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Patients with severe polytrauma: management and imaging protocols

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Abstract Traumatic injuries can be severe and complex, requiring the coordinated efforts of a multidisciplinary team.

Imaging tests play a fundamental role in rapid and accurate diagnosis. In particular, whole-body computed tomography (CT) has become a key tool. There are different CT protocols depending on the patient's condition; whereas dose-optimized protocols can be used in stable patients, time/precision protocols prioritizing speed at the cost of delivering higher doses of radiation should be used in more severe patients.

In unstable patients who cannot be examined by CT, X-rays of the chest and pelvis and FAST or e-FAST ultrasound studies, although less sensitive than CT, enable the detection of situations that require immediate treatment.

This article reviews the imaging techniques and CT protocols for the initial hospital workup for patients with multiple trauma.

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PALABRAS CLAVE
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Protocolo;
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Radiología simple;
Ecografía

Manejo y protocolos de imagen en el paciente politraumatizado grave

Resumen La enfermedad traumática es una patología grave y compleja, que requiere de la actuación coordinada de un equipo multidisciplinar.

Las pruebas de imagen desempeñan un papel fundamental para un diagnóstico rápido y preciso; en particular, la tomografía computarizada (TC) de cuerpo completo se ha convertido en la herramienta clave. Existen diferentes protocolos de TC en función de la gravedad del paciente; en los más graves se prioriza una exploración más rápida a costa de aumentar la radiación (protocolo tiempo-precisión) y en los estables se pueden realizar protocolos con dosis optimizada.

En los pacientes inestables que no pueden acceder a la TC, se emplean radiografías de tórax y pelvis, y ecografía *Focused Assessment with Sonography for Trauma* (FAST) o e-FAST, menos sensibles que la TC, pero que permiten diagnosticar situaciones que requieren tratamiento inmediato.

El objetivo del artículo es revisar las técnicas de imagen y los protocolos de TC en la atención inicial hospitalaria del paciente politraumatizado.

Introduction

Patients with multiple trauma have traumatic, potentially fatal injuries in different organs or systems that have associated systemic effects. In Western countries, trauma is the leading cause of death in people under the age of 45 years and the fifth leading cause overall, added to which is the high rate of morbidity and disability with very significant socioeconomic costs.[1]

As trauma is *"time-dependent"*, it is crucial to have an organised system that can intervene quickly and effectively, including *pre-hospital care* teams and *specialised intra-hospital care* teams, made up of healthcare professionals from various disciplines working in an ordered and coordinated manner. Radiology, both diagnostic and therapeutic, plays a fundamental role in these teams.

The initial assessment of multiple trauma patients is based on the Advanced Trauma Life Support or ATLS® protocol,[2] the aim of which is early identification and treatment of life-threatening injuries, with the rule "treat first what kills first". This is achieved through a quick, ordered assessment of the classic ABCDE.

History taking and clinical examination are imprecise in trauma,[3] while imaging tests, particularly computed tomography (CT), have high sensitivity and specificity in evaluating most traumatic injuries, including vascular injuries. Well-established imaging protocols that allow imaging tests to be performed rapidly and interpreted accurately are necessary. The aim of this article is to review the imaging techniques used and the CT protocols in place for the initial hospital care of patients with multiple trauma.

Initial basic radiological management or primary survey

This includes rapid and accessible radiological tests, which are performed during the initial assessment of the patient to screen for injuries that require immediate treatment, such as tension pneumothorax or haemothorax, cardiac tamponade or massive abdominal or pelvic haemorrhage. These tests are performed in the immediate care room, with portable or integrated equipment, without the need for transfers, without interfering with the patient's resuscitation and without delaying therapeutic measures. They include conventional X-rays and Focused Assessment with Sonography for Trauma (FAST).

Anterior-posterior chest X-ray in supine position

The anterior-posterior (AP) chest X-ray is part of the ATLS® immediate care protocol, as it provides essential information on life-threatening injuries, such as tension pneumothorax or haemothorax, mediastinal haematoma or ruptured diaphragm, in addition to informing on the placement of tubes and lines.

X-ray of the pelvis

Pelvic ring injury is an indicator of severe trauma, frequently associated with other major injuries and haemorrhagic shock. The development of pelvic immobilisation measures such as the pelvic binder has helped improve the haemodynamic situation of patients with pelvic trauma.

Although pelvic X-ray was traditionally part of the ATLS® protocol, it is now only indicated in unstable patients whose degree of haemodynamic instability prevents a CT scan.

