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# Computed tomography angiography is associated with low added utility for detecting clinically relevant vascular injuries among patients with extremity trauma

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## ABSTRACT

**Background** Extremity CT angiography (CTA) is frequently used to assess for vascular injury among patients with extremity trauma. The injured extremity index (IEI), defined as the ratio of systolic occlusion pressure between injured and uninjured extremities, has been implemented to screen patients being considered for CTA. Physical examination together with IEI is extremely sensitive for significant extremity vascular injury. Unfortunately, IEI cannot always be calculated. This study aimed to determine whether patients with normal pulse examinations and no hard signs of vascular injury benefitted from further imaging with CTA. We hypothesized that CTA has become overused among patients with extremity trauma, as determined by the outcome of vascular abnormalities that underwent vascular intervention but were missed by physical examination.

**Methods** The charts of traumatically injured patients who underwent extremity CTA were retrospectively reviewed. This study was performed at a level 1 trauma center for patients who presented as trauma activations from September 1, 2019 to September 1, 2020.

**Results** One hundred and thirty-six patients with 167 injured limbs were included. Eight limbs (4.8%) underwent an open vascular operation, whereas five limbs (3.0%) underwent an endovascular procedure. One of the 167 limbs (0.6%) had a vascular injury seen on CTA and underwent intervention that was not associated with a pulse abnormality or hard signs of vascular injury. This patient presented in a delayed fashion after an initially normal IEI and examination. Proximity injuries and fractures alone were not highly associated with vascular injuries.

**Discussion** Many patients with normal pulse examination and no hard signs of vascular injury underwent CTA; the vast majority of these patients did not then have a vascular intervention. Given the consequences of missed vascular injuries, further work is required to prospectively assess the utility of CTA among patients with extremity trauma.

**Level of evidence** III.

## INTRODUCTION

Traumatically injured patients frequently present with extremity injuries in both civilian and combat settings.<sup>1–4</sup> These injuries vary widely in severity, from minor to limb-threatening with vascular injury.<sup>5</sup> In general, the “hard signs” of vascular injury including absent distal pulses, expanding hematoma, visible arterial bleeding, bruit or thrill, and regional ischemia

prompt further workup or interventions such as conventional angiography (CA) or operative exploration.<sup>6,7</sup> In the absence of hard signs of vascular injury, other tests have been used to determine the presence of vascular injury. These include careful physical examination, calculation of an injured extremity index (IEI), ultrasound, and CT angiography (CTA).<sup>8</sup> The IEI is a useful index analogous to the ankle brachial index; it describes the ratio of systolic occlusion pressure between injured and uninjured extremities. There are a number of published test characteristics of these methods from the past decades.<sup>9–12</sup> For example, lack of hard signs and normal IEI together are extremely sensitive for vascular injury,<sup>8,13</sup> and the Eastern Association for the Surgery of Trauma practice management guidelines do not recommend further workup of patients with a normal physical examination and IEI greater than 0.9.<sup>14</sup> Unfortunately, IEI cannot always be calculated as it requires inflation of a blood pressure cuff, which may be difficult in those with an extensive area of injury.

Extremity CTA and CA have been used to assess for vascular injury among patients with concerning examination findings (“soft signs”) but without hard signs of vascular injury. Some providers use CTA or CA due to concern for vascular injury based on associated fractures or injury location close to a major vessel.<sup>15,16</sup> CTA has been shown to be highly sensitive for vascular injury with fewer risks than CA.<sup>17,18</sup> In addition, CTA is a faster and more cost-effective method for detection of extremity vascular injury than CA.<sup>19</sup> Recent guidelines from the American Association for the Surgery of Trauma and the World Society of Emergency Surgery recommend CTA as the first-line imaging modality for the workup of suspected peripheral vascular injury.<sup>7</sup> As with CA, CTA requires contrast administration and radiation exposure.<sup>20</sup>

In our experience, many traumatically injured patients who undergo CTA are identified to have no vascular injury or a vascular injury for which they did not undergo any intervention. This study aimed to determine whether patients with a normal pulse examination and no hard signs of vascular injury benefitted from further imaging with CTA. We hypothesized that CTA has become overused among patients with extremity trauma, as determined by the outcome of vascular abnormalities that underwent vascular intervention but were missed by physical examination.

