1 The Evolving Role of Computed Tomography (CT) in Trauma Care

Christina L. Jacovides, Nnamdi D. Udeh, Jeremy W. Cannon, and Friedrich Knollmann

Introduction

Since its invention, computed tomography (CT) has played a critical and increasingly important role in the workup and management of acutely injured patients. As an adjunct to trauma protocols and algorithms, in hemodynamically stable patients, CT provides rapid assessment and diagnosis of injuries in multiple body cavities, guiding additional triage of injuries and therapeutic interventions. The following chapters will focus on the specific roles for CT within individual body regions, discuss the role for CT in specific patient populations (e.g., children, patients with renal failure), and discuss new developments on the horizon as CT technology and image interpretation continue to evolve. The goal of this chapter is to introduce the role of CT within the larger trauma system and to establish the historical context in which modern CT finds itself. Understanding how CT fits into overall trauma algorithms and how its role has changed over time sets the stage for its continued evolution.

C. L. Jacovides (✉)
Division of Trauma, Acute Care Surgery, Surgical Critical Care, and Burn Surgery, Temple University Hospital, Philadelphia, PA, USA
e-mail: Christina.Jacovides@tuhs.temple.edu

N. D. Udeh
Department of Radiology, Hospital of the University of Pennsylvania, Philadelphia, PA, USA
e-mail: Nnamdi.Udeh@Pennmedicine.upenn.edu

J. W. Cannon
Division of Traumatology, Surgical Critical Care and Emergency Surgery, Surgery at the Hospital of the University of Pennsylvania and the Presbyterian Medical Center of Philadelphia, Philadelphia, PA, USA
e-mail: Jeremy.Cannon@pennmedicine.upenn.edu

F. Knollmann
Department of Medical Imaging, Penn Presbyterian Medical Center, Philadelphia, PA, USA
e-mail: Friedrich.Knollmann@pennmedicine.upenn.edu

History of ATLS

Understanding how CT fits into the overall workup of injured patients requires an understanding of trauma algorithms and systems. Trauma is not a new pathology—patients have presented for medical care for injury for thousands of years. However, the last 50 years have witnessed the growing development of and protocolization of trauma care, starting with the establishment of trauma algorithms and the development of trauma systems.

In 1976, a tragic plane crash resulted in serious injuries to orthopedic surgeon Dr. Jim Styner and his family. He felt that the trauma care they received was inadequate based on the standards of the day, and he originated the first Advanced Trauma Life Support (ATLS) course in 1978 to standardize the practice of trauma resuscitations [1]. In the years since the establishment of the ATLS course and protocols, trauma care in the

F. Knollmann (ed.), *Trauma Computed Tomography*, https://doi.org/10.1007/978-3-031-45746-3_1

first hour after trauma has changed significantly worldwide. Since the development of ATLS, there has been increasing focus on and interest in the development of trauma centers and trauma systems to optimize the immediate stabilization and long-term complex care of injured patients.

The major tenet of ATLS is that patients who present to a trauma center with traumatic injuries should be rapidly evaluated and resuscitated by a trauma team. This resuscitation is algorithmic, focusing first on the most life-threatening injuries (e.g., establishing an airway, confirming that the patient has bilateral breath sounds, and evaluating the extremities for pulses and the presence of exsanguinating hemorrhage). In the process of this evaluation, trauma surgeons and emergency personnel use adjunctive imaging modalities for rapid assessment of the patient's condition. These include focused abdominal ultrasound in trauma (FAST) exams as well as plain films of the chest, abdomen, pelvis, head/neck, and extremities, as indicated. Once physical exam and initial adjuncts are completed, the trauma team determines the next best location for the patient, depending on the injury complex identified at initial presentation [2].

Following the initial resuscitation, patients either undergo treatment for their injuries or additional diagnostic studies to better define those injuries. Patients who are too unstable for additional imaging may be taken directly to the operating room for operative exploration to better define and address their injuries. Patients who are stable and have clearly defined injuries based on plain films and physical exam may be treated for their injuries. The many patients in the middle ground who are clinically stable and for whom additional diagnostic modalities may better clarify their injury patterns undergo additional imaging. In many cases, this additional imaging involves CT [2].