FAST and e-FAST ultrasound

This is ultrasound examination for trauma patients. It is FAST when applied to the abdomen and *extended-FAST* (e-FAST) when extended to the chest. It is a simple, innocuous, rapid (1–2 min) and reproducible examination for identifying free intraperitoneal fluid (FAST) and free fluid in the pleural and pericardial cavities (e-FAST) which, in the context of acute trauma, is interpreted as haemoperitoneum, haemothorax and haemopericardium, respectively. e-FAST ultrasound has been shown to have greater sensitivity than AP chest X-ray for detecting pneumothorax.[4]

It is indicated in patients who are haemodynamically unstable to detect situations requiring immediate treatment, such as tension pneumothorax or haemothorax, pericardial tamponade or massive haemoperitoneum. It is not recommended in stable patients due to its low sensitivity for detecting visceral lesions. It is limited in patients with skin wounds, burns, subcutaneous emphysema, pneumoperitoneum and obesity.

Technically, the abdominal cavity is scanned with a 3.5—5 MHz convex probe with four views: subxiphoid for the study of the haemopericardium; right upper quadrant; left upper quadrant; and pelvis for the detection of haemoperitoneum ("The 4 Ps": pericardium, perihepatic, perisplenic and pelvic regions).[5]

Haemothorax is also assessed with a low-frequency convex probe exploring the costophrenic sinuses, while high-frequency linear transducers (5—10 MHz) with an approach between the second and fourth intercostal spaces in the midclavicular line are preferred for pneumothorax assessment.[6]

The inferior vena cava can also be assessed to help determine the patient's volume status and response to volume replacement.[5–8]

Computed tomography

CT is the fundamental imaging test in patients with multiple trauma due to its speed, availability and high diagnostic accuracy.[9] When planning scans, effective communication between the Trauma and Radiodiagnosis teams is very important.

Computed tomography room and equipment requirements

The CT room should be as close as possible, preferably less than 50 m, to the immediate care area for patients with multiple trauma in order to minimise transfer time, be fitted out with adequate equipment for resuscitation manoeuvres and be available 24 h a day.[10] Scanners equipped with 64 rows of detectors[11] with dose reduction techniques are preferred. *Hybrid operating theatres,*[12] which integrate all the diagnostic and therapeutic tools in a single room (for example, surgery, vascular angiography, CT, conventional radiology, e-FAST, infusion and cell recovery equipment) will improve the management of patients with multiple trauma.

Indications. Whole-body computed tomography or selective computed tomography

Selecting patients who need whole-body CT (WBCT) after trauma continues to be challenging. The choice is clear when there is a combination of abnormal vital signs, a high-energy injury mechanism, and clinical findings indicative of serious injury. However, debate continues to surround the risk-benefit ratio of routine WBCT after a high-energy impact when there is no clinical suspicion of injury, as 39–47% of patients who are given this scan may not have injuries.[13]

The clinical trial REACT-2[14] published in 2016, the first international, multicentre, randomised open-label study in trauma patients, did not show significant differences in mortality rates between the groups of patients who had WBCT compared to those who had a selective CT according to the ATLS® guidelines. However the study did show a reduction in the scanning and diagnosis time and an increase in the radiation dose in the WBCT group, although 46% of the patients with selective CT required WBCT in the end.

The unnecessary exposure to radiation of a relatively young population group is one of the major drawbacks of the routine application of WBCT in patients with multiple trauma. The recommendation is to use it with caution, optimising the selection criteria according to the injury mechanism, vital signs, clinical suspicion and the patient's age and comorbidities.

The algorithm proposed in the European Society of Emergency Radiology (ESER) guidelines[15] considers the classification of patients as polytrauma or non-polytrauma. As there is no prospective definition of the polytrauma patient, this decision is made by the immediate care team leader. The group with polytrauma is a candidate for WBCT, which will vary depending on the patient's needs. The non-polytrauma group are candidates for a selective CT, making it possible to avoid overexposure to radiation with adequate diagnostic security.