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## PATIENTS AND METHODS

### Study design

The charts of patients who presented to our level 1 trauma center between September 1, 2019 and September 1, 2020 were reviewed through our trauma registry. All patients who presented as trauma activations and underwent extremity CTA with Omnipaque intravenous contrast within 24 hours of presentation and before disposition to the operating room were included in the study.

Patients' charts meeting the inclusion criteria were reviewed for patient characteristics, vital signs, physical examination findings and IEI, mechanism of injury, injury details, Injury Severity Score (ISS), imaging findings, consultations placed, and interventions performed. A pulse abnormality was defined as documentation of diminished or absent pulses in the injured extremity. Other hard signs were defined as pulsatile bleeding, expanding hematoma, palpable thrill, audible bruit, or evidence of regional ischemia such as neurologic compromise or a cold limb.<sup>21</sup> A vascular abnormality on CTA was defined as any arterial injury including partial non-opacification, complete non-opacification, extravasation, abrupt termination, or arteriovenous fistula that the attending radiologist determined to be traumatic.

Open vascular operations were defined as open operations performed on injured blood vessels by any service, including trauma surgery, vascular surgery, orthopedic surgery, and plastic and reconstructive surgery. Endovascular procedures were defined as procedures including angiography, nitroglycerin infusion, coil embolization, and absorbable gelatin powder embolization performed by any service, including vascular surgery and interventional radiology. Open operations and endovascular procedures involved revascularization, bleeding control, or purely diagnostic angiography. Pharmacologic therapy was defined as administration of a medication due to a vascular injury.

### Statistical analysis

Descriptive data were generated for variables of interest. Test results for physical examination and CTA were compared using a McNemar's test.<sup>22</sup> Stata/IC V.16.1 for Mac (StataCorp. College Station, TX, USA) was used for data analysis.

## RESULTS

During the 1-year study period, 136 patients with 167 injured limbs met the inclusion criteria and were included in the study (table 1). Most patients experienced blunt trauma (88 of 136 patients) and were male (104 of 136 patients). The median age was 37, ranging from 11 to 92. The median ISS was 10, ranging from 0 to 59. Of 136 patients, 101 experienced lower extremity trauma (74.3%), with 29 of 136 patients (21.3%) experiencing upper extremity trauma and 6 of 136 patients (4.4%) experiencing trauma to both upper and lower extremities. Of 167 limbs, 115 (68.9%) had an associated fracture in the imaged extremity. Of 167 limbs, 124 (74.3%) underwent an operation, most commonly for fracture.

Of 167 limbs, 52 (31.1%) had either a pulse abnormality or another hard sign of vascular injury (table 2). Of 167 limbs, 51 (30.5%) were found to have a vascular abnormality on CTA. Of 167 limbs, 18 (10.8%) had a normal pulse examination with no hard signs of vascular injury but were found to have a vascular abnormality on CTA. Among these limbs, six had partial non-opacification of a vessel, four had complete non-opacification of a vessel, seven had extravasation, and one had an arteriovenous fistula. In contrast, 15 of 167 limbs (9.0%) had a documented

**Table 1** Demographics and baseline characteristics

Total patients, n	136
Total limbs, n	167
Age, median (IQR)	37 (29)
Female, n (%)	32 (24)
Mechanism of injury, n (%)	
Blunt	88 (65)
Penetrating	48 (35)
Affected extremity, n (%)	
Left upper	18 (11)
Right upper	18 (11)
Left lower	70 (42)
Right lower	61 (37)
Associated fracture, n (%)	115 (69)
No other CT performed, n (%)	32 (24)
Injury Severity Score, median (IQR)	10 (11)
Heart rate, median (IQR)	98 (30)
Systolic blood pressure, median (IQR)	130 (42)
Diastolic blood pressure, median (IQR)	78 (23)
Glasgow Coma Scale score, median (IQR)	15 (1)
Disposition from emergency department, n (%)	
Home	1 (1)
Ward	44 (32)
Intensive care unit	10 (7)
Operating room	81 (60)

Percentages for affected extremity and associated fracture are based on total number of limbs. Percentages for other rows are based on total number of patients.

pulse abnormality with no vascular abnormality on CTA. Of 167 limbs, only 7 (4.2%) had a documented IEI, all of which were greater than 0.9. Vascular consultation was obtained for 16 of 167 limbs (9.6%).