The Development of Trauma Systems

ATLS defines the actions of individual providers to stabilize injured patients within the first hour after injury, but trauma care cannot exist in a vacuum. Successful stabilization of injured patients requires not only immediate provider input, but a robust trauma system to support the ongoing care of injured patients. As ATLS has been disseminated worldwide, there has been a concurrent expansion and formalization of trauma systems to mobilize the resources required to care for injured patients.

In the USA, trauma centers are designated at five levels. These range from Level 1 trauma centers, which are comprehensive tertiary referral centers that serve as regional resources in the overall trauma system and can provide total trauma care to the injured patient, to Level 5 trauma centers, which can provide basic initial evaluation and stabilization of injured patients prior to transfer for definitive care. These five levels are designated by state and local entities and the specific details of these designations vary from state to state. Nationally, however, the American College of Surgeons (ACS) has the role of verifying that designated trauma centers at each level have the appropriate resources required for their level [3]. It is through a combination of excellent ATLS care delivered within this network of trauma centers that injured patients may be acutely stabilized and provided with the long-term specialty care that their injuries require for management.

While patients with more trivial traumatic injuries may not necessarily benefit from referral to higher level trauma centers, survival and outcomes tend to be better for patients with major trauma who are treated in an advanced level trauma center [4–6].

History of CT and Its Role in Trauma Systems

The role of CT has evolved greatly since it was first introduced in the setting of trauma. CT was first invented in 1967 by Sir Godfrey Hounsfield, with the first patient CT scan (a brain CT) performed in 1971. CT scanners became much more prevalent during the 1980s and 1990s, and as technology has developed, new techniques have improved CT image quality, reduced time to image acquisition, and reduced radiation doses [7]. These developments have resulted in an evolution in the use of CT in trauma. Early use of CT was limited in trauma to only those patients who were truly stable enough for imaging and who also would have non-subtle findings on thick-slice CT. With modern CT scanners, the decreased time to image acquisition and the significant improvement in resolution of images means that more trauma patients are candidates for imaging prior to definitive intervention. As a result, there have been significant shifts in the use of CT in trauma as well as in patterns of interventions in trauma patients.

As CT technology improves, moreover, the indications for appropriateness of CT imaging in trauma patients continue to expand. The tenets of good trauma care remain in place—e.g., only patients who are stable enough to be in a CT scanner should undergo imaging—but because CTs may be obtained much more rapidly with newer scanners, more patients are stable enough for CT now than there were in the early years of CT. Moreover, with newer scanners has come finer resolution on CT imaging and nuanced protocols that allow for the visualization of injury patterns which previously not routinely imaged. As a result, there has been a growing use of CT in the evaluation of injured patients.

By definition, level 1 trauma centers must also have 24-h availability of CT imaging [3, 8]. While CT is now widely available across most developed countries, the degree of specialization of the radiologist providing the interpretation of imaging results in increased rates of identification of both diagnoses that alter patient care and those that do not (e.g., incidental findings) [9]. As many centers move toward specialization and subspecialization of imaging interpretation, the interaction between different specialists contributes to the ongoing education of the next generation of radiologists.

Following the same principle, the practice of diagnostic radiology has also steered toward higher degrees of specialization, with the expectation that a sufficient clinical practice base and subspecialization allow for higher quality of patient care. Accordingly, subspecialization in radiology has progressed especially in large academic medical centers, which also share the academic mission that is bestowed upon the level 1 trauma center.

In an ideal world, the most advanced imaging services would be immediately available at all times and could be immediately correctly interpreted to the benefit of the patient. The current concept of a level 1 trauma center with 24-h availability of CT comes closest to this ideal situation. Sharing the diagnostic experience from subspecialities aids in disseminating the resultant insights.

However, there is always the risk of over-utilization of advanced imaging services and the identification of incidental findings that may have no bearing on a patient's clinical state or may prompt additional invasive procedures to the patient's detriment.

