Diagnostic Performance of Computed Tomography Angiography in Peripheral Arterial Injury due to Trauma: A Systematic Review and Meta-analysis

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WHAT THIS PAPER ADDS
CTA is a highly accurate diagnostic tool for detecting arterial injury of the extremities due to trauma. Trauma centers with the availability of a CT scanner in or close by the emergency room can perform a CTA to detect or exclude arterial injury of the extremity. Digital subtraction angiography should be reserved for interventions or if CTA is non-diagnostic or inconclusive in patients with suspicion of arterial trauma of the extremity.

Objectives: To evaluate the diagnostic accuracy of computed tomography angiography (CTA) in detecting arterial lesions in patients with suspected arterial injury of the upper or lower extremity due to trauma.

Methods: A systematic review and meta-analysis was carried out. Medline and Embase were searched on August 13, 2012, for studies comparing CTA with surgery, digital subtraction angiography (DSA), or follow-up, which allowed extraction of data into two-by-two tables. The methodological quality of included studies was assessed using the QUADAS tool. Summary estimates of sensitivity and specificity of CTA in identifying or excluding arterial lesions were obtained using a bivariate model.

Results: This review included 11 studies making up a total of 891 trauma patients. The included studies were of moderate methodological quality and at risk of misclassification and verification bias. Some 4.2% of all CTA studies were non-diagnostic. The summary estimates of sensitivity and specificity of CTA were 96.2% (95% CI 93.5—97.8%) and 99.2% (95% CI 96.8—99.8%), respectively.

Conclusion: Despite methodological flaws, the excellent estimates of sensitivity and specificity indicate that CTA is an accurate modality for evaluating arterial lesions in patients with extremity trauma and can replace DSA.

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Keywords: Computed tomography angiography, Peripheral arterial injury, Systematic review, Meta-analysis

INTRODUCTION
Trauma can cause severe arterial injuries to the extremities, and these injuries require immediate diagnostic work-up. While in some cases massive bleeding will require prompt surgical exploration, in most patients there is time for evaluation with radiological imaging to define a treatment strategy. Until recently, intra-arterial digital subtraction angiography (DSA) was the modality of choice in evaluating patients with suspicion of vascular injury. However, because of its widespread availability, computed tomography angiography (CTA) is rapidly replacing DSA for the diagnostic work-up of patients with vascular trauma.

Before CTA can be universally implemented, it needs to be established in methodologically sound studies that CTA is sufficiently accurate in evaluating patients with suspected arterial injury due to trauma.

In a recent systematic review, CTA was found to be accurate in evaluating suspected peripheral arterial injury, with reported sensitivities between 95% and 100% and specificities between 87% and 100%. However, the interpretation of these outcomes is difficult, as assessment of methodological quality for the included studies and meta-analysis was not performed.

Our aim was to perform a systematic review, with assessment of methodological quality, and a meta-analysis to obtain the best available estimates of the diagnostic performance of CTA in patients with peripheral arterial injury in an emergency setting.

MATERIALS AND METHODS
This review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The review protocol was not published or registered in advance.
Eligibility criteria

Types of studies. Original diagnostic study designs including 10 or more patients. No restrictions to language or publication date were applied.

Types of patients. Patients with suspected or known peripheral arterial injury due to trauma without restrictions to age.

Types of imaging/reference. CTA performed with subsequent DSA, surgery, or follow-up as reference standard.

Types of outcome measures. Presence or absence of an arterial lesion of the upper or lower extremity. For studies to be included in this review it must be possible to construct two-by-two contingency tables to compare CTA with DSA, surgery, or follow-up as a reference standard.

Duplicate studies were excluded from this review.

Information sources

Studies were identified by searching the electronic databases Medline (PubMed) and OVID Embase 1980 to present. The last search was performed on August 13, 2012. The literature search was conducted by one of the authors (M.K.K.) with the assistance of a clinical librarian.

Search strategy

The search strategy for Medline consisted of three components, with search terms defined for each component, i.e. (1) peripheral vascular injury, (2) computed tomography, and (3) angiography or surgery. Databases were searched by combining the search terms using ‘OR’, and by combining the three components using ‘AND’.