Of 167 limbs, 8 (4.8%) underwent an open vascular operation, whereas 5 (3.0%) underwent an endovascular procedure. All of these limbs had a CTA abnormality (table 3). Of these 13 limbs, 12 (92.3%) had an abnormal pulse examination and/or hard signs of vascular injury (table 4). The remaining limb was from a patient who returned as a trauma activation in a delayed fashion after having had a normal IEI, normal pulse examination, and no CTA when the patient presented initially after a stab wound. This patient would not have undergone CTA based on current guidelines given his normal IEI.<sup>14</sup> On re-presentation 3 months later, he had no signs of vascular injury, with his only abnormal physical examination finding being thigh swelling. He underwent CTA showing a traumatic arteriovenous fistula, which was coil-embolized. One of 167 limbs (0.6%) underwent pharmacologic intervention (aspirin) as a result of a vascular injury (dissection flap) detected on CTA; this patient initially had a normal pulse examination which was then documented as diminished on re-evaluation. In summary, CTA abnormalities were detected in all vascular injuries that underwent intervention (0% false negative rate for detection of injury that underwent intervention), whereas one injury that eventually underwent intervention had no abnormalities on physical examination (7.7% false negative rate for detection of injury that underwent intervention). CTA abnormalities were seen in 38 limbs that did not undergo intervention, whereas physical examination abnormalities were seen in 40 (25% and 26% false positive rates for detection of injury that underwent intervention, respectively). Among 50 of 136 patients with a CTA abnormality, 31 were seen by a provider in another encounter with

**Table 2** Vascular injuries for all limbs

Signs of vascular injury, n (%)	52 (31)
Abnormal pulse examination	43 (26)
Regional ischemia	13 (8)
Expanding hematoma	2 (1)
Pulsatile bleeding	2 (1)
Bruit	0 (0)
Thrill	0 (0)
Injured extremity index, n (%)	
Documented	7 (4)
Normal	7 (4)
Abnormal	0 (0)
Abnormal CTA, n (%)	51 (31)
Vascular consultation made, n (%)	16 (10)
Open vascular operation performed, n (%)	8 (5)
Endovascular procedure performed, n (%)	5 (3)
Pharmacologic therapy administered, n (%)	1 (1)

Percentages are based on total number of limbs.  
CTA, CT angiography.

a minimum 6-month follow-up period. None of these 31 patients developed a new clinically significant vascular injury.

Overall, 1 of the 167 limbs (0.6%) that underwent extremity CTA during the 1-year study period had a vascular injury seen on CTA with subsequent intervention that was not associated with a pulse abnormality or hard signs of vascular injury. Test characteristics of CTA and physical examination with regard to the ability to detect a vascular abnormality did not significantly differ ( $p=0.73$ ).

### DISCUSSION

The availability and speed of CTA have facilitated its use among trauma patients with concern for extremity vascular injury. The serious and potentially lifelong consequences of missed vascular injuries may further contribute to the high prevalence of CTA use.<sup>23</sup> CTA requires the delivery of ionizing radiation and the administration of contrast, although the risk of added radiation for patients undergoing concurrent CT for other injuries is small and there may be no added risk for contrast if already being administered for concurrent CTs. Regardless, for all patients, CTA requires the use of healthcare resources, with each extremity CTA costing thousands of dollars.<sup>24</sup> Many patients in our cohort underwent CTA in the setting of a proximity injury or a long bone fracture; like other studies, our work confirmed a low incidence of clinically significant vascular injury in this setting.<sup>25</sup> In fact, no patients in our cohort with a long bone fracture and no other signs of vascular injury underwent vascular intervention. Some authors consider associated fractures to be a “soft sign” of vascular injury; this is not supported by our findings.<sup>21</sup>

Nevertheless, certain fracture and injury patterns are more associated with vascular injuries than others and a high index of suspicion for vascular injury should be maintained in those settings.<sup>25</sup> CT scanner resolution has increased significantly in the past years and facilitates operative and interventional planning when serious injuries are detected. Although more injuries are found on CTA than by physical examination alone, only a very small fraction undergo intervention.