Appropriateness Criteria in a Trauma Setting

The problem of potential over-utilization has been addressed by the American College of Radiology (ACR) through development of appropriateness criteria [10]. These criteria are established using available literature and categorize available imaging in multiple modalities as either "Usually appropriate," "May be appropriate," or "Usually not appropriate" in a variety of clinical settings. For major blunt trauma in hemodynamically unstable patients, they note that plain films and ultrasound are usually appropriate, and that CT whole body with or without IV contrast may be appropriate. In hemodynamically stable patients with major blunt trauma, CT whole body with IV contrast is extended to be considered "usually appropriate." The ACR also provides guidance on imaging for patients with major blunt polytrauma in situations in which specifically facial, extremity, bowel, and genitourinary injury is suspected, as well as guidance for the imaging of pregnant patients. Separate guidance is given for patients with penetrating trauma to the lower abdomen and pelvis [11], although this is the only guidance given for patients with penetrating injury. The ACR also provides guidance on the appropriateness of imaging studies used in a variety of other suspected trauma pathologies, including blunt chest trauma with suspected cardiac injury [12], extremity/joint trauma [13–17], spine trauma [18], head trauma [19, 20], facial trauma [21], as well as trauma in children (head and spine) [22, 23].

Recommendations about the appropriateness of imaging options in traumatically injured patients come from these summary documents from the ACR but also from a variety of surgical and trauma perspectives from various entities. The American College of Surgeons (ACS)'s Trauma Quality Improvement Program (TQIP) has put forth guidelines for best practices guidelines in imaging [8]. The Eastern Association for the Surgery of Trauma (EAST) trauma practice management guidelines include commentary on overall evaluation and treatment of a variety of trauma pathologies, including guidance on appropriateness of various diagnostic and therapeutic imaging modalities [24]. The Western Trauma Association (WTA) has established algorithms for defining appropriateness in workup and management of traumatic injuries [25].

The ACS TQIP imaging guidelines state that trauma centers should all have multidetector computed tomographic (MDCT) trauma protocols established for each body region. CT imaging must be readily available in trauma centers. Additionally, they recommend that the CT scanner be as close to the trauma bay as possible, that trauma patients receive priority imaging ahead of patients with conditions that are not life-threatening, and that trauma imaging be interpreted promptly with information relayed back to the trauma team expeditiously to allow for rapid decision-making. In order to obtain high-quality vascular imaging with CTA and reconstruction for definitive care of patients with vascular injuries (e.g., at level 1 and 2 trauma centers), they recommend a 64-channel scanner. For more routine imaging or in trauma centers that typically transfer more critically injured patients, 16-channel scanners may be adequate.

The ACS TQIP guidelines make additional commentary on the need to consider radiation exposure risk (particularly in children and pregnant patients) in determining the appropriate CT studies ordered. It is important to note that one of the basic tenets of care of the pregnant trauma patient is that the pregnant patient should receive the same treatment as the non-pregnant patient since excellent trauma care for the pregnant patient optimizes outcomes for the fetus. Moreover, most diagnostic imaging modalities used in trauma provide radiation doses far below the level that has been associated with increased rate of development of fetal anomalies or of fetal death [26]. The guidelines also comment on contrast considerations including the need for intravenous contrast for the purposes of assessing for contrast blush and solid organ injury, as well as the potential but low risk for contrast nephropathy, which is typically discounted given the significant increase in diagnostic yield of contrast-enhanced imaging. Finally, they discuss the importance of adequate sedation in the agitated or pediatric patient for various imaging modalities and make the important point that trauma resuscitation should be continued during imaging acquisition, if necessary [8].

Controversies in Trauma CT

As with any evolving technology in an evolving field, there remain numerous points of ongoing research and investigation regarding best practices in the utilization of CT imaging in trauma patients. We highlight here some of the more notable ongoing controversies in CT imaging in trauma patients.

Whole-Body CT Scan Versus Selective CT Scan

The introduction of multidetector CT technology has greatly accelerated the ease with which whole-body CT images may be obtained. Early studies suggested that whole-body CT, obtained using a streamlined image acquisition protocol to depict the head, neck and torso, may improve patient survival in severely injured patients [27].