The search of Embase consisted of two components, i.e. (1) peripheral vascular injury and (2) computed tomography. The searches in both databases were checked for completeness by verifying whether previously assessed potential relevant articles were found. Search terms of missed articles were identified and added to the search strategy until all previously acquired relevant articles were identified. Details of the search strategy are provided in the electronic Supplementary Material, Appendix 1.

Study selection

Two authors (S.J. and M.K.K.) independently assessed the title and abstract of the identified articles for eligibility according to our eligibility criteria, in an unblinded standardized manner. After this initial selection, the full texts of the potentially eligible articles were retrieved and assessed for eligibility by the same authors. Discrepancies between the authors for eligibility were resolved by discussion. The reasons for exclusion were recorded for all of the excluded full-text articles. Potentially missed relevant articles were identified by checking the reference lists of the included articles.

Data extraction

A data extraction sheet was developed based on several included studies. Two authors (S.J. and M.K.K.) extracted the required data independently from the included articles using the data extraction sheet. Disagreements were resolved by discussion between the two authors.

The following data were extracted: (1) study design; prospective/retrospective and consecutive/non-consecutive series of patients, (2) characteristics of study patients; number of patients, age, gender, location and type of injury (i.e. upper or lower extremity and blunt or penetrating trauma), (3) CTA characteristics; number of slices, slice thickness, reconstructions performed, and number of observers, (4) type of reference standard, and (5) outcome measures: arterial lesion versus no arterial lesion according to CTA and reference test, number of non-diagnostic CTAs and interobserver agreement of CTA. An arterial lesion was defined as an occlusion, luminal narrowing, dissection, bleeding, pseudoaneurysm, or arteriovenous fistula. An arterial spasm was not regarded as an arterial lesion, since patients with arterial spasms are managed expectantly and mostly recover without intervention, and spasms can be induced by DSA. If CTA data of multiple observers were presented, the mean outcome of these observers was recorded.

Methodological quality and risk of bias in individual studies

The methodological quality and potential bias of the included studies were assessed independently by two authors (S.J. and M.K.K.). We used the Quality Assessment of Diagnostic Accuracy Studies (QUADAS) tool,5 which was developed for use in systematic reviews to assess quality of diagnostic accuracy studies. In total, 11 QUADAS items were assessed: (1) adequateness of inclusion and exclusion criteria; (2) avoidance of misclassification bias, scored as ‘adequate’ if only surgery or DSA was performed as a reference test; avoidance of (3) partial verification and (4) differential verification bias; adequateness of the description of the (5) CTA and (6) DSA procedure, scored as ‘adequate’ if the DSA or follow-up procedure was described; avoidance of review bias in the assessment of (7) CTA imaging or (8) the reference test (i.e. the observers blinded to the outcome according to the other index or reference test); (9) were clinical data adequately available for the observers; and were all (10) CTA scans and (11) patients used for analysis, with uninterpretable scans or missing patients explained.

Each item of the methodological quality was scored as adequate (‘yes’), inadequate (‘no’), or not reported (‘unclear’). Disagreements were resolved by discussion between the two review authors.

Summary measures

The primary outcome measures were summary estimates of sensitivity and specificity of CTA in detecting arterial lesions. A secondary outcome measure was the interobserver agreement in assessing arterial lesions on CTA.

Planned methods of analysis

For each study we constructed two-by-two contingency tables for CTA compared with the reference standard showing the true-positive (TP), false-positive (FP), false-negative (FN), and true-negative (TN) results. We
calculated sensitivity as $\frac{TP}{FN + TP}$ and specificity as $\frac{TN}{FP + TN}$. For both the sensitivity and specificity criteria, data were pooled universally and by subgroup, i.e. outcome on 16- to 64-slice CT scanner, one- to four-slice CT scanner, upper extremity, lower extremity, blunt trauma, and penetrating trauma. Data were only pooled if at least five studies were available, and depending on whether statistical inconsistency was absent. Since in the relevant source articles patients were included based on the suspicion of one or multiple arterial lesion(s), both per-patient and per-lesion analysis could be used in this review to assess sensitivity and specificity. For pooling of the study results, per-patient analysis was preferred over per-lesion analysis if both data types were available.