Imaging test and management algorithm

Improvements in immediate care protocols have helped reduce the number of unstable patients who cannot undergo CT. A patient is considered to be unstable when systolic blood pressure is below 90 mmHg, although there is no unanimous consensus and this can be modified by different cofactors such as age and comorbidity.[16]

The patient's haemodynamic status, the clinical examination and the radiological findings in the initial management can help greatly in decision-making, such that before performing an urgent CT:

- Unstable patients with positive e-FAST may require urgent damage-control surgery or resuscitative endovascular balloon occlusion of the aorta (REBOA).[17]
- Unstable patients with negative e-FAST and suspected severe pelvic trauma may require interventional radiology procedures before or after emergency pelvic fixation.[18]

Besides these scenarios, the difference between stable and unstable patients can vary the duration of WBCT and the radiation dose. Following the ESER guidelines,[15] in patients with compromised vital signs or suspected serious injury, it is essential to perform an examination of the highest quality as quickly as possible (*time-optimised or time/precision protocol*), while in haemodynamically stable patients without suspected serious injury who are young, the quality of the study can be improved and radiation exposure significantly reduced at the expense of slightly lengthening the examination time (*dose-optimised protocol*).

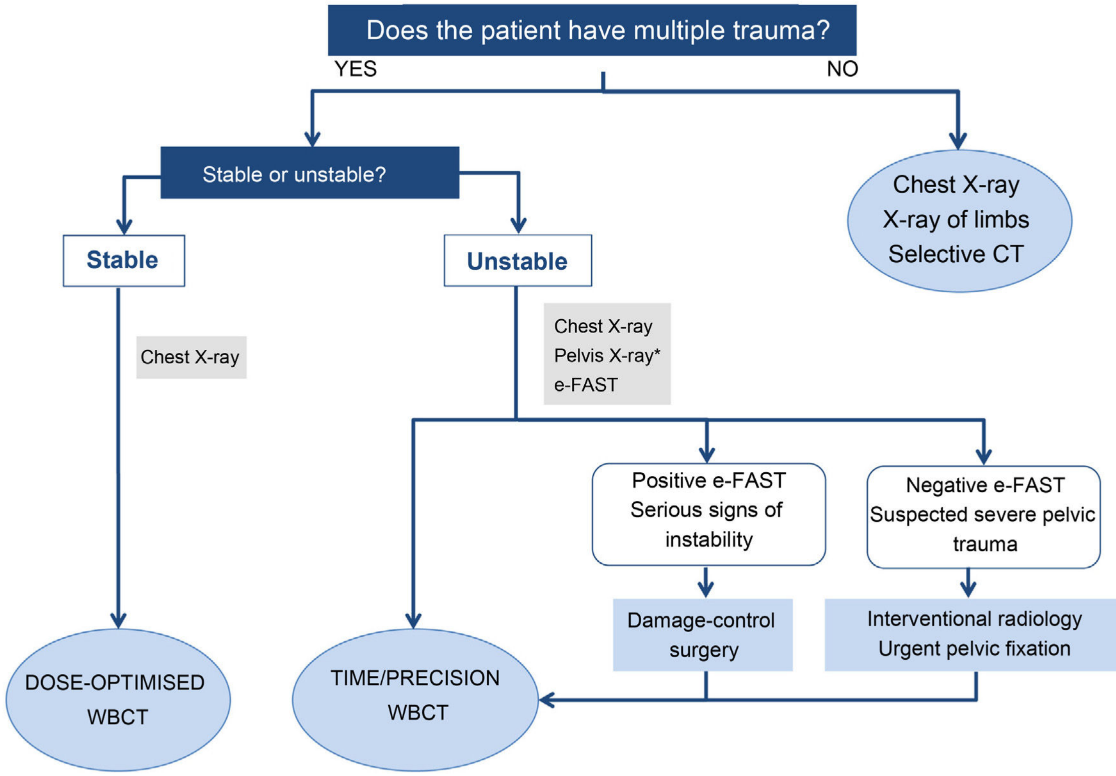

Figure 1 Proposed diagnostic algorithm for radiological tests in patients with multiple trauma. Deciding whether or not a patient has multiple trauma and assessing their degree of stability falls to the leader of the trauma care team. It is important to note that in some patients with haemorrhagic shock, either due to pelvic fracture or internal injuries, WBCT may be postponed due to damage-control surgery, urgent pelvic fixation or interventional radiology treatments.
e-FAST: extended FAST ultrasound; WBCT: whole-body computed tomography.
* Assess whether or not pelvis X-ray is useful.

The management algorithm at our centre is summarised in Fig. 1.

Positioning of the patient for the computed tomography scan

The patient is positioned in the CT scanner entering feet first, due to less artefact from the device and monitor cables, and greater accessibility to the patient.