The subsequently performed REACT-2 study randomized severely injured patients to either "conventional" organ-focused CT vs. whole-body CT did not demonstrate this survival benefit—even after post hoc analysis of patients with polytrauma presentation and traumatic brain injury [28]. Nevertheless, the widespread availability of accelerated techniques for whole-body imaging has contributed to a dramatic increase in the usage of CT in trauma patients in recent years [29].

The potential harms associated with whole-body CT include the increased radiation exposure inherent in whole-body scanning as opposed to selective scanning, and the fact that whole-body imaging results in the identification of incidental findings which may be clinically insignificant, but which may result in invasive and risky diagnostic procedures to determine their implications. While there is some concern that whole-body CT might also be associated with increased cost, the REACT-2 study did not find that whole-body CT increased costs [28].

The presumptive benefit of whole-body CT is that standardized rapid imaging can result in earlier identification of injuries and fewer missed injuries. However, care must be taken in assessing the value of whole-body CT in comparison to selective CT. For example, while several observational studies report a mortality benefit with whole-body CT, Gupta et al. noted that patients who undergo whole-body CT have injury severity scores (ISS, a trauma scoring system typically used to determine the extent and clinical significance of a patient's injuries) that are twice that of those who undergo selective CT only, but that if "unnecessary" CT scans are excluded, the two groups have similar ISS scores [30]. Moreover, in one recent investigation, about 75% of trauma CT studies did not result in any injury diagnosis [31]. Efforts to identify clinical criteria that qualify a patient for whole-body CT will increase diagnostic yield and prevent over-utilization.

In addition to optimizing patient selection, there is nuance in the whole-body versus selective CT scan options in terms of the specific techniques used to obtain each set of images. Guidelines specify many details of the imaging technique [32] and ongoing technological developments such as spectral imaging continue to expand the usage of CT in trauma care while decreasing total radiation dose and improving overall image quality [33]. With every new technology comes the need for balance—modern CT scanners have incredible capabilities, but we must still employ this technology cautiously, always keeping in mind the risk/benefit ratio for use in each individual patient.

An example of a whole-body CT protocol is reproduced in Table 1.1.

Table 1.1 Whole-body CT protocol

Protocol name	Trauma one run
Indication	Polytrauma
Protocol designed for (scanner model)	GE revolution apex
Patient preparation	Arms to be elevated after second series
First series	Head non contrast
Oral contrast	NA
IV contrast	NA
Tube settings	
kV	120
mA	550
Dose modulation	Off
Scan type	Axial
Tube rotation time (s)	0.6 s
Table speed (mm/s)	
Slice collimation	
Reconstructed slice thickness	5 mm
Anatomical coverage	Vertex to C1
Reconstruction kernel	STND, ASIR 50%
Breath hold	NA
Window settings	100/30
Post processing	0.625 ax, 3 cor, 2 mm ax
Other	
Typical dose	
CTDIvol	
DLP	
Eff. Dose	
Second series	C-spine
Oral contrast	NA
IV contrast	NA
Tube settings	
kV	120
mA	SmartmA, 220–400 mA

(continued)

Table 1.1 (continued)

Protocol name	Trauma one run
Dose modulation	SmartmA, noise index 12
Tube rotation time (s)	0.7 s
Table speed (mm/s)	56.25 mm/s
Slice collimation	
Reconstructed slice thickness	2.5 mm
Anatomical coverage	Above odontoid to T1
Reconstruction kernel	STND, ASIR 50
Breath hold	NA
Window settings	350/50
Post processing	2.5 bone, 2 mm sag
Other	
Typical dose	
CTDIvol	
DLP	
Eff. Dose	
Third series	Chest-abdomen-pelvis
Oral contrast	NA
IV contrast (mL, mL/s)	70/3, 55/2, 20 NaCl 2 cc/s
	Delay: 65 s
Tube settings	
kV	120
mA	SmartmA 120–550
Dose modulation	SmartmA, noise index 12
Tube rotation time (s)	0.5 s
Table speed (mm/s)	158.75 mm/s
Pitch	0.992
Slice collimation	0.625 mm
Reconstructed slice thickness	5 mm
	0.625 TrueFidelity
Anatomical coverage	C-A-P
Reconstruction kernel	STND, ASIR 50
Breath hold	Inspiration
Window settings	400/40
Post processing	1 mm STND, lung, 3 mm STND, lung, 2 mm sag and Cor
Other	
Typical dose	
CTDIvol	
DLP	
Eff. Dose	