Statistical heterogeneity was assessed with the $I^2$ statistic. The $I^2$ statistic is a measure of inconsistency describing the percentage of total variation between studies due to heterogeneity. If an $I^2$-value was larger than 50%, data would not be pooled because of heterogeneity. If both $I^2$-values for sensitivity and specificity were less than 50%, data were pooled using a bivariate statistical model, resulting in summary estimates of sensitivity and specificity with 95% CIs. In a bivariate model, studies with a more precise estimate of sensitivity or specificity are given a higher weight in the meta-analysis. In cases where FN or TN results were absent a value of 0.05 was used instead of zero to calculate the ln(DOR).

RESULTS

Study selection

Our initial search yielded 584 articles, 406 in Medline and 178 in Embase. After removal of duplicate articles, 534 articles remained. Titles and abstracts of these articles were screened, and 506 articles were excluded because eligibility criteria were not met. The full text of 28 articles was examined in more detail. Of these, 17 articles were excluded; seven were not diagnostic studies, five did not perform a CTA or reference test, and a further five did not contain data from which it was possible to construct a two-by-two contingency table. A total of 11 studies were finally included in this review. Checking the reference lists of the 11 included articles did not result in retrieval of additional relevant articles. See flow diagram in Fig. 1.

![Flow diagram of search and study selection](Image)

**Figure 1.** Flow diagram of search and study selection. CTA = computed tomography angiography.
## Table 1. Study characteristics of included studies.

