% negative neck exploration rate in patients with hard signs who went directly to theatre compared with 0% in the CT-A group, without a significant increase in missed injuries.

Similarly, Madsen et al.[21] demonstrated the feasibility of using CT-A in patients with hard signs. The study included 13 patients with hard signs of injury who were haemodynamically stable and underwent CT-A, despite injury zone. Of these, 11 (84.6%) had vascular injuries on CT, 8 (61.5%) of whom required surgical exploration. There were no complications or mortalities in this group.

Borsetto et al.[17] also mentions a 15% reduction in negative neck exploration rates in patients with hard signs who underwent CT-A. There were 15 (22%) patients with hard signs evaluated with CT-A, with an 11% increase in specificity for vascular injuries with the addition of CT-A compared to clinical assessment alone in those with hard signs.

DISCUSSION

Mandatory exploration for platysma penetrating neck injuries arose out of experience in World War 2, likely in response to the diagnostically and therapeutically austere environment. The zonal approach was first mentioned in the 1970s[4] and has featured prominently in many protocols since. Although this description still has benefit in emphasising the potential difficulties in managing the junctional injuries of Zones 1 and 3, the advent of high-quality cross-sectional imaging has facilitated a transition from mandatory surgical intervention to selective neck exploration.

CT-A appears to be a rapid, non-invasive, and highly sensitive[22-26] way of evaluating PNIs in haemodynamically stable patients, which also reduces rates of non-therapeutic neck explorations[22-24, 27, 28]. A recent meta-analysis comparing angiography and CT-A in assessing neck trauma confirmed CT-A as the gold standard imaging modality, demonstrating an overall sensitivity and specificity of 97% and 99%, respectively[25]. Our review supports this with four of five studies achieving CT-A sensitivity and specificity greater than 80%[3, 15, 16, 21], In a 2005 10-year retrospective study comparing the utilisation of CT-A versus non-utilisation in PNIs, authors demonstrated a negative neck exploration rate of 3% in the CT-A group compared with 33% for the non-CT-A group ($P < 0.001$), with zero negative neck explorations and fewer conventional angiograms compared with the non-CT-A group.[28] Similarly, in our review all studies, apart from one, demonstrated fewer negative neck explorations in the CT-A groups (Table 3). The single paper[20] with a higher raw number of negative neck explorations in the CT-A group had the least number of study participants of 43 and did still produce a 71% therapeutic neck exploration rate in the CT-A group. Thus, this review indicates that CT-A can target those requiring surgical intervention, thereby reducing rates of non-therapeutic explorations.

Recently, there has been a move towards "no zone" PNI management, based on symptoms rather than anatomical zones.[1, 19, 23] This algorithm states that those with hard signs of injury should proceed directly to exploration, whilst those with soft signs of injury should undergo CT-A, and only if positive, continue to the operating theatre. Some studies add that high impact mechanisms, such as gunshots, in asymptomatic patients should still undergo CT-A.[29] Our review identified three studies[14, 19, 20] examining the "no zone" approach, all of which demonstrated its safety with no complications or missed injuries in those conservatively managed. Conversely, some authors suggest caution with the "no zone" approach, particularly regarding zone 1 injuries. Bhatt et al.[30] published a case of an asymptomatic patient with a zone 1 injury who went to theatre due to complete occlusion of the right common carotid artery seen on CT-A. However, intra-operatively, an occult hypopharyngeal injury was noted, that had not been identified by CT-A. The authors thus emphasise maintaining a high index of suspicion in patients with zone 1 injuries who may require further intervention despite imaging findings. Our results indicate that stable PNI patients can be safely managed with a "no zone" algorithm through CT-A evaluation, but all patients should be carefully monitored to ensure no missed injuries.

Clinical assessment is also an important aspect in PNIs, featuring in eight of the nine protocols reviewed. The single study that did not specifically evaluate physical examination findings focussed instead on CT-A use.[18] Thorough and serial physical examination of patients with PNIs is more than 95% sensitive in detecting arterial and aerodigestive injuries that require intervention.[13] Traditionally, PNIs are triaged into three categories: hard signs, soft signs and asymptomatic. There are variable definitions of hard signs, which encompass the vascular, aerodigestive and neurologic systems. These include haemodynamic instability, active bleeding, expanding or pulsatile haematoma[3, 15-21], massive subcutaneous emphysema[3, 14, 16, 18, 19], respiratory distress, air bubbling from the wound, haematemesis and focal neurological deficits. See supplementary materials for a summary of hard and soft sign criteria used in each study (Table S2).