Optimizing Imaging Protocols for Injured Patients

Given the risks of increased contrast load and radiation exposure as well as the goal of reducing the time required to obtain appropriate diagnostic imaging in acutely injured patients, there are continued debates about the optimal protocols for CT imaging. Numerous authors have proposed a variety of different protocols for CT by varying patient positioning [34], timing of contrast bolus, use of enteric (e.g., oral and/or rectal contrast) [35, 36], and various maneuvers/protocols for evaluation of specific injuries (e.g., CT cystogram for evaluation of bladder injuries) [37]. The overall goal is to obtain imaging that has the best possible diagnostic yield in the shortest amount of time while exposing the patient to the least risk from contrast, radiation, or overdiagnosis. By combining the expertise of trauma surgeons and radiologists, we can hope to optimize the most important factors for critically injured patients for whom accurate, timely diagnosis is crucial for appropriate treatment.

In trauma, patient positioning and cooperation may add time to the acquisition of imaging data. Although placing both arms above the head during whole-body CT has been shown to reduce overall patient dose and increase image quality rating compared to one or two arms in the gantry [38], there are often factors that may limit a patient's ability to be appropriately positioned. Depending on the mechanism of injury, a patient may only be able to have one arm or neither arm outside of the gantry. Though not ideal, this compromise has still been shown to be effective in detecting life-threatening injuries [39]. As an alternative to having both arms up, Studer et al. propose a protocol in which the patient's arms are placed on a ventral pillow rather than above their heads and note that this adjustment reduces the overall time required for scan [34], with subsequent studies showing that image quality is also improved with this technique [40]. In critically ill patients for whom CT has been deemed appropriate but who may be clinically tenuous, reducing the time required to obtain accurate imaging by even a few minutes may have a significant clinical impact.

In addition to varying patient positioning, CT protocols may vary the timing and amount of contrast dye injection as well as the timing and number of images obtained after injection. This allows for multi-phase imaging that makes diagnosis of arterial, venous, solid organ, liver/portal vein, genitourinary injury, etc. possible. Numerous authors have proposed a variety of protocols for optimizing these imaging techniques [41–43].

System-Based Staffing Considerations

All trauma centers must find a way to balance their available resources to provide the best possible care for patients at all times. Finding ways to creatively deploy available resources while still ensuring excellent care regardless of time of day or day of week is a crucial part of the development of a trauma center. Any trauma centers that leverage trainee assistance in interpretation of images must have an established protocol for rapid and accurate interpretation of imaging to provide timely and appropriate care to all trauma patients. This is particularly true for and important at level 1 trauma centers, since education and research are at the forefront of their mission [3]. Several authors have investigated the degree of discrepancy between resident reads of trauma scans and attending radiologists' reads, with overall findings of low discrepancy rates. Moreover, they note that some of these discrepancies are related to perceived complexity of a case and that even attending radiologists disagree about final findings in many of these cases. They note, moreover, low rates of additional intervention as a result of these discrepancies [44, 45].

Some trauma centers, to cover staffing needs, have turned to teleradiologist support instead of or in addition to in-house resident or attending interpretation of images. The potential benefit of teleradiologists is that they are attending radiologist with more experience than trainee radiologists; the downside is that they are remote, they have less interaction with the trauma patient and trauma team caring for the patient, and they may have slower turnaround times for imaging reads since they are not in-house. Yeates et al. found that residents tend to have more overcalls and shorter turnaround time for image interpretation, while teleradiologists had more discrepancies (as compared to a final attending radiologist's interpretation) and more missed injuries but fewer overcalls. They concluded that the combination of resident and teleradiologists interpretations together reduced the overall chance of missed injuries and reduced discrepancies [46].

