RESEARCH REPORT

Comparing Doppler Ultrasonography and Computerized Tomography Angiography in Emergency Department Evaluation of Earthquake-Related Crush Injuries: A Case Series Analysis

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Abbreviations:
ALT: alanine aminotransferase
AST: aspartate aminotransferase
ATA: anterior tibialis artery
CK: Creatin Kinase
CTA: computerized tomography angiography
ED: emergency department
HBOT: hyperbaric oxygen therapy
LDH: lactate dehydrogenase
POC: point-of-care
PTA: posterior tibialis artery
USG: ultrasonography

Abstract

Objective: This case series aims to provide a comprehensive description of the utilization of doppler ultrasonography (USG) and computerized tomography angiography (CTA) in evaluating patients with earthquake-induced crush injuries in the emergency department (ED).

Methods: This retrospective case series was conducted on 11 patients who presented with crush injuries following a seismic event. These patients underwent initial assessment using doppler USG, with CTA performed when deemed necessary. Clinical outcomes and diagnostic findings were systematically reviewed.

Results: A cohort of 11 earthquake-related crush injury patients (six females, five males; age 3-59 years), predominantly with lower extremity injuries, with entrapped durations that ranged from 12 to 128 hours. Transport centers received patients from both affected regions and nearby provinces. Initial X-rays identified fractures in two cases. Doppler USG and subsequent CTA were employed for vascular evaluation, with CTA confirming doppler USG findings. Of the 11 patients, five exhibited abnormal doppler USG findings. Four patients required dialysis and four underwent amputation surgery. Fasciotomy and debridement procedures were performed in five and seven patients, respectively. Three patients received hyperbaric oxygen therapy (HBOT).

Conclusion: Doppler USG emerged as a dependable tool for assessing vascular injuries in earthquake-related crush injuries, offering an effective alternative to CTA without the associated contrast agent risks. These findings underscore the need for further research to establish definitive imaging guidelines in these challenging clinical scenarios.

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Introduction

On February 6, 2023 in Turkey, two seismic events of significant magnitude, measuring 7.7 and 7.6 on the Richter scale, occurred within a span of nine hours. According to the report by the Emergency Medicine Association of Turkey (EMAT; Ankara, Turkey), these seismic events had a profound impact on ten provinces, namely Kahramanmaraş, Hatay, Gaziantep, Osmaniye, Malatya, Adana, Diyarbakır, Şanlıurfa, Adıyaman, and Kilis. Official statistics revealed a devastating toll with 50,399 fatalities, 80,278 individuals sustaining injuries, and the collapse of 6,444 buildings.[1] In response to the formidable challenges faced in delivering health care services to severely affected provinces, the Ministry of Health in the Republic of Turkey (Ankara, Turkey) initiated the implementation of transport center systems.

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Subsequently, it transformed three provinces—Adana, Mersin, and Diyarbakır—characterized by lower seismic damage, ample health care facility capacity, and convenient access to air, land, and sea transportation, into designated transport centers.[2] Consequently, in a two-tiered health care delivery approach, injured individuals from the severely impacted provinces first sought medical attention in their respective regions. Subsequently, they were transported by land, air, and sea to the aforementioned three transport centers. Here, they underwent clinical stabilization and received essential early-stage medical interventions before being airlifted to more distant provinces. This necessitated the administration of rapid and critical treatments, particularly within these transport centers, amidst the backdrop of the exigent circumstances imposed by the disaster.

Natural calamities exert not only the immediate impact of structural collapse, but also carry the potential for catastrophic health consequences, precipitating abrupt fatalities through traumatic injury to vital organs. An equally noteworthy consideration in this context is the propensity of fallen building structures to constrict non-essential organs, akin to muscular tissues.[3] Subsequent to seismic events, a spectrum of health afflictions and disorders may manifest, spanning from skeletal fractures, organ and soft-tissue traumas, to cardiovascular maladies, pulmonary ailments, and communicable diseases.[4] Patients, following their initial medical consultation and disaster triage, undergo prompt deployment of primary care interventions, alongside the pursuit of a more nuanced diagnostic delineation and the assessment of tissue impairments. The injury paradigm witnessed during earthquakes is predominantly characterized by low-energy, protracted, crush-type traumas, extensive soft-tissue damage, and belated clinical presentation.