The reviewed studies suggest that asymptomatic patients may be safely observed without imaging with CT-A. Although Inaba et al. found 2 injuries on CT-A in asymptomatic patients[16], the clinical significance of these were unknown. Six years later in their multicentre study authors demonstrated the safety of observation alone in asymptomatic patients with no missed injuries and zero positive CTAs in those who did undergo imaging due to injury proximity to neck structures.[15] This was confirmed by two other studies[14, 19], which found no clinically significant injuries in asymptomatic patients who underwent CT-A regardless of the zone of injury. Similarly, Madsen et al.[21] demonstrated low yield for CT-A in asymptomatic patients, but did find seven vascular injuries in asymptomatic patients with gunshot wounds, one of which required surgical exploration (also had concomitant abdominal injury). Therefore, the data suggests that observation alone is safe in asymptomatic patients, except for those with high impact mechanisms.

All studies agree that patients with soft signs should be investigated with CT-A. Up to 29%[14] of patients with soft signs had positive CT-As, with those requiring intervention for injuries on CT-A ranging from 4% to 24%,[14, 19] thereby reflecting the importance of CT-A in the work-up of this cohort.

There is some variability amongst the papers in the evaluation of patients exhibiting hard signs of injury who are haemodynamically stable. Although most[14-16, 19] recommend

mandatory exploration in those with hard signs, some allow for pre-operative evaluation with CT-A for those who are haemodynamically stable even with hard signs[3, 17, 21, 31]. These studies demonstrated that selective CT-A use in patients with hard signs can significantly lower negative neck exploration rates without significant increases in complications. Importantly, however, one study only examined patients with zone 2 injuries,[3] so may not necessarily be extrapolated to all zones of injury; and another study recorded six patients who were initially haemodynamically unstable but responded to resuscitation and proceeded to CT-A,[20] however it is not stated whether these patients had hard signs or whether they subsequently underwent exploration or not. Not all hard signs necessitate immediate operation if amenable to stabilisation, such as securing an airway, or closely monitoring a bruit or neurologic deficit. The advantages of this approach are that surgeons have more information pre-operatively for planning, patients may be able to undergo less invasive procedures such as angiography depending on CT-A results and it can facilitate further reductions in negative neck exploration. There is evidence that at least 30% of patients in this cohort may safely avoid an operation.[21]

CONCLUSION

This systematic review provides level 2A evidence that the "no zone" approach to PNI management through the use of highly sensitive and specific CT-A imaging coupled with thorough clinical examination is a is a safe algorithm, which reduces rates of negative neck exploration. Clinical assessment remains important for stratification of patients into hard, soft and asymptomatic groups, with some allowance for clinician discretion with regards to haemodynamically stable patients with hard signs, and asymptomatic patients with a high impact mechanism or concerning features.

Disclosure Statement

There is no conflict of interest or financial gain in the production of this case report.

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FIGURE LEGENDS

FIGURE 1: PRISMA Methodology Flowchart

SUPPORTING INFORMATION

DOCUMENT S1: Detailed Search Strategy

TABLE S1: Hard and Soft Signs Criteria Used in Each Study

TABLES

TABLE 1: "Hard" and "soft" signs of PNIs

"Hard" Signs		
Vascular	**Oesophageal**	**Respiratory**
• Rapidly expanding or pulsatile hematoma • Severe hemorrhage or uncontrollable bleeding • Shock refractory to fluid resuscitation • Decreased or absent pulse • Vascular bruit or thrill • Neurologic deficit (suggestive of cerebral ischemia)	• Significant hematemesis	• Respiratory distress • Massive haemoptysis • Massive subcutaneous emphysema • Air bubbling through wound
"Soft" Signs		
• Stable haematoma • Hoarseness • Dysphagia • Mild subcutaneous emphysema • Minor haematemesis/haemoptysis		