For the positioning of the arms (Fig. 2), raised above the head produces fewer artefacts in the assessment of solid viscera and a lower radiation dose, while providing adequate image quality in neck CT-angiogram. This is the preferred position in the dose-optimised protocol, whenever possible. Leaving one of the arms alongside the body (swimmer's position) increases the radiation dose by 18% and if both arms, by 45%.[19]

In the time/precision protocol, the patient should be positioned with arms crossed over their trunk or over their abdomen and supported on a pillow; this involves a 25% increase in radiation dose and produces fewer artifacts in solid viscera than if they were placed alongside the body.

Whole-body computed tomography protocol

The WBCT protocol in patients with multiple trauma is still not properly standardised. In patients with severe trauma, after head CT without intravenous contrast (IVC), the best strategy is a multiphase CT protocol in arterial and portal phases, with the objective of early detection and characterisation of vascular lesions (active bleeding and pseudoaneurysms) (Fig. 3); this is highly important given that haemorrhage is the main preventable cause of death in these patients.[20,21] The drawbacks of the multiphase protocol are greater radiation than single-acquisition protocols (single-phase and split-bolus protocols) and a larger number of images that need to be interpreted quickly.

The WBCT protocol in patients with severe multiple trauma should include the following (Fig. 4):

- CT of the brain without IVC.
- CT of the cervical spine. In the dose-optimised protocol this will be without IVC. In the time/precision protocol, it forms part of the same chest-abdomen-pelvis helix in the arterial phase. Because a thin slice thickness is used, in the event of facial trauma it is recommended to include the entire facial structures in the study of the cervical spine.
- Chest-abdomen-pelvis CT in arterial phase.
- Abdomen-pelvis CT in portal phase.

Performing a baseline chest-abdomen-pelvis phase (without IVC) is not justified because of the low diagnostic yield and to avoid unnecessary radiation. High concentration non-

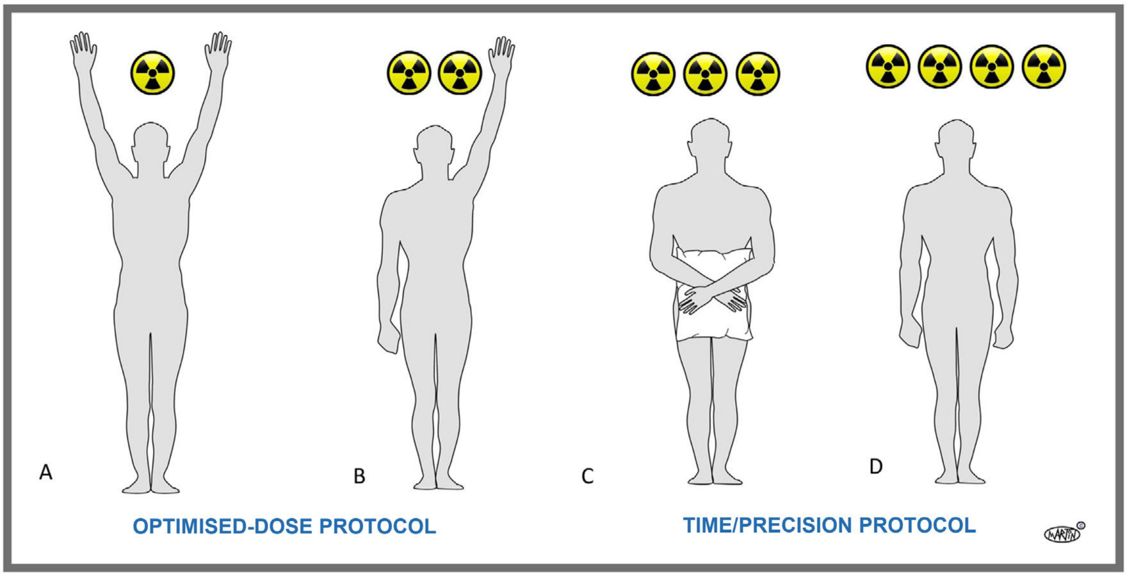

Figure 2 Effect of the position of the arms on the WBCT. (A) Arms up is the position that provides the highest quality in the assessment of solid viscera and, of all the positions, the one with the least radiation. In addition, it provides adequate image quality in CT angiography of the supra-aortic trunks. This is the position recommended in dose-optimised WBCT protocols provided it is possible to raise the arms. (B) If it is not possible to raise one of the arms, the radiation increases by 18% compared to the position with raised arms, but means less radiation than the position with both arms lowered. (C) Arms crossed over a pillow. In the time/precision WBCT protocol, the preference is to place the arms crossed over the body hugging a pillow, either on the chest or the abdomen, as long as there are no injuries rendering this impossible. This position represents a 25% higher radiation dose compared to the arms-up position. (D) The arms-down position is the least recommended, as it produces greater artefact in the assessment of solid viscera and a 45% higher dose of radiation than with the arms up. It should therefore be avoided whenever possible.
WBCT: whole-body computed tomography.