In the context of disaster response, the assessment of injured individuals necessitates the utilization of point-of-care (POC) tests due to the exigent conditions brought forth by the catastrophe, thereby underscoring their paramount significance.[5] Within the spectrum of POC tests, ultrasound emerges as the pivotal imaging modality recommended for deployment by disaster response teams.[6] Notably, in cases of extremity crush injuries, the primary objective revolves around the preservation of all viable tissues.[7] Consequently, the determination of the extent of vascular compromise in the affected extremity and the subsequent formulation of an appropriate therapeutic strategy assume pivotal importance. Thus, the foundational component of the proposed Mangled Extremity Severity Score (MESS) score, conceived for the purpose of gauging extremity injuries, lies in the identification of ischemia stemming from circulatory impairment in the afflicted individual.[8,9] Within the context of earthquake-induced injuries, clinicians, notably emergency physicians and surgeons, face an augmented demand for the comprehensive evaluation of vascular injuries. The gold standard methodology in this regard remains angiography.[10] However, it is imperative to acknowledge the potential risk of renal impairment associated with the administration of radiopaque contrast agents during contrast enhanced procedures.[11] Consequently, particularly in cases of earthquake-induced crush injuries, the absence of a well-established body of literature comparing angiography to doppler ultrasonography (USG) underscores the need for further research and exploration.

The objective of this case series is to compare the effectiveness of doppler USG and computerized tomography angiography (CTA) in the emergency department (ED) evaluation of crush extremity injuries resulting from earthquakes. Specifically, the aim was to assess the diagnostic accuracy and clinical relevance of these imaging modalities in identifying vascular complications and guiding the management of patients who presented with crush injuries after earthquake incidents. Additionally, the study seeks to provide a comprehensive analysis of the demographic characteristics, clinical outcomes, and treatment interventions observed in this cohort. By scrutinizing the findings from both doppler USG and CTA, the goal was to contribute valuable insights that may inform more effective and efficient approaches to the emergency evaluation and management of earthquake-related crush injuries.

Methods

In these retrospective cases, data pertaining to patients who presented to University of Health Sciences, Gazi Yaşargil Training and Research Hospital (Diyarbakır, Turkey), designated as one of the response hubs following the Kahramanmaraş earthquakes on February 6, 2023, and subsequently underwent evaluation due to crush injuries, including extremity CTA, were retrospectively retrieved from hospital records, patient files, and the Hospital Information Management System (HIMS). Ethical clearance for this study was obtained from the Ethics Committee of University of Health Sciences, Gazi Yaşargil Training and Research Hospital (Decision No. 447).

The duration of entrapment was defined as the time elapsed from the onset of seismic activity until the physical extraction of the patient from beneath a structure damaged during the earthquake.

Complete blood count and biochemical analyses of patients' blood samples were conducted at the hospital's laboratory, encompassing blood gas analysis, complete blood counts, and biochemical profiling. Radiographic images of patients were obtained through portable bedside X-ray equipment and subsequently documented in the patients' medical records. Radiologists provided the interpretations for these X-ray images. Doppler USG assessments, conversely, were executed at the patient's bedside by a radiologist, with findings reported and recorded in the patient's medical files. The decision to perform CTA on patients was a collaborative effort involving cardiovascular surgeons, plastic and reconstructive surgeons, and orthopedic surgeons. In adherence to the ED disaster protocol, all patients presenting with crush injuries as a consequence of earthquake-related incidents received intravenous fluid and bicarbonate infusions.