TABLE 2: Study Characteristics

Author	Year	Study Design	Methods	Results
Inaba et al.[16]	2006	• Prospective single centre cohort • 16 months • Level 1 trauma centre	• 106 patients	• Immediate exploration in 15 patients, MCTA in 91 patients • 12/91 MCTA patients truly positive and taken to theatre • No missed injuries • CTA sensitivity 100% and specificity 93.5%
Osborn et al.[18]	2008	• Retrospective single centre cohort • 5 years • Level 1 trauma centre	• 134 patients • 69 patients excluded (including those not penetrating the platysma) • 65 final participants	• No CT-A in 41 patients, CT-A in 24 patients • 42% negative exploration rate • CTA routinely used in stable patients in 2003, resulting in reduction in negative exploration rates • 1 missed injury on CTA (external jugular vein) – not bleeding at time of CTA
Inaba et al.[15]	2012	• Prospective multicenter cohort • 2.5 years • Level 1 trauma centres	• 453 patients • Inclusion criteria: > 16yrs, penetrating injury mechanism, injury site bounded above by inferior border of mandible and occipital bone, and below by the suprasternal notch anteriorly and the seventh cervical vertebra posteriorly	• 39 patients with hard signs underwent immediate exploration, 189 asymptomatic patients observed and 225 patients with soft signs had MDCTA • 100% sensitivity and 97.5% specificity of MDCTA for detecting vascular or aerodigestive injuries • No missed injuries
Schroll et al.[3]	2015	• Retrospective single centre cohort • 4 years • Level I trauma centre	• 597 records reviewed • 414 excluded (not zone II injuries) • 135 excluded (nil hard signs) • 48 participants	• 22 underwent immediate exploration, 23 underwent CTA and 3 died prior to evaluation • 83% sensitivity and 100% specificity of CTA in determining which patients with hard signs required neck exploration

			• Inclusion criteria: injuries in zone II that penetrated the platysma, > 18 years of age, alive on arrival, complete charts	• Significantly higher number of patients requiring neck exploration in immediate exploration group, compared to CTA group (p=0.017) • Number of negative neck explorations significantly reduced with CTA (p<0.001) • No significant difference in missed injury rate between neck exploration and CTA groups
Prichayudh et al.[14]	2015	• Retrospective single centre cohort • 10 years • Level I trauma centre	• 86 patients	• 36 with hard signs, 26 with soft signs and 24 asymptomatic • CTA sensitivity 100%, specificity 61%, PPV 30%, NPV 100% • No missed injuries • Data supports “no zone” approach
Madsen et al.[21]	2018	• Retrospective single centre cohort • 4 years • Major trauma centre	• 510 patients • 130 excluded (CT-A not used or not the initial investigation) • 380 final participants	• CTA sensitivity 94%, specificity 97%, PPV 89%, NPV 99% • 8 CTAs falsely positive and 4 falsely negative (three had delayed pseudoaneurysm and one had a non-bleeding injury found whilst exploring for oesophageal injury) • Supports CTA for all gunshot wounds and selective management for stab wounds
Ibraheem et al.[19]	2018	• Retrospective single centre cohort • 8 years • Level I trauma centre	• 337 patients • Inclusion criteria: isolated neck trauma, > 18yrs, alive on arrival, complete charts	• 82 with hard signs, 156 with soft signs and 99 asymptomatic • No significant difference in rates of therapeutic neck exploration between zones • No missed injuries or delayed complications • Proposed “no zone” approach algorithm based on symptoms to reduce non-therapeutic exploration rates
Borsetto et al.[17]	2019	• Retrospective single centre cohort • 6 years	• 157 records	• All patients underwent MDCT and neck exploration • Reduced negative neck exploration rates with introduction of CT-A in those with soft signs

		• Major trauma centre	• 90 excluded (no MDCT, no neck exploration or unavailable CT for analysis) • 67 participants	• CT-A plus physical examination increased specificity of vascular injuries requiring intervention
Hundersmarck et al.[20]	2019	• Retrospective multicenter cohort • 9 years • Two level I trauma centres	• 43 patients	• 29 patients haemodynamically stable – all underwent CTA • 12 haemodynamically unstable – 6 proceeded to exploration due to non-response to resuscitation • 2 patients excluded because haemodynamically unstable secondary to thoraco-abdominal injuries, not neck • No missed injuries or delayed complications