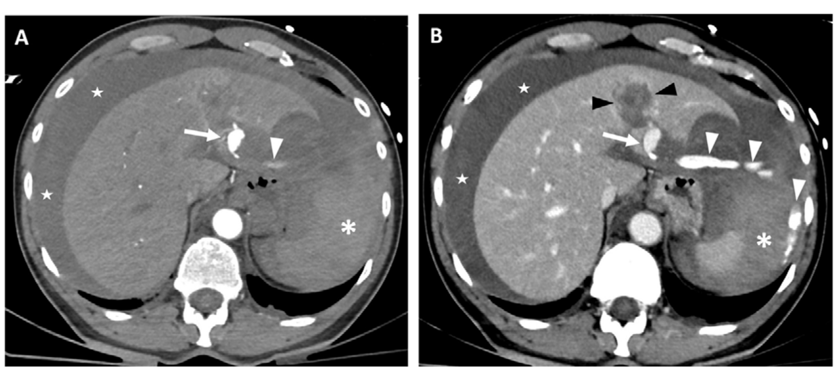

Figure 3 Contained vascular injury and active bleeding. A 51-year-old female patient, who had an accident with an electric scooter, with haemodynamic instability maintained with a massive transfusion protocol. CT in arterial (A) and portal (B) phases. Extensive laceration of the left lobe of the liver (short black arrows), especially in segment 3, with a pseudoaneurysm (white arrow) and active arterial bleeding (arrowheads). Significant haemoperitoneum, predominantly perihepatic and perisplenic (asterisks). Active bleeding manifests as poorly defined extravascular contrast foci that increase in size in later phases, while contained vascular lesions (pseudoaneurysms or arteriovenous fistulas) are well-defined round lesions of equal size and with similar vascular behaviour to arterial structures in all phases, so they are most evident in the arterial phase and wash out in later phases.

ionic iodinated contrast (350 mg I/mL) should be used, with an injection speed of 3−4 ml/s followed by a bolus of saline. The total dose is adjusted to the patient's weight (1.5 ml/kg).

The arterial phase is usually performed with the automatic bolus detection technique with a localiser in the descending aorta, a 10-second delay and a low-dose technique. This provides a vascular map and detects possible contained vascular lesions (pseudoaneurysms or arteriovenous fistulas) that may go unnoticed in the portal phase.[22,23] It is also useful to identify active arterial bleeding (Fig. 3). However, it has to be taken into account that active arterial bleeding may not appear in the arterial phase if it is intermittent, due to vasospasm or hypovolaemic shock.

The abdomen-pelvis portal phase with a delay of 70−75 s is optimal for recognising parenchymal lesions of solid