Results

Throughout the duration of the study, 79 patients were observed with crush injuries and sought medical attention. Doppler USG was performed on all these patients, and CTA was additionally conducted in 11 cases. In this cohort of patients, sex distribution revealed six females and five males. The age range was from three to 59 years. The assessment of the duration of entrapment beneath debris unveiled a range spanning from a brief 12 hours to an extended 128 hours. Notably, seven patients accessed the transport center through ambulance services or outpatient visits from the province in which the center was located. In contrast, the remaining four patients originated from earthquake-affected regions, such as Adıyaman and Kahramanmaraş. Upon scrutiny of the sites of injury among this cohort, a predominant pattern of lower extremity injuries emerged. Specifically, all but three patients exhibited injuries in both lower extremities, with only three presenting injuries limited to a single lower extremity. Demographic profiles of patients who sought care at the transport

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Dialysis Status	Patient	Sex	Age	Duration of Entrapment (hours)	Injured City	Injured Extremity
No Dialysis	P1	F	13	128	Adıyaman	Right Lower
	P2	M	9	101	Diyarbakır	Bilateral Lower
	P3	F	13	48	Kahramanmaraş	Bilateral Lower
	P4	F	33	14	Diyarbakır	Right Lower
	P5	F	35	18	Diyarbakır	Left Lower
	P6	F	22	12	Diyarbakır	Bilateral Lower
	P7	M	59	48	Adıyaman	Bilateral Lower
Dialysis	P8	M	24	14	Kahramanmaraş	Bilateral Lower
	P9	M	29	24	Diyarbakır	Bilateral Lower
	P10	F	3	120	Diyarbakır	Bilateral Lower
	P11	M	28	32	Diyarbakır	Bilateral Lower

Table 1. Demographic Information of Patients Undergoing CTA, Duration of Entrapment, Injured City, and Injury Sites
Abbreviation: CTA, computerized tomography angiography.

center due to earthquake-induced injuries following entrapment, subsequently followed for crush injuries, were stratified into two groups for analysis. These groups were distinguished by whether patients received dialysis during their follow-up, as detailed in Table 1.

The employed imaging modalities in the management of these 11 patients following their admission to the ED are summarized in Table 2. Among these patients, initial X-ray examinations identified lower extremity bone fractures in two cases (P1 and P2). All patients who underwent CTA had undergone prior bilateral lower extremity doppler USG. Notably, in the doppler USG assessments of two patients (P1 and P2), "inadequate blood flow" or "diminished flow" was observed in the lower extremities, while in three patients (P8, P9, and P10), the evaluations reported "absence of blood flow" in the anterior tibial artery (ATA), posterior tibial artery (PTA), and dorsalis pedis artery. Consequently, among the 11 patients for whom CTA was deemed necessary, only five individuals exhibited abnormal findings in their lower extremity doppler USG assessments.

Among the five patients (P1, P2, P8, P9, and P10) for whom doppler USG assessments reported abnormal findings, distinct patterns emerged. Notably, in the case of patient P1, although the lower extremity doppler USG indicated pathology, the subsequent CTA revealed normal blood flow. Patient P2, on the other hand, exhibited "inadequate blood flow" in the doppler USG, but the CTA demonstrated weakened proximal flow in the ATA and PTA with "no flow" detected distally. Similarly, patients P8, P9, and P10 displayed "no flow" in their doppler USG assessments, a finding consistent with the CTA results. Conversely, for the remaining six patients (P3, P4, P5, P6, P7, and P11) in whom doppler USG evaluations did not reveal any pathological findings, the CTA interpretations also confirmed the absence of acute pathology (Table 2).

The 11 patients who underwent CTA were categorized into two distinct groups: the first group comprised seven patients (P1, P2, P3, P4, P5, P6, and P7) who did not require dialysis during their follow-up, while the second group consisted of four patients (P8, P9, P10, and P11) who did. Data for various laboratory parameters, including pH, creatinine, urea, potassium, sodium, creatine kinase (CK), aspartate aminotransferase (AST), alanine aminotransferase (ALT), and lactate dehydrogenase (LDH), were collected at the time of their initial admission and on the second day post-admission for all 11 patients who underwent CTA. These data are presented in Table 3 for descriptive purposes. It is noteworthy that the CTAs for these patients were performed immediately after their initial ED admission, meaning that the initial assessments were conducted at the moment of ED arrival and before CTA imaging, while the second day assessments corresponded to the day of the CTA. For the patients who did not require dialysis, they received standard protocol fluid and bicarbonate treatment following crush injuries. Table 4 provides data on the pH, creatinine, urea, potassium, sodium, CK, LDH, and calcium levels for patients who required dialysis, collected at the time of their initial ED admission, pre-dialysis, and post-dialysis during their follow-up.