<table>
<thead>
<tr>
<th>Source</th>
<th>Design</th>
<th>Number of patients</th>
<th>Number of males (%)</th>
<th>Age, mean (SD) or (range)</th>
<th>Extremity injury</th>
<th>Number of slices CT scanner</th>
<th>Slice thickness</th>
<th>Reconstructions done</th>
<th>Reference standard when CTA positive</th>
<th>Reference standard when CTA negative</th>
<th>Assessment of lesion (per patient/per lesion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soto 1999⁹</td>
<td>Prospective</td>
<td>45</td>
<td>42 (93)</td>
<td>26.2 (16–56)</td>
<td>Upper and lower</td>
<td>1</td>
<td>1.0 mm</td>
<td>MIP and SSD</td>
<td>DSA</td>
<td>DSA</td>
<td>Per patient</td>
</tr>
<tr>
<td>Soto 2001¹⁰</td>
<td>Prospective</td>
<td>139</td>
<td>120 (86)</td>
<td>28.6 (16–77)</td>
<td>Upper and lower</td>
<td>1</td>
<td>1.0 mm</td>
<td>MIP, VRT, MPR and SSD</td>
<td>Surgery, DSA</td>
<td>Surgery, FU</td>
<td>Per-lesion</td>
</tr>
<tr>
<td>Busquéts 2004¹¹</td>
<td>Retrospective</td>
<td>95</td>
<td>82 (86)</td>
<td>31.0 (5.6)</td>
<td>Upper and lower</td>
<td>NA</td>
<td>1.0 mm</td>
<td>MIP, VRT, CPR and SSD</td>
<td>Surgery, DSA</td>
<td>DSA, FU</td>
<td>Both</td>
</tr>
<tr>
<td>Joshi 2004¹²</td>
<td>Retrospective</td>
<td>23</td>
<td>NA</td>
<td>NA</td>
<td>Upper and lower</td>
<td>4</td>
<td>2.5 mm</td>
<td>MIP, VRT and SSD</td>
<td>Surgery</td>
<td>FU</td>
<td>Per patient</td>
</tr>
<tr>
<td>Inaba 2006¹³</td>
<td>Retrospective</td>
<td>59</td>
<td>51 (86)</td>
<td>37.0 (10–79)</td>
<td>Lower</td>
<td>4</td>
<td>1.6 mm</td>
<td>3D reconstruction</td>
<td>Surgery, DUS, FU</td>
<td>DSA, DUS, FU</td>
<td>Both</td>
</tr>
<tr>
<td>Rieger 2006¹⁴</td>
<td>Retrospective</td>
<td>87</td>
<td>71 (82)</td>
<td>37.0 (NA)</td>
<td>Upper and lower</td>
<td>4</td>
<td>0.8 mm</td>
<td>VRT and MPR</td>
<td>Surgery, DSA</td>
<td>Surgery, FU</td>
<td>Per lesion</td>
</tr>
<tr>
<td>Iezzi 2007¹⁵</td>
<td>Retrospective</td>
<td>47</td>
<td>29 (62)</td>
<td>38.6 (18–78)</td>
<td>Upper and lower</td>
<td>4</td>
<td>1.5 mm</td>
<td>MIP, VRT and MPR</td>
<td>Either surgery, DSA, FU</td>
<td>Either surgery, DSA, FU</td>
<td>Per patient</td>
</tr>
<tr>
<td>Hogan 2009¹⁶</td>
<td>Retrospective</td>
<td>32</td>
<td>NA</td>
<td>NA (0–18)</td>
<td>Upper and lower</td>
<td>4</td>
<td>1.6 mm</td>
<td>3D reconstruction</td>
<td>Either surgery, imaging or FU</td>
<td>Either surgery, imaging or FU</td>
<td>Per lesion</td>
</tr>
<tr>
<td>Seamon 2009¹⁷</td>
<td>Prospective</td>
<td>21</td>
<td>19 (90)</td>
<td>26.1 (18–50)</td>
<td>Upper and lower</td>
<td>64 or 16</td>
<td>0.75 mm</td>
<td>3D reconstruction</td>
<td>Surgery, DSA</td>
<td>Surgery, DSA</td>
<td>Per lesion</td>
</tr>
<tr>
<td>Foster 2011¹⁸</td>
<td>Retrospective</td>
<td>284</td>
<td>217 (76)</td>
<td>40.0 (16–89)</td>
<td>Lower</td>
<td>64</td>
<td>0.625 mm</td>
<td>MPR</td>
<td>Surgery</td>
<td>FU</td>
<td>Per patient</td>
</tr>
<tr>
<td>Inaba 2011¹⁹</td>
<td>Prospective</td>
<td>73</td>
<td>64 (88)</td>
<td>30.3 (12.7)</td>
<td>Upper and lower</td>
<td>64</td>
<td>1.0 mm</td>
<td>MIP, VRT and CPR</td>
<td>Surgery, DSA</td>
<td>DSA, DSA</td>
<td>Both</td>
</tr>
</tbody>
</table>

*Note.* CPR = curved-planar reforma; CTA = computed tomography angiography; DSA = digital subtraction angiography; DUS = duplex ultrasound; FU = follow-up; MIP = maximum intensity projection; MPR = multiplanar reformation; NA = not available; SSD = shaded surface display; VRT = volume-rendered technique.

*¹ Ten (Busquéts et al.¹¹) and four (Inaba et al.¹³) patients did not have a reference test.*
**Study characteristics**

**Patients.** All included studies were published in English, and four of these were prospective studies.9,10,17,19 In total, 905 patients were included in the studies with a median of 59 patients (range 21–284). The proportion of males was 82%, with gender not reported in two studies.12,16 One study16 focused on arterial injuries in 32 children (age range 0–18 years). Nine studies9–12,14–17,19 assessed arterial injuries of both the upper and lower extremity and two13,18 assessed arterial injuries of the lower extremity only. In two studies, a reference standard was not available for a subset of patients (10 and 4 patients, respectively).11,13 Detailed study characteristics are shown in Table 1.

**CTA and reference test.** The type of CT scanner varied between single and 64-slice scanners. The CT images had a median slice thickness of 1.000 mm (range 0.625–2.500 mm). All studies obtained three-dimensional CTA reconstructions. Other reconstructions performed were maximum-intensity projections, volume-rendered techniques, multiplanar reformations, and shaded surface displays. The reference tests varied among surgery, imaging (i.e. DSA, duplex ultrasound, or magnetic resonance angiography), and clinical follow-up. Detailed study characteristics are shown in Table 1.