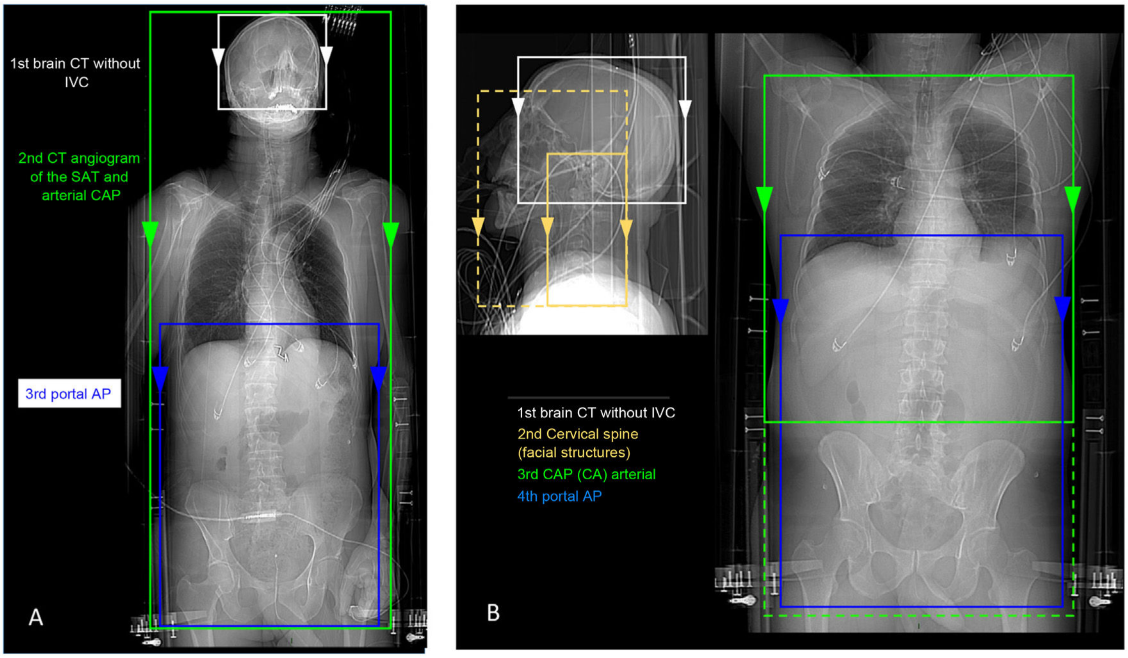

Figure 4 WBCT protocols. (A) Time/precision WBCT. This is performed with a single scan carried out with the arms down crossed over the chest or the abdomen whenever possible and consists of a head CT without IVC, followed by an arterial phase study that includes the circle of Willis, neck, chest, abdomen and pelvis and venous phase of the abdomen and pelvis. (B) Dose-optimised WBCT. Firstly, a topogram of the skull and neck is performed with the arms lowered and a CT of the brain without IVC and then a CT of the cervical spine without IVC. Subsequently, a topogram of the chest, abdomen and pelvis is performed with both arms raised if possible, with an arterial phase of the chest, abdomen and pelvis (or at least the chest and abdomen) followed by a portal phase of the abdomen and pelvis. In both protocols, the indication for late-phase or CT cystography should be assessed, and should be performed with a low-dose technique.
AP: abdomen-pelvis; CAP: chest, abdomen and pelvis; CT: computed tomography; IVC: intravenous contrast; SAT: supra-aortic trunks; WBCT: whole body computed tomography.

organs, as it achieves a homogeneous opacification of the viscera and is more sensitive than the arterial phase for assessing active bleeding (Fig. 3).

Depending on the radiological findings and clinical suspicion, the following can be added to this standard protocol:

- Late phase at 3 min with a low-dose technique to assess urinary tract injury or confirm and characterise active bleeding.
- CT cystography to rule out bladder injury, by means of retrograde bladder filling through a catheter with a water-soluble iodinated contrast solution diluted to 10% (about 200–300 ml). This can be performed simultaneously with the late phase.
- CT-angiogram of the upper or lower limbs in arterial phase in case of suspected vascular injury.

In the dose-optimised protocol, performing a CT of the chest-abdomen-pelvis with split-bolus IVC can be considered.[24] It obtains an arterial phase and a venous phase in a single acquisition, significantly reducing the radiation dose. As a drawback, it increases the amount of IVC administered and it can cause difficulties in the detection and characterisation of vascular lesions, such as, for example, the distinction between contained vascular lesion and active bleeding, and the arterial or venous origin of pelvic haemorrhage.

Fig. 5 shows the WBCT protocols used in our institution.

The use of oral contrast is not recommended in patients with multiple trauma. It is reserved for those patients, usually with penetrating trauma, in whom there is a low or intermediate suspicion of hollow viscus perforation. The absence of any leakage of oral contrast does not completely rule out hollow viscus perforation. Contrast administration also delays the examination and prevents an adequate assessment of the bowel wall, making it difficult to detect signs of intestinal trauma or ischaemia.

Structured report

The CT report for multiple trauma patients is divided into three parts[25]:

- The *first part*, a generally verbal scanner-side report, to describe life-threatening findings. *The concept of* damage-control radiology *includes early diagnosis of central nervous system lesions, foci of haemodynamic instability and lesions requiring surgery and urgent intervention.*
- The *second part*, where all the radiological images are analysed, preparing a detailed, preferably structured, written report of all the existing injuries.