Multiple previous studies have highlighted the importance of physical examination in patients with suspected vascular injury. Indeed, one previous study investigated the overuse of CTA in the detection and management of lower extremity vascular injury; this study found hard signs of vascular injury on physical examination to be paramount to management and recommended against the use of CTA as an initial screening tool.<sup>26</sup> Other authors have noted the importance of a thorough examination and tertiary survey to reduce the risk of missed vascular injuries.<sup>27</sup> A recent study by Romagnoli and colleagues<sup>28</sup> has questioned the importance of hard and soft signs and the distinction between these categories. They have proposed a clinically relevant regrouping of vascular injuries as hemorrhagic or ischemic based on associated signs. They similarly recognize CTA as identifying clinically insignificant vascular injuries. Our study also re-evaluates the traditional strict divide between soft and hard signs by including diminished pulses, a traditional soft sign, together with hard signs as being highly indicative of clinically significant vascular injury. Within the proposed reclassification of vascular injuries, pulse abnormalities such as those explored in our study would reflect only ischemic injuries without significant ability to detect hemorrhagic injuries.

This study has multiple limitations. It is a retrospective cohort study at a single institution focusing on a clinical decision. This is a major limitation as the study may not capture all confounding clinical factors and nuance to decision making and it may reflect use of CTA at this institution. As this is a retrospective study, we cannot know with precision why CTA or an operation was performed for each patient, and there may be utility to knowing of a vascular injury in the absence of intervention. Furthermore, very few patients had an IEI documented, which may have contributed to use of CTA. The low incidence of IEI documentation in our cohort likely reflects both inadequate use of IEI and incomplete documentation. Our institution is actively working to increase IEI measurement and recording. Multiple studies have found that IEI reduces the need for CTA in evaluating for vascular injury.<sup>8,13</sup> Regardless, this study supports the use of other examination findings in settings in which IEI cannot be performed. This includes pulse examination, although that itself may be limited and varied in the emergency department and trauma setting. Pulse examination documentation, which was the basis for this study, may be subject to recall bias particularly in the setting of a busy trauma service; this limits our study’s conclusions. Additionally, this study only assessed patients who underwent CTA and did not include patients who may have had vascular injury detected by other means. Although this likely reflects most patients with vascular

**Table 3** CTA findings and associated interventions for all limbs

	No intervention	Reperfusion procedure	Bleeding control procedure	Diagnostic angiogram	Pharmacologic therapy
No CTA abnormality	116	0	0	0	0
Partial non-opacification	10	0	0	0	1
Complete non-opacification	9	6	0	0	0
Extravasation	14	0	3	1	0
Abrupt termination	4	1	1	0	0
Arteriovenous fistula	0	0	1	0	0

CTA, CT angiography.

**Table 4** Pulse abnormalities or other hard signs and associated interventions for all limbs

	No intervention	Reperfusion procedure	Bleeding control procedure	Diagnostic angiogram	Pharmacologic therapy
No pulse abnormality or other hard sign	114	0	1	0	0
Pulse abnormality	32	7	3	1	1
Other hard sign	12	3	2	0	0

The bleeding control procedure in the patient with no pulse abnormality or other hard signs was coil embolization of a traumatic arteriovenous fistula in a patient who re-presented 3 months after a stab wound.

injury given the high prevalence of CTA use at our institution, it may miss those patients with hemodynamic instability and hard signs who underwent immediate operative repair; however, inclusion of such patients would further support the importance of physical examination in detecting vascular injury.

## CONCLUSIONS

In summary, abnormal pulse examination and hard signs were highly associated with clinically significant ischemic extremity vascular injury in our study. Proximity injuries and long bone fractures alone were not highly associated with clinically significant ischemic vascular injuries. Given the consequences of missed vascular injuries, further work is required to prospectively assess the utility of CTA among patients with extremity trauma who have a normal pulse examination and no hard signs of vascular injury.

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**Competing interests** None declared.

**Patient consent for publication** Not required.

**Ethics approval** This study involves human participants and was approved by University of California, San Francisco (20-32416) and the city's Department of Public Health. This was a retrospective cohort study involving chart review in which identifying information was not reported. The lack of informed consent was reviewed by the IRB.

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**Data availability statement** Data are available upon reasonable request.

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