**Outcomes.** The primary outcome was arterial lesions on a per-patient basis in five studies.9,12,15,16,18 Three studies11,13,19 assessed CTA outcome per patient and per lesion, and the remaining three studies10,14,17 assessed arterial lesions on a per-lesion basis.

**Methodological quality and risk of bias in individual studies**

The overall quality of the studies according to the QUADAS tool was moderate. The prospective studies9,10,17,19 had relatively little risk of bias, while the retrospective studies11–16,18 had a higher risk of incorporated bias.

Inclusion and exclusion criteria were clearly reported in five studies.9,10,14,17,19 The risk of partial verification bias was avoided in all prospective studies,9,10,14,17,19 but not in any of the retrospective studies.11–16,18 One study9 avoided the risk of differential verification bias and three studies9,15,17 clearly described the DSA or follow-up procedure. The methodological quality of individual studies is presented in Fig. 2 and overall results in Fig. 3.

**Syntheses of results**

**All included studies.** Outcomes for CTA detection of arterial lesions due to trauma, compared with a reference test, were available for 891 patients in all 11 included articles. For 644 (72%) of these patients, outcomes could be analyzed on a per-patient basis. Of the remaining 247 (28%) patients, 263 potential arterial lesions were available for analysis, resulting in a total of 907 outcomes of CTA that were eligible for our meta-analysis. CTA was non-diagnostic in 38 (4.2%) cases of these 907 outcomes.

Inconsistency between these studies due to heterogeneity ($I^2$) was 0% for sensitivity and 47% for specificity. Analysis using the mixed effects model resulted in a summary estimate of sensitivity of 96.2% (95% CI, 93.5–97.8%) and specificity of 99.2% (95% CI, 96.8–99.8%). Excluding studies of Busquets et al.11 and Hogan et al.16 for analysis due to poor methodological quality did not have a significant effect on the summary estimates, i.e. a sensitivity of 96.1% (95% CI, 93.1–97.8%) and specificity of 98.9% (95% CI, 96.2–99.7%). The results and meta-analysis of the included individual studies are provided in Table 2 and Fig. 4.

**Publication bias.** Linear regression analysis showed a non-significant ($p = .73$) regression coefficient of 3.2 (95% CI –17.1 to 23.6). A funnel plot of the natural logarithm of the diagnostic odds ratio plotted against the sample size per study is presented in Fig. 5. The analysis and plot indicate that there is no publication bias.
Subgroup analyses. Meta-analysis was performed for the one- to four-slice CT scanner subgroup.9,10,12–16 Because of insufficient data, meta-analyses of results for the subgroups 16- to 64-slice CT scanner, upper extremity trauma, lower extremity trauma, blunt trauma, and penetrating trauma were not performed.

One- to four-slice CT scanner. Suspected arterial lesions were evaluated by a single- or four-slice CT scanner in 443 cases. Of these CTAs, eight (1.8%) were non-diagnostic. Analysis using the fixed-effects model resulted in a summary estimate of sensitivity ($I^2 = 0$%) of 95.4% (95% CI, 91.7–97.5%) and specificity ($I^2 = 0$%) of 97.2% (95% CI, 94.0–98.7%). Excluding Hogan et al.16 for the analysis due to poor methodological quality resulted in a sensitivity of 95.7% (95% CI, 91.9–97.7%) and specificity of 96.9% (95% CI, 93.4–98.6%). The results and meta-analysis of the one- to four-slice CT scanner subgroup are presented in Table 3 and Fig. 6.

Other subgroups. Three studies reported outcomes for the 16- to 64-slice CT scanner subgroup17–19 and lower extremity trauma12,13,18 subgroups. Of the CTAs performed in the 16- to 64-slice CT scanner subgroup 30 (7.9%) were non-diagnostic. See Table 3 for the results of the 16- to 64-slice CT scanner and lower extremity trauma subgroups. For subgroups upper extremity trauma,12 blunt trauma,16 and penetrating16 trauma only one study reported an outcome specifically for these subgroups. Data for these subgroups are not shown.