TABLE 3: Rates of negative neck exploration in CT-A vs non CT-A groups

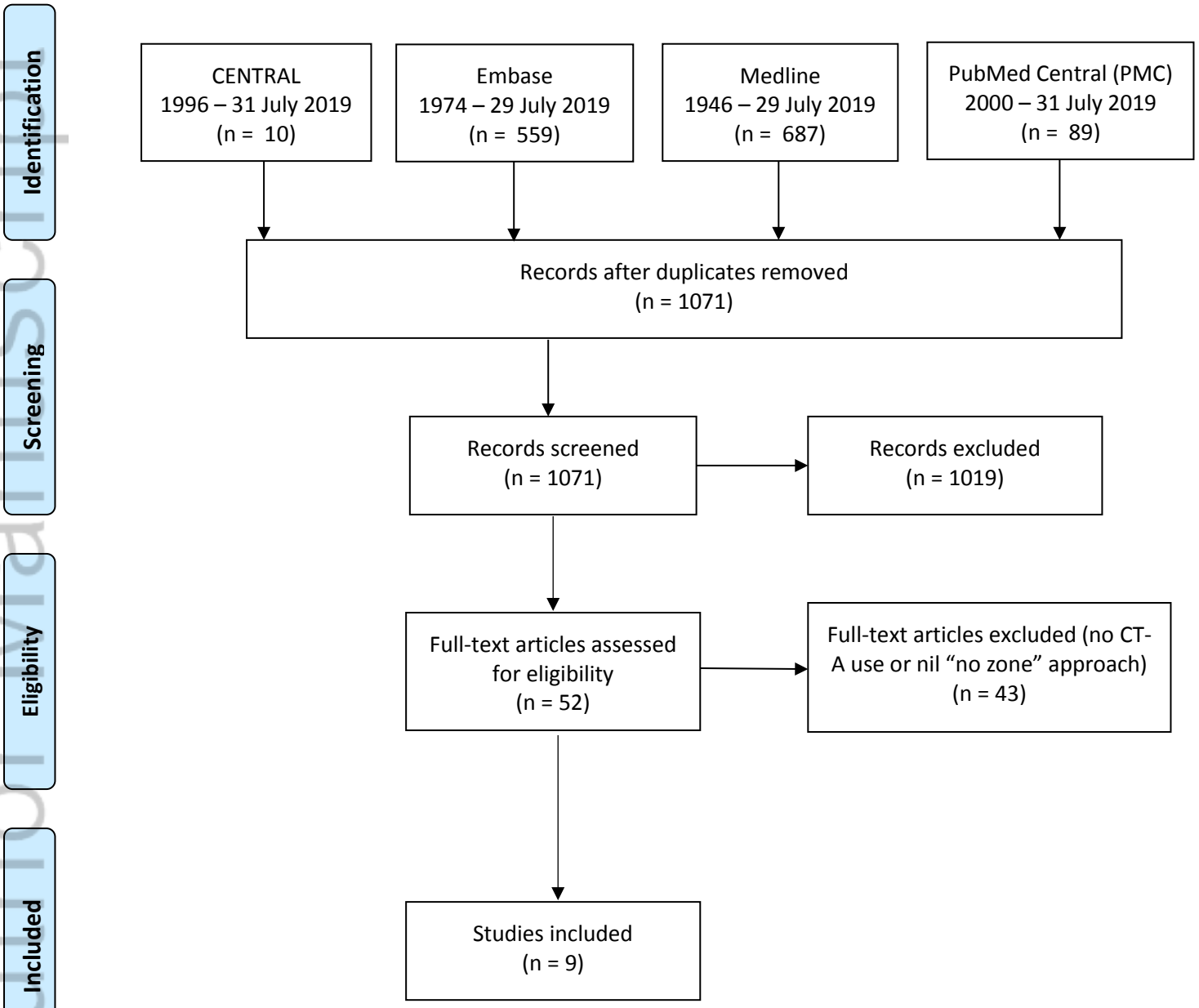
	CT-A			**No CT-A**		
Study	Participants	Neck explorations	Negative neck explorations	Participants	Neck explorations	Negative neck explorations
Osborn et al.[18]	24	6	0 (0%)	41	27	13 (48%)
Prichayudh et al.[14]	21	5	1 (20%)	60	36	2 (6%)
Schroll et al.[3]	23	6	0 (0%)	22	22	8 (36%)
Ibraheem et al.[19]	223	28	14 (50%)	114	94	35 (37%)
Hundersmarck et al.[20]	29	14	4 (29%)	9	9	0 (0%)