Out of the cohort of 11 patients, four (P8, P9, P10, and P11) underwent dialysis, while four (P7, P8, P10, and P11) required amputation surgery. Additionally, five patients (P7, P7, P9, P10, and P11) underwent fasciotomy, and seven patients (P3, P6, P7, P8, P9, P10, and P11) underwent debridement procedures. Furthermore, three patients (P7, P9, and P10) received hyperbaric oxygen therapy (HBOT) as part of their therapeutic interventions. Detailed information regarding the treatments administered during the patients' follow-up can be found in Table 5.

Discussion

In cases of injuries resulting from earthquakes and requiring emergency care, one of the most prevalent types of injuries is extremity crush injuries.[12] Crush injuries initially manifest as localized muscle damage at the injury site but can lead to systemic consequences as breakdown products enter the circulatory system. Therefore, managing both the affected extremity and the potential systemic repercussion of the injury becomes imperative. At this juncture, the primary assessment in determining extremity viability involves the evaluation of extremity circulation, specifically, the assessment of vascular integrity.

In non-seismic periods, the widely accepted gold standard for evaluating vascular integrity is the use of angiography with contrast agents. Nevertheless, it's worth emphasizing that these contrast agents are well-documented as a leading cause of acute kidney

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		X-Ray	USG		CTA	
Dialysis Status	**Patient**		**Right**	**Left**	**Right**	**Left**
Dialysis	P1	Fracture	Normal	ATA and PTA Inadequate Blood Flow	Normal	Normal
	P2	Fracture	Normal	ATA and PTA Inadequate Blood Flow	Normal	ATA and PTA Inadequate Blood Flow in Proximal and No Flow in Distal
	P3	–	Normal	Normal	Normal	Normal
	P4	–	Normal	Normal	Normal	Normal
	P5	–	Normal	Normal	Normal	Normal
	P6	–	Normal	Normal	Normal	Normal
	P7	–	Normal	Normal	Normal	Normal
Dialysis	P8	–	Normal	ATA, PTA, and Dorsalis Pedis No Flow	Normal	ATA, PTA, and Dorsalis Pedis No Flow
	P9	–	ATA, PTA, and Dorsalis Pedis No Flow	Normal	ATA, PTA, and Dorsalis Pedis No Flow	Normal
	P10	–	ATA, PTA, and Dorsalis Pedis No Flow	Normal	ATA, PTA, and Dorsalis Pedis No Flow	Normal
	P11	Fracture	Normal	Normal	Normal	Normal

Table 2. Imaging Methods Used in the Management of Patients After Emergency Department Admission
Abbreviations: USG, ultrasonography; CTA, computerized tomography angiography; ATA, anterior tibialis artery; PTA, posterior tibialis artery.

Patient		**pH**	**Creatin (mg/dL)**	**Urea (mg/dL)**	**Potassium (mEq/L)**	**Sodium (mEq/L)**	**CK (IU/L)**	**AST (U/L)**	**ALT (U/L)**	**LDH (U/L)**
P1	Day 1	7.5	0.96	157	4.3	149	15,228	403	51	871
	Day 2	***7.56***	***0.59***	***45***	***3.51***	***143***	***18,788***	***321***	***70***	***1,278***
P2	Day 1	7.22	2.78	343	6.08	145	23,724	457	219	1,491
	Day 2	**7.47**	**0.37**	**21**	**4.16**	**136**	**7,500**	**215**	**125**	**1,425**
P3	Day 1	7.36	0.59	64	5.57	130	5,375	984	323	2,300
	Day 2	**7.41**	**0.42**	**16**	**3.6**	**129**	**365**	**612**	**300**	**335**
P4	Day 1	7.38	0.59	42	4.5	137	8,139	89	36	462
	Day 2	**7.39**	**0.59**	**28**	**4.28**	**137**	**12,906**	**70**	**45**	**564**
P5	Day 1	7.39	0.74	31	4.61	136	20,569	506	76	923
	Day 2	**7.34**	**0.78**	**40**	**3.4**	**134**	**25,569**	**320**	**104**	**800**
P6	Day 1	7.41	0.58	20	3.61	138	1,209	16	16	163
	Day 2	**7.45**	**0.48**	**21**	**3.84**	**136**	**143**	**20**	**18**	**155**
P7	Day 1	7.44	1.67	204	4.71	152	18,627	288	179	1,366
	Day 2	**7.42**	**0.73**	**22**	**4.33**	**137**	**2,500**	**100**	**83**	**508**

Table 3. Patients Undergoing CTA and Not Requiring Dialysis during Follow Up
Abbreviations: CTA, computerized tomography angiography; CK, Creatin Kinase; AST, aspartate aminotransferase; ALT, alanine aminotransferase; LDH, lactate dehydrogenase.

injury within the hospital setting.[13] In cases of earthquake-induced crush injuries, it is noteworthy that rhabdomyolysis, with its predominant systemic toxic effect on the kidneys, imposes restrictions on the use of contrast agents in these patients. The term "gold standard" signifies a criterion that is applicable under ideal conditions. It is essential to recognize that this designation does not imply a flawless test but rather designates the best available test with a recognized standard outcome.[14] Considering these factors, the selection of the gold standard imaging modality for identifying vascular injuries in earthquake-related injuries becomes a topic of deliberation. This is particularly relevant because earthquakes offer a context where non-invasive and bedside

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Patient		pH	Creatin (mg/dL)	Urea (mg/dL)	Potassium (mEq/L)	Sodium (mEq/L)	CK (IU/L)	LDH (IU/L)	Calcium (mg/dL)
P8	ED	7.01	2.26	56	6.53	141	249,293	4,520	5.8
	BD	6.90	3.03	85	6.50	139	30,120	4,612	6.0
	AD	7.42	1.27	46	3.95	136	4,192	3,251	5.2
P9	ED	7.09	2.08	68	6.16	135	105,751	3,148	7.2
	BD	7.004	2.25	77	7.31	141	98,004	3,498	6.5
	AD	7.43	1.07	42	3.4	132	5,890	566	8.3
P10	ED	7.31	1.28	221	3.89	155	15,118	1,244	6.73
	BD	7.1	4.5	156	5.8	134	52,065	3,564	6.4
	AD	7.45	2.1	65	4.1	138	2,548	489	8.6
P11	ED	7.38	0.92	48	4.47	137	1,530	371	8.5
	BD	7.20	4.2	72	6.28	137	36,500	8,256	8.00
	AD	7.34	1.50	22	3.5	132	4,321	430	6.02

Table 4. Blood Gas and Biochemistry Parameters of Patients who Underwent CTA and Required Dialysis during Follow Up
Abbreviations: CTA, computerized tomography angiography; ED, emergency department; BD, before dialysis; AD, after dialysis; CK, Creatin Kinase; LDH, lactate dehydrogenase.

Patient	Dialysis	Amputation	Fasciotomy	Debridement	HBOT
P1	–	–	–	–	–
P2	–	–	–	–	–
P3	–	–	+	+	–
P4	–	–	–	–	–
P5	–	–	–	–	–
P6	–	–	–	+	–
P7	–	+	+	+	+
P8	+	+	–	+	–
P9	+	–	+	+	+
P10	+	+	+	+	+
P11	+	+	+	+	–

Table 5. Treatment Modalities Employed in the Management of Patients
Abbreviation: HBOT, hyperbaric oxygen therapy.

doppler USG, a readily accessible and patient-friendly method, can be effectively employed to assess vascular injuries.[15] It is important to acknowledge that providing a definitive guideline in this context remains a complex challenge at present.

In this case series involving 11 patients, it was observed that none of the patients who underwent bedside extremity doppler USG exhibited any pathology, and subsequently, no pathological findings were detected in the CTA scans performed for these individuals. It is widely recognized that the primary limitation of USG lies in its reliance on the operator's proficiency, anatomical knowledge, and the availability of sufficient time for a comprehensive assessment.[16] In the context of a busy ED, as is often the case during events like earthquakes, the trustworthiness of USG as a user-dependent method for critical surgical decision making has been a subject of scrutiny. This consideration may have influenced clinicians' decisions to opt for CTA among the 11 patients included in this case series. However, it is noteworthy that in this particular case series, no additional pathology was identified in the CTA scans for patients who initially showed no pathology on doppler USG.