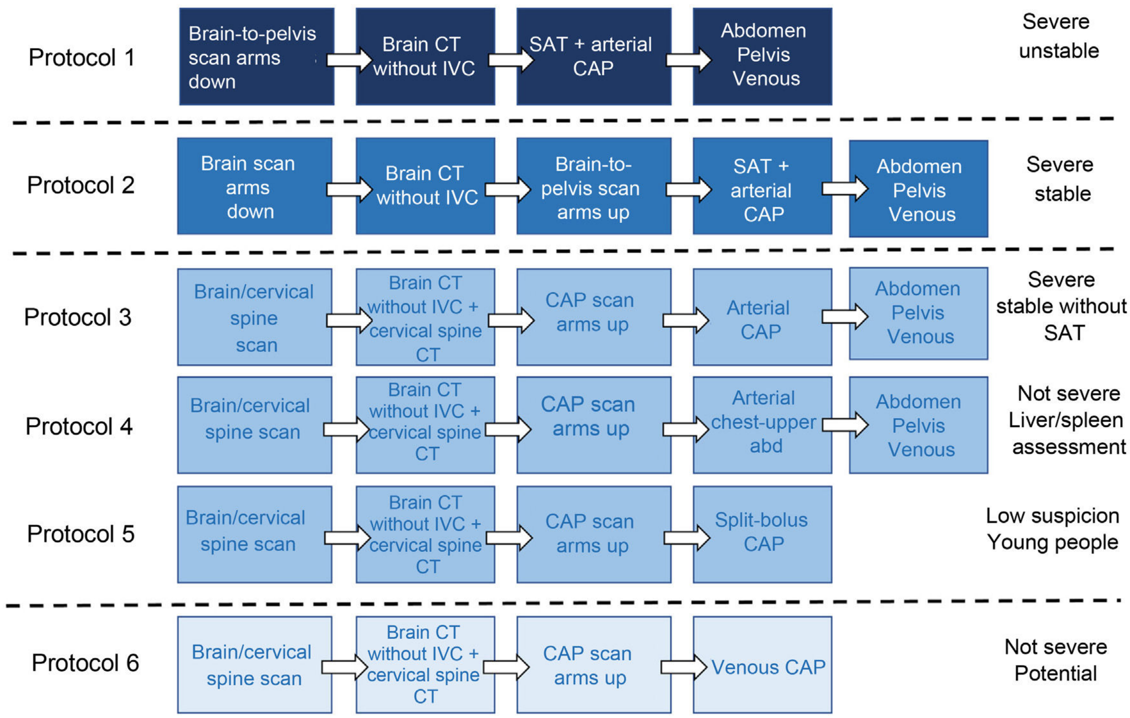

Figure 5 Proposed WBCT protocols in patients with multiple trauma. Protocol 1 would correspond to the time/precision protocol proposed by the ESER guidelines. The rest of the protocols would correspond to different variations of the dose-optimised protocol. We recommend applying protocol 5 to young patients with low suspicion of severe injury. Protocol 6 applies to "potential" patients in whom there is low suspicion of arterial haemorrhagic injury. Some of these patients may require CT to assess the axial skeleton; in this case, we recommend administering IVC to avoid the need for a second scan due to incidental findings of trauma. It is important to have well-established protocols to improve communication between the radiologist and the specialist radiodiagnostic technician performing the examination.
IVC: intravenous contrast; ESER: European Society of Emergency Radiology; CT: computed tomography; WBCT: whole body computed tomography; SAT: supra-aortic trunks; CAP: chest, abdomen and pelvis.

- The *third part*, produced within the first 24 h by other expert radiologists, whose purpose is to detect injuries that may have gone unnoticed or been misinterpreted.

In image processing, sagittal and coronal multiplanar reconstructions are very useful to assess the spine, pelvis and diaphragm, and oblique sagittal reconstruction following the axis of the aortic arch to assess the aorta. Volumetric reconstructions can help in the assessment of facial trauma and trauma to the bony pelvis.

Protocol in penetrating trauma

The differences in the injury mechanism, patient severity and the clinical and radiological management mean that penetrating trauma differs considerably from blunt-force trauma. The high mortality rate among unstable patients or patients with life-threatening injuries means that surgical exploration is very often necessary before performing a CT for the initial assessment of damage[26,27] (Table 1).

In patients who are candidates for CT, this can be planned selectively if the penetrating injuries have a specific anatomical location. In the case of injuries in multiple regions, in unconscious patients or for which the mechanism of injury is unknown, it is advisable to perform a WBCT. Since massive haemorrhage is one of the main complications, the arterial and venous phases would be indicated to rule out vascular injury and active bleeding.