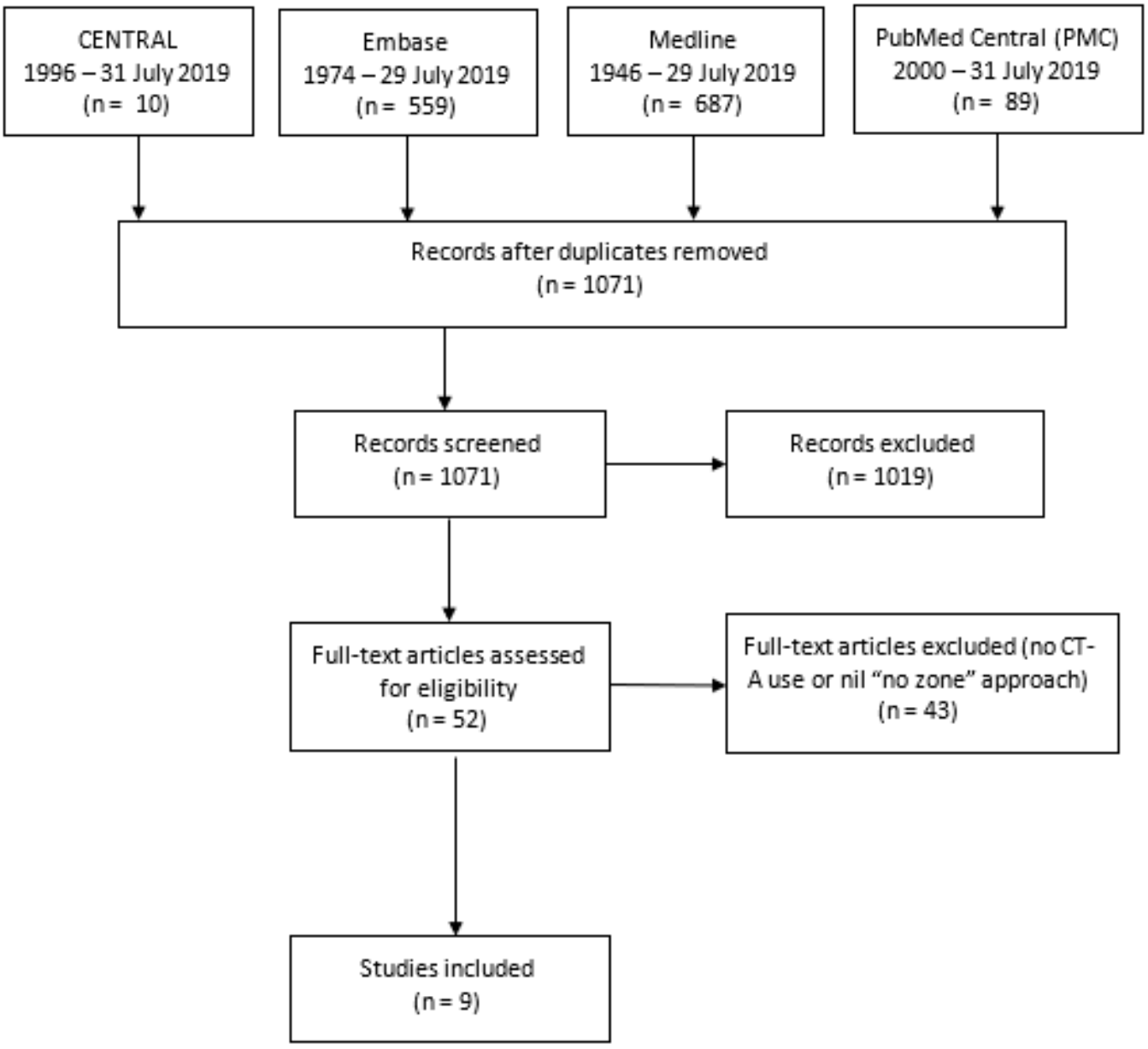
TABLE 4: CT-A sensitivity and specificity

Study	**Inclusion criteria**	**Patients evaluated with CTA**	**CTA Sensitivity**	**CTA Specificity**
Inaba et al.[16]	Soft signs and asymptomatic; all zones	91 (85.8%)	100%	93.5%
Inaba et al.[15]	Soft signs only; all zones	225 (49.7%)	100%	97.5%
Prichayudh et al.[14]	Soft signs only; all zones	21 (24.4%)	100%	61%
Schroll et al.[3]	Hard signs only; zone 2 only	23 (48%)	83%	100%
Madsen et al.[21]	Hard signs, soft signs, asymptomatic; all zones	380 (74.5%)	93.9%	97.5%

FIGURES

FIGURE 1: Methodology Flowchart





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