Reproducibility. Interobserver agreement of CTA outcome was provided by four studies.9,10,14,15 In these studies the Cohen kappa coefficient ranged from 0.89 to 1.00 (Table 2).

DISCUSSION

Summary of evidence

This meta-analysis shows that CTA compared with the reference standard DSA, surgery or follow-up is an accurate diagnostic tool for detecting arterial injury of the extremities due to trauma, with a sensitivity of 96.2% and specificity of 99.2%. CTA is non-diagnostic in 4.2% of the patients evaluated for suspected arterial injury and has a high interobserver agreement. The methodological quality of the included studies was

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**Table 2. Results and meta-analysis of the included individual studies.**

<table>
<thead>
<tr>
<th>Study</th>
<th>TP</th>
<th>FP</th>
<th>FN</th>
<th>TN</th>
<th>Non-diagnostic</th>
<th>Sensitivity in % (95% CI)</th>
<th>Specificity in % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soto 1999</td>
<td>18</td>
<td>0</td>
<td>1</td>
<td>24</td>
<td>2 (4.4%)</td>
<td>0.90</td>
<td>95 (74, 100)</td>
</tr>
<tr>
<td>Soto 2001</td>
<td>58</td>
<td>1</td>
<td>3</td>
<td>75</td>
<td>5 (3.5%)</td>
<td>1.00</td>
<td>95 (86, 99)</td>
</tr>
<tr>
<td>Busquéts 2004</td>
<td>23</td>
<td>0</td>
<td>0</td>
<td>62</td>
<td>0 (0%)</td>
<td>NA</td>
<td>100 (85, 100)</td>
</tr>
<tr>
<td>Joshi 2004</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0 (0%)</td>
<td>NA</td>
<td>100 (75, 100)</td>
</tr>
<tr>
<td>Inaba 2006</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>34</td>
<td>1 (1.8%)</td>
<td>NA</td>
<td>100 (83, 100)</td>
</tr>
<tr>
<td>Rieger 2006</td>
<td>63</td>
<td>6</td>
<td>1</td>
<td>29</td>
<td>0 (0%)</td>
<td>0.91/0.92/0.95</td>
<td>98 (92, 100)</td>
</tr>
<tr>
<td>Iezzi 2007</td>
<td>26</td>
<td>2</td>
<td>1</td>
<td>18</td>
<td>0 (0%)</td>
<td>0.89</td>
<td>96.0 (81, 100)</td>
</tr>
<tr>
<td>Hogan 2009</td>
<td>11</td>
<td>1</td>
<td>0</td>
<td>20</td>
<td>0 (0%)</td>
<td>NA</td>
<td>100 (72, 100)</td>
</tr>
<tr>
<td>Seamon 2009</td>
<td>10</td>
<td>0</td>
<td>1</td>
<td>11</td>
<td>1 (4.5%)</td>
<td>NA</td>
<td>100 (69, 100)</td>
</tr>
<tr>
<td>Foster 2011</td>
<td>42</td>
<td>2</td>
<td>0</td>
<td>218</td>
<td>22 (7.7%)</td>
<td>NA</td>
<td>100 (92, 100)</td>
</tr>
<tr>
<td>Inaba 2011</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>44</td>
<td>7 (9.6%)</td>
<td>NA</td>
<td>100 (85, 100)</td>
</tr>
<tr>
<td>Meta-analysis</td>
<td>306</td>
<td>12</td>
<td>6</td>
<td>545</td>
<td>38 (4.2%)</td>
<td>0.89–1.00</td>
<td>96.2 (93.5, 97.8)</td>
</tr>
</tbody>
</table>

*Note.* The forest plot shows individual and pooled estimates for diagnostic sensitivity and specificity. FN = false negative; FP = false positive; $k$ = kappa (interobserver agreement); TN = true negative; TP = true positive.

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**Figure 4.** Summary estimate and per study sensitivity and specificity of all included studies.
moderate and there were no indications of publication bias. No randomized controlled trials were included.