Conclusion

As CT technology continues to improve, the role for CT in the immediate and ongoing evaluation of the injured patient continues to evolve. With faster acquisition and higher resolution of imaging has come increased utilization of CT. There remains a need to balance the basic tenets of trauma care (e.g., that unstable patients require immediate intervention rather than ongoing non-therapeutic diagnostic workup) with the potential benefits of imaging to guide targeted interventions. The remaining chapters will elaborate further on specific controversies and important questions for consideration in the imaging of various organ systems and structures and will delve further into some of the current controversies in each of these areas. CT remains a powerful tool in the armamentarium of the modern trauma surgeon and system. Understanding the nuances in image acquisition and interpretation as well as the strengths and weaknesses of different imaging protocols gives the trauma surgeon the clearest understanding of potential injuries and the best guidance for necessary interventions in the critically injured patient.

References

1. About advanced trauma life support. ACS [cited 2023 Jan 26]. https://www.facs.org/quality-programs/trauma/education/advanced-trauma-life-support/about/.
2. American College of Surgeons. Atls course administration and faculty guide. 10th ed. Chicago, IL: American College of Surgeons; 2017.
3. Trauma Center Levels Explained-American Trauma Society. [cited 2023 Jan 26]. https://www.amtrauma.org/page/traumalevels.
4. Dakessian A, Bachir R, El Sayed MJ. Association between trauma center designation levels and survival of patients with motor vehicular transport injuries in the United States. J Emerg Med. 2020;58(3):398–406.
5. Mehta VV, Grigorian A, Nahmias JT, Dolich M, Barrios C, Chin TL, et al. Blunt trauma mortal-