There is a lack of consensus surrounding the use of a triple-contrast protocol (intravenous, oral and rectal) or a simple CT protocol with IVC alone. The use of triple contrast is widespread in the United States, despite the lack of consensus and it not featuring among the American College of Radiology recommendations.

As there is no consensus on whether or not to use oral or rectal contrast, it is not usually administered routinely and is reserved for suspected cases of hollow viscus perforation in stable patients, at the discretion of the treating medical team.

If it is considered that positive oral contrast needs to be used, 800 ml should be administered in two separate 400-ml doses, the first 30 min before and the second immediately before the CT; 1,000 ml of rectal contrast (water-soluble iodinated contrast diluted to 4%) should also be given, administered when the patient is on the CT table by hydrostatic pressure.

Table 1 Indications for urgent surgical exploration in penetrating trauma.

Penetrating trauma to the brain/cervical spine	Penetrating trauma to the torso
Vascular	Haemodynamic instability
• Expansive or pulsating haematoma	• Peritonism
• Active bleeding through the wound	• Evisceration of bowel loops
• Haemodynamic instability	• Rectal or gastrointestinal tube bleeding
• Absence of pulses	
• Murmur	
Respiratory (larynx, trachea, bronchi)	
• Airway obstruction	
• Air leak from the wound	
• Tension pneumothorax	
• Massive subcutaneous emphysema	
Gastrointestinal (pharynx, cervical oesophagus)	
• Haematemesis	
• Leak of saliva from the wound	
• Subcutaneous emphysema	

Radiation dose

The main limitation of the use of CT is radiation exposure, especially in young patients. The effective dose of radiation in a WBCT study is approximately 20.9 mSv.[14] Radiation >20 mSv before the age of 40 years has been shown to increase the risk of developing cancer in 1/1,000 patients.[28] Efforts have therefore been made with technological advances to reduce radiation dose while maintaining good image quality, for example, through iterative reconstruction, tube current modulation[29,30] or with split-bolus IVC delivery protocols.

Other imaging methods/possible diagnostic improvements

Spectral computed tomography

Spectral energy CT offers new tools in the diagnosis of patients with multiple trauma with a lower dose, as it provides a baseline study without radiation penalty and can increase the visibility of haematomas and active bleeding with the use of subtraction images.[31] It also enables assessment of bone oedema and occult fractures.

Ultrasound with intravenous contrast

Ultrasound with IVC has the advantage of not using ionising radiation and is particularly useful in children, pregnant women and women of childbearing potential. It can be used in patients with kidney failure or allergy to iodinated contrast media.

Although how to integrate it into the study of patients with multiple trauma is not well defined, it currently plays an important role in the follow-up of conservatively treated traumatic injuries to the abdominal viscera (liver, spleen and kidneys), or as a first-line examination in isolated mild or low-energy abdominal trauma.[32,33]

Magnetic resonance imaging

MRI is indicated in patients with clinical or radiological suspicion of injuries that may go unnoticed on CT, such as spinal injuries[34] or microhaemorrhages from diffuse axonal injury, in some abdominal and pelvic injuries, especially for the assessment of pancreatic and bile duct trauma,[35] in complex musculoskeletal trauma and in pregnant patients and children.[36]

Artificial intelligence

This can facilitate the work of the radiologist, shortening the reading time of the WBCT, for example, with the application of specific bone algorithms for the spine and ribs.[37]

Conclusion

The radiologist's role is key and it is they who must decide on the imaging protocol best suited to the multiple trauma patient. It is therefore important to have active participation in, and good communication and integration with the multidisciplinary team attending such patients.

CT has become the fundamental imaging technique for immediate assessment and decision-making in patients with multiple trauma. In the most severe patients, multiphase WBCT studies are preferred, as they provide better detection and characterisation of vascular lesions and active bleeding, highly important in the management of these patients. Chest and pelvis X-rays and FAST or e-FAST ultrasound are reserved for patients who cannot access the CT scanner.

All hospitals should have well-established WBCT protocols that enable the rapid and accurate diagnosis of injuries.

Authorship

All authors declare having contributed substantially to all aspects of the preparation of the manuscript:

(1) study conception and design, or data collection, or data analysis and interpretation; (2) the drafting of the article or the critical review of the intellectual content; and (3) final approval of the version submitted.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

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