Implications for practice

The main advantage of performing CTA instead of DSA is the time gained to adequate treatment. Performing DSA requires several logistical steps, such as arranging transfer of the patient, assembling an angiography team, and preparing an angiosuite. This takes about 2 hours on average, which is a considerable delay from presentation to the final diagnosis with DSA. If a CT scanner is available in the emergency room, a CTA can be performed within several minutes and the operating room can be entered much sooner than with pre-interventional DSA. The time gained by a diagnostic work-up with CTA can be critical for the patient in terms of limb salvage and function. However, improved outcome, in terms of limb salvage or better function by performing a CTA instead of DSA has not yet been shown by prospective studies.

Other advantages of CTA over DSA are that CTA can depict the surrounding structures of the arterial lesion, which may be important for the trauma and vascular surgeons to compose a treatment strategy. Moreover, by performing CTA, potential complications from DSA such as arterial dissection, groin hematoma, puncture site bleeding, and thrombosis are avoided.

CTA for peripheral arterial trauma also has some disadvantages. A possibility that has to be considered during the interpretation of CTA is that it can mistake a spasm for an occlusion, which could lead to unnecessary interventions. Furthermore, for some patients arterial lesions can be better treated endovascularly, e.g. coiling of an artery, which can immediately be performed during DSA.

Limitations of this study

The methodological quality of the included studies was moderate and many were at risk of misclassification or verification bias. Most studies used surgery or DSA as a reference standard when CTA was positive, but followed up the patients only when CTA was negative. Arterial lesions missed by CTA (false negatives), which would directly have been identified with surgery or DSA, could also be missed by using follow-up as a reference standard. Thereby, the lesion will be misidentified as a true negative, and will result in an overestimation of specificity. However, if CTA identified the arterial lesion, surgery or DSA was more likely to be performed, resulting in an overestimation of sensitivity. It is

Table 3. Subgroup results and meta-analysis.

<table>
<thead>
<tr>
<th>Study</th>
<th>TP</th>
<th>FP</th>
<th>FN</th>
<th>TN</th>
<th>Non-diagnostic</th>
<th>Sensitivity in % (95% CI)</th>
<th>Specificity in % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–4 CT slices</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soto 1999\textsuperscript{9}</td>
<td>18</td>
<td>0</td>
<td>1</td>
<td>24</td>
<td>2</td>
<td>(4.4%)</td>
<td>95 (74, 100)</td>
</tr>
<tr>
<td>Soto 2001\textsuperscript{10}</td>
<td>58</td>
<td>1</td>
<td>3</td>
<td>75</td>
<td>5</td>
<td>(3.5%)</td>
<td>95 (86, 99)</td>
</tr>
<tr>
<td>Joshi 2004\textsuperscript{12}</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>(0%)</td>
<td>100 (75, 100)</td>
</tr>
<tr>
<td>Inaba 2006\textsuperscript{13}</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>34</td>
<td>1</td>
<td>(1.8%)</td>
<td>100 (83, 100)</td>
</tr>
<tr>
<td>Rieger 2006\textsuperscript{14}</td>
<td>63</td>
<td>6</td>
<td>1</td>
<td>29</td>
<td>0</td>
<td>(0%)</td>
<td>98 (92, 100)</td>
</tr>
<tr>
<td>Iezzi 2007\textsuperscript{15}</td>
<td>26</td>
<td>2</td>
<td>1</td>
<td>18</td>
<td>0</td>
<td>(0%)</td>
<td>96 (81, 100)</td>
</tr>
<tr>
<td>Hogan 2009\textsuperscript{16}</td>
<td>11</td>
<td>1</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>(0%)</td>
<td>100 (72, 100)</td>
</tr>
<tr>
<td>Meta-analysis</td>
<td>209</td>
<td>10</td>
<td>6</td>
<td>210</td>
<td>8</td>
<td>(1.8%)</td>
<td>95.4 (91.7, 97.5)</td>
</tr>
<tr>
<td>16–64 CT slices</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seamon 2009\textsuperscript{17}</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>1</td>
<td>(4.5%)</td>
<td>100 (69, 100)</td>
</tr>
<tr>
<td>Foster 2011\textsuperscript{18}</td>
<td>42</td>
<td>2</td>
<td>0</td>
<td>218</td>
<td>22</td>
<td>(7.7%)</td>
<td>100 (92, 100)</td>
</tr>
<tr>
<td>Inaba 2011\textsuperscript{19}</td>
<td>22</td>
<td>2</td>
<td>0</td>
<td>44</td>
<td>7</td>
<td>(9.6%)</td>
<td>100 (85, 100)</td>
</tr>
<tr>
<td>Total</td>
<td>74</td>
<td>2</td>
<td>0</td>
<td>273</td>
<td>30</td>
<td>(7.9%)</td>
<td>NA</td>
</tr>
<tr>
<td>Lower extremity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joshi 2004\textsuperscript{12}</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>(0%)</td>
<td>100 (72, 100)</td>
</tr>
<tr>
<td>Inaba 2006\textsuperscript{13}</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>34</td>
<td>1</td>
<td>(1.8%)</td>
<td>100 (83, 100)</td>
</tr>
<tr>
<td>Foster 2011\textsuperscript{18}</td>
<td>42</td>
<td>2</td>
<td>0</td>
<td>218</td>
<td>22</td>
<td>(7.7%)</td>
<td>100 (92, 100)</td>
</tr>
<tr>
<td>Total</td>
<td>73</td>
<td>2</td>
<td>0</td>
<td>258</td>
<td>23</td>
<td>(6.5%)</td>
<td>NA</td>
</tr>
</tbody>
</table>