ity: does trauma center level matter? J Surg Res. 2022;276:76–82.
6. Bukur M, Felder SI, Singer MB, Ley EJ, Malinoski DJ, Margulies DR, et al. Trauma center level impacts survival for cirrhotic trauma patients. J Trauma Acute Care Surg. 2013;74(4):1133–7.
7. Half a century in CT: how computed tomography has evolved. ISCT 2016 [cited 2023 Jan 26]. https://www.isct.org/computed-tomography-blog/2017/2/10/half-a-century-in-ct-how-computed-tomography-has-evolved.
8. Ball JW. Best practices guidelines in imaging. American College of Surgeons, trauma quality improvement program; 2018 [cited 2023 Feb 2]. https://www.facs.org/media/oxdjw5zj/imaging_guidelines.pdf.
9. Bell ME, Patel MD. The degree of abdominal imaging (AI) subspecialization of the reviewing radiologist significantly impacts the number of clinically relevant and incidental discrepancies identified during peer review of emergency after-hours body CT studies. Abdom Imaging. 2014;39(5):1114–8.
10. ACR Appropriateness Criteria. American College of Radiology; [cited 2023 Jan 31]. https://acsearch.acr.org/list.
11. Expert Panel on Urological Imaging, Heller MT, Oto A, Allen BC, Akin O, Alexander LF, et al. ACR appropriateness criteria® penetrating trauma-lower abdomen and pelvis. J Am Coll Radiol. 2019;16(11S):S392–8.
12. Expert Panels on Cardiac Imaging and Thoracic Imaging, Stojanovska J, Hurwitz Koweek LM, Chung JH, Ghoshhajra BB, Walker CM, et al. ACR appropriateness criteria® blunt chest trauma-suspected cardiac injury. J Am Coll Radiol. 2020;17(11S):S380–90.
13. Bancroft LW, Kransdorf MJ, Adler R, Appel M, Beaman FD, Bernard SA, et al. ACR appropriateness criteria acute trauma to the foot. J Am Coll Radiol. 2015;12(6):575–81.
14. Expert Panel on Musculoskeletal Imaging, Smith SE, Chang EY, Ha AS, Bartolotta RJ, Bucknor M, et al. ACR appropriateness criteria® acute trauma to the ankle. J Am Coll Radiol. 2020;17(11S):S355–66.
15. Expert Panel on Musculoskeletal Imaging, Taljanovic MS, Chang EY, Ha AS, Bartolotta RJ, Bucknor M, et al. ACR appropriateness criteria® acute trauma to the knee. J Am Coll Radiol. 2020;17(5S):S12–25.
16. Expert Panel on Musculoskeletal Imaging, Torabi M, Lenchik L, Beaman FD, Wessell DE, Bussell JK, et al. ACR appropriateness criteria® acute hand and wrist trauma. J Am Coll Radiol. 2019;16(5S):S7–17.
17. Tuite MJ, Kransdorf MJ, Beaman FD, Adler RS, Amini B, Appel M, et al. ACR appropriateness criteria acute trauma to the knee. J Am Coll Radiol. 2015;12(11):1164–72.
18. Expert Panel on Neurological Imaging and Musculoskeletal Imaging, Beckmann NM, West OC, Nunez D, Kirsch CFE, Aulino JM, et al. ACR appropriateness criteria® suspected spine trauma. J Am Coll Radiol. 2019;16(5S):S264–85.
19. Expert Panel on Neurological Imaging, Shih RY, Burns J, Ajam AA, Broder JS, Chakraborty S, et al. ACR appropriateness criteria® head trauma: 2021 update. J Am Coll Radiol. 2021;18(5S):S13–36.
20. Shetty VS, Reis MN, Aulino JM, Berger KL, Broder J, Choudhri AF, et al. ACR appropriateness criteria head trauma. J Am Coll Radiol. 2016;13(6):668–79.
21. Expert Panel on Neurological Imaging, Parsons MS, Policeni B, Juliano AF, Agarwal M, Benjamin ER, et al. ACR appropriateness criteria® imaging of facial trauma following primary survey. J Am Coll Radiol. 2022;19(5S):S67–86.
22. Expert Panel on Pediatric Imaging, Ryan ME, Pruthi S, Desai NK, Falcone RA, Glenn OA, et al. ACR appropriateness criteria® head trauma-child. J Am Coll Radiol. 2020;17(5S):S125–37.
23. Expert Panel on Pediatric Imaging, Kadom N, Palasis S, Pruthi S, Biffl WL, Booth TN, et al. ACR appropriateness criteria® suspected spine trauma-child. J Am Coll Radiol. 2019;16(5S):S286–99.
24. Trauma Practice Management Guidelines. [cited 2023 Jan 31]. https://www.east.org/education-career-development/practice-management-guidelines/category/trauma.
25. Western Trauma Association Algorithms-Western Trauma Association. [cited 2023 Jan 31]. https://www.westerntrauma.org/western-trauma-association-algorithms/.
26. Raptis CA, Mellnick VM, Raptis DA, Kitchin D, Fowler KJ, Lubner M, et al. Imaging of trauma in the pregnant patient. Radiographics. 2014;34(3):748–63.
27. Huber-Wagner S, Lefering R, Qvick LM, Körner M, Kay MV, Pfeifer KJ, et al. Effect of whole-body CT during trauma resuscitation on survival: a retrospective, multicentre study. Lancet. 2009;373(9673):1455–61.
28. Sierink JC, Treskes K, Edwards MJR, Beuker BJA, den Hartog D, Hohmann J, et al. Immediate total-body CT scanning versus conventional imaging and selective CT scanning in patients with severe trauma (REACT-2): a randomised controlled trial. Lancet. 2016;388(10045):673–83.
29. Salastekar NV, Duszak R, Santavicca S, Horný M, Balthazar P, Khaja A, Hughes DR, Hanna TN. Utilization of chest and abdominopelvic CT for traumatic injury from 2011 to 2018: evaluation using a National commercial database. AJR Am J Roentgenol. 2023;220(2):265. [cited 2023 Feb 15]. https://pubmed.ncbi.nlm.nih.gov/36000666/.
30. Gupta M, Gertz M, Schriger DL. Injury severity score inflation resulting from pan–computed tomography in patients with blunt trauma. Ann Emerg Med. 2016;67(1):71–75.e3.
31. Hansen CK, Strayer RJ, Shy BD, Kessler S, Givre S, Shah KH. Prevalence of negative CT scans in a level one trauma center. Eur J Trauma Emerg Surg. 2018;44(1):29–33.
32. Wirth S, Hebebrand J, Basilico R, Berger FH, Blanco A, Calli C, et al. European Society of Emergency Radiology: guideline on radiological polytrauma