While the current literature lacks a conclusive pathophysiological explanation for renal injury linked to rhabdomyolysis or radiographic contrast agents, it is commonly accepted that it encompasses the direct cytotoxic impact of harmful substances circulating as a result of radiographic contrast and rhabdomyolysis on renal tissue. This process also encompasses alterations in renal hemodynamics and tubulo-dynamics, along with their interplay. Notably, existing research has not yielded conclusive insights into the consequences of their concurrent presence.[17,18] However, in a prior investigation conducted by this research team at the same institution, aimed at determining dialysis requirements in patients presenting with crush injuries during acute seismic events, it was observed that among a total of 205 admissions for earthquake-related crush injuries at the transport center, only 35 patients required dialysis during their follow-up.[19] When this is combined with the finding that four out of the 11 patients who underwent CTA required dialysis, it suggests that the need for dialysis may be nearly double in patients who undergo CTA.

In the aftermath of earthquakes, the damage sustained by extremities can result in the release of intracellular substances into the

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systemic circulation, leading to shifts in vascular permeability and the activation of mechanisms such as nitric oxide, which heighten the predisposition of injured individuals to hypotension.[20] Notably, both hypotension and severe dehydration are recognized as factors that increase the susceptibility of individuals to contrast-induced renal injury.[21] This prompts consideration that the utilization of contrast-enhanced imaging in earthquake-related crush injuries may potentially contribute to the development of renal injury.

In the context of all types of disasters, including earthquakes, the imperative for swift decision making and effective patient management within the ED and among surgical teams is paramount. Achieving this efficiency often hinges on the availability of well-prepared guidelines for diagnostic approaches. Clinical guidelines, systematically developed at both national and global levels, serve as invaluable tools in assisting clinicians in rendering standardized, evidence-based decisions. Their implementation not only fosters the enhancement of health care quality but also mitigates the variability that may exist in clinical practices.[22] These guidelines furnish clinicians with a structured framework to render standardized, expeditious, and practicable decisions, which, in turn, offer legal safeguards and streamline the decision-making process. As evident in this case series, the role of individual clinician judgments looms large in the context of patient management. While the efficacy of CTA in discerning vascular damage resulting from earthquake-related injuries remains constrained by the paucity of controlled research, it becomes increasingly apparent that there exists a compelling necessity for imaging algorithms tailored specifically to earthquake injuries. Such algorithms would serve to alleviate the burden on clinicians and expedite the decision-making process.

Limitations

The limitations of this study may include, firstly, the inclusion of a limited number of participants and the focus on only 11 patients who experienced a specific earthquake event, which may limit the generalizability of the findings. Given the nature of disasters, characterized by their sudden onset and the challenging conditions in which they unfold, conducting prospective studies becomes inherently difficult. Therefore, the retrospective nature of this case series is a pragmatic approach, yet it has limitations in establishing cause-and-effect relationships. Prospective, randomized controlled trials, while challenging due to the unpredictable nature of disasters, may be important to confirm these findings. Secondly, doppler USG is a technique that can exhibit variability in imaging results depending on operator experience. Differences in operator skill levels can influence the reliability of the obtained results

Conclusion

This case series highlights the use of doppler USG and CTA in managing earthquake-related crush injuries. Doppler USG proved valuable for non-invasively assessing vascular injuries, particularly when no pathology was initially detected. The choice between imaging modalities remains debatable, with potential risks associated with CTA, such as increased dialysis needs.

Author Contributions

RC, MO, ACT, RA, and SY conceived the study and designed the trial. RC, MO, ACT, and AS supervised the conduct of the trial and data collection. RC, MO, ACT, SY, and RA undertook recruitment of participating centers and patients and managed the data, including quality control. ACT provided statistical advice on study design and analyzed the data; RC, MO, ACT, and AS chaired the data oversight committee. RC, MO, ACT, RA, and SY drafted the manuscript, and all authors contributed substantially to its revision. RC, MO, ACT, RA, and SY takes responsibility for the paper as a whole.

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