Note. The forest plot shows individual and pooled estimates for diagnostic sensitivity and specificity. FN = false negative; FP = false positive; $\kappa$ = kappa (interobserver agreement); NA = not assessed; TN = true negative; TP = true positive.
uncertain whether overestimation of both sensitivity and specificity due to verification bias is clinically relevant. False-negative CTAs would not have resulted in severe complications, as shown by follow-up, but the false-positive CTAs could result in unnecessary surgical or endovascular intervention.

The sensitivity and specificity in this meta-analysis should also be interpreted with caution. Non-diagnostic studies were not included in the analysis, resulting in an overestimation of sensitivity and specificity. It is striking that studies with lower resolution CT scanners (1–4 slices) had a non-diagnostic study rate of 1.8%, whereas studies with higher resolution CT scanners (16–64 slices) had a 7.9% non-diagnostic rate. One would expect this to be the opposite, since CT scanners with a higher number of CT slices usually result in images of higher quality. An explanation may be that the studies using a 16- to 64-slice CT scanner are of a higher methodological standard; 67% of the 16- to 64-slice studies were prospective and published between 2009 and 2011, while only 25% of the one- to four-slice CT studies were prospective and published between 1999 and 2007.

Effects of each methodological characteristic on the diagnostic outcome values, such as sensitivity analysis, could not be evaluated due to the limited number of included studies. Moreover, performing subgroup analysis was not possible for every subgroup, i.e. 16- to 64-slice CT scanner, upper extremity trauma, blunt trauma, and penetrating trauma subgroup. The number of included studies was low and the sample sizes were small, and patient and study characteristics were not always available.

The results of this meta-analysis are in line with the outcome reported in the systematic review by Patterson et al.\(^3\) Patterson et al. included three articles which were excluded in this meta-analysis, since two-by-two contingency tables could not be constructed for two of these, and the third\(^4\) only included five patients. On the other hand, Patterson et al. missed or excluded three further articles\(^5,12,15\) that were included in this study. Two other included articles\(^18,19\) were published after the search was performed by Patterson et al.

**CONCLUSION**

Considering the sensitivity and specificity of the technique, as well as its methodological flaws, this study shows that CTA is an accurate modality for detecting arterial lesions in patients with extremity trauma. Therefore, trauma centers could perform a CTA when suspicion of arterial trauma of the extremity is present. DSA in these patients should be reserved for interventional purposes or if CTA is non-diagnostic or inconclusive.

**CONFLICT OF INTEREST/FUNDING**

None.

**ACKNOWLEDGMENT**

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**APPENDIX A. SUPPLEMENTARY DATA**

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ejvs.2013.04.034.

**REFERENCES**