imaging and service (short version). Insights Imaging. 2020;11(1):135.
33. Kahn J, Fehrenbach U, Böning G, Feldhaus F, Maurer M, Renz D, et al. Spectral CT in patients with acute thoracoabdominal bleeding-a safe technique to improve diagnostic confidence and reduce dose? Medicine (Baltimore). 2019;98(25):e16101.
34. Studer S, van Veelen NM, van de Wall BJM, Kuner V, Schrading S, Link BC, et al. Improving the protocol for whole-body CT scans in trauma patients. Eur J Trauma Emerg Surg. 2022;48(4):3149–56.
35. Paes FM, Durso AM, Pinto DS, Covello B, Katz DS, Munera F. Diagnostic performance of triple-contrast versus single-contrast multi-detector computed tomography for the evaluation of penetrating bowel injury. Emerg Radiol. 2022;29(3):519–29.
36. Durso AM, Paes FM, Caban K, Danton G, Braga TA, Sanchez A, et al. Evaluation of penetrating abdominal and pelvic trauma. Eur J Radiol. 2020;130:109187.
37. Haroon SA, Rahimi H, Merritt A, Baghdanian A, Baghdanian A, LeBedis CA. Computed tomography (CT) in the evaluation of bladder and ureteral trauma: indications, technique, and diagnosis. Abdom Radiol (NY). 2019;44(12):3962–77.
38. Brink M, de Lange F, Oostveen LJ, Dekker HM, Kool DR, Deunk J, et al. Arm raising at exposure-controlled multidetector trauma CT of thoracoabdominal region: higher image quality, lower radiation dose. Radiology. 2008;249(2):661–70.
39. Kahn J, Grupp U, Maurer M. How does arm positioning of polytraumatized patients in the initial computed tomography (CT) affect image quality and diagnostic accuracy? Eur J Radiol. 2014;83(1):e67–71.
40. Karlo C, Gnannt R, Frauenfelder T, Leschka S, Brüesch M, Wanner GA, et al. Whole-body CT in polytrauma patients: effect of arm positioning on thoracic and abdominal image quality. Emerg Radiol. 2011;18(4):285–93.
41. Kim SJ, Ahn SJ, Choi SJ, Park DH, Kim HS, Kim JH. Optimal CT protocol for the diagnosis of active bleeding in abdominal trauma patients. Am J Emerg Med. 2019;37(7):1331–5.
42. Flammia F, Chiti G, Trinci M, Danti G, Cozzi D, Grassi R, et al. Optimization of CT protocol in polytrauma patients: an update. Eur Rev Med Pharmacol Sci. 2022;26(7):2543–55.
43. Baghdanian AH, Armetta AS, Baghdanian AA, LeBedis CA, Anderson SW, Soto JA. CT of major vascular injury in blunt abdominopelvic trauma. Radiographics. 2016;36(3):872–90.
44. Chung JH, Strigel RM, Chew AR, Albrecht E, Gunn ML. Overnight resident interpretation of torso CT at a level 1 trauma center an analysis and review of the literature. Acad Radiol. 2009;16(9):1155–60.
45. Carney E, Kempf J, DeCarvalho V, Yudd A, Nosher J. Preliminary interpretations of after-hours CT and sonography by radiology residents versus final interpretations by body imaging radiologists at a level 1 trauma center. AJR Am J Roentgenol. 2003;181(2):367–73.
46. Yeates EO, Grigorian A, Chinn J, Young H, Colin Escobar J, Glavis-Bloom J, et al. Night radiology coverage for trauma: residents, teleradiology, or both? J Am Coll Surg. 2022;235(3):